Canadian Institute of
Guided Ground Transport
Queen's University
at Kingston, Ontario

Final Report

PRELIMINARY TECHNOLOGY REVIEW

CIGGT Report No. 93-1

prepared for
The Quebec-Ontario High Speed Rail Project

in association with

Canarail, Inc.
Swederail
LGL & Associates
J.H. Parker & Associates

June 7, 1993

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The Quebec-Ontario High Speed Rail Project

by

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Queen's University at Kingston
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This paper resulted from research conducted through the Canadian Institute of Guided Ground Transport. It represents the views of the authors and does not necessarily have the endorsement of the University or other participating organizations.

EXECUTIVE SUMMARY

Introduction and Scope

This preliminary technology review was commissioned by the Steering Committee for the Quebec/Ontario High Speed Rail Project. It called for a rigorous and objective assessment of two families of high-speed rail technologies, leading to the identification of a representative technology from each family. These families were:

- o medium-fast [200-250 kph] technologies incorporating body tilting; and
- o very fast [300 kph+] technologies currently without body tilting.

To be considered in this investigation, HSR technologies had to be: currently in commercial service; capable of providing intercity trip times superior to those of existing modes; and potentially able to develop future generations of equipment capable of operating over the same infrastructure.

The review encompassed a wide range of issues concerning: the technical characteristics of canadidate technologies; adaptability to Canadian operating, regulatory and climatic conditions; and issues associated with accessibility to the handicapped, current R&D activities, environmental impacts and potential for production of components in Canada.

Technology Characterizations

Two medium-fast tilt technologies and and three very fast non-tilt technologies met the criteria set out by the Steering Committee. The tilt trains were the ABB X-2000, operated by Swedish State Railways and the Fiat ETR-450, operated by the Italian State Railways. The 300 kph trains were the GEC-Alsthom TGV, operated by the SNCF, the ICE, operated by German Federal Railways, and the Shinkansen Sr. 300, operated by Central Japan Railway Company.

Two criteria were applied to select the representative technology:

(1) For otherwise equally qualified technologies, the one with the longest history of operation at the qualifying speed shall be preferred; and

(2) Notwithstanding (1), a representative technology must reflect current engineering practices at the major subsystem level and offer a reasonable expectation that the subsystems currently in service will continue to be the norm for at least the next five years.

On this basis, the TGV was selected for the 300 kph+ category, because its service record is longer, while the competing technologies were not strongly differentiated with respect to the second criterion. The X-2000 was selected as the representative tilt train technology since, although its operating history is longer, the ETR-450 did not pass criterion (2) of 'subsystem stability'.

Five other areas of investigation were pursued as part of the technology review:

- **bi-level equipment:** it was concluded that the driving forces behind French and Japanese experiments with such equipment—the need to accommodate peak demand without adding trains—is unlikely to be a factor here;

- **potential for carrying light freight:** it was concluded that there was no technological reason why light freight could not be carried, although the lack of a pre-existing electrified network would be a handicap. The main issues to be resolved are commercial ones.

- **compatibility of infrastructure with future generations of technology:** Basic physical compatibility is not an issue. Ability to fully exploit performance improvements will be an issue. For example, the 'representative' alignment for the 200-250 kph family has been laid out for 250 kph curves. The next generation of X-2000 rolling stock will be tested at 280-300 kph, and further developments are possible. Similarly, the 350 kph design speed of the TGV-NG does not represent the ultimate speed limit. It was also noted that anticipated future reductions in aerodynamic drag for both technologies may make it possible to increase speeds in urban areas. Measures should be taken to prevent bottlenecks which prevent such opportunities from being exploited.

- **accessibility to the handicapped:** although wheelchair tie-downs and a handicapped-accessible toilet are available on both technologies, additional such facilities will be required. High level platforms are an additional requirement at stations and terminals.

- **reliability:** both technologies exhibit a very high level of operational reliability, backed up by systematic preventative maintenance which is intensive by North American standards. On-time performance, a first-order indicator of system reliability, stands at 97% for SNCF (on dedicated track) and 95% for SJ.

Design Standards

The report addresses alignment geometry standards, clearance requirements and design standards for infrastructure subsystems. Our recommendations are summarized in Tables 1-3.

Table 1 summarizes the recommended standards for transition spirals, based on HSR geometric criteria currently in use on high speed lines.

TABLE 1: RECOMMENDED STANDARDS FOR TRANSITION SPIRALS	
Parameter	Suggested Value
Maximum Superelevation	180 mm, 201 to 300 kph; 150 mm, up to 200 kph
Rate of change in superelevation - normal - exceptional	 0.36 mm/m 0.6 mm/m
Minimum Spiral Length	300 m, 300 kph; 250 m, 200-250 kph
Minimum Spiral Separation	150m
Calculation Equation for Cubic Parabola Approximation	$y = x^3/6RL$, where L is the length of the transition curve peojected on the x-axis, and R is the radius of curvature of the constant-radius curve section
Calculation equation for length of transition curve (for maximum jerk of 0.2 m/sec^3)	$L = 0.118\ V^3/R$, where V is vehicle speed in kph and R is as above in m.

Table 2 summarizes our recommendations concerning minimum clearway and other right of way related separation distances.

TABLE 2: RECOMMENDED RIGHT-OF-WAY WIDTHS AND SEPARATIONS			
PARAMETER	NEW CONSTRUCTION, NEW ALIGNMENT	NEW CONSTRUCTION, EXISTING ALIGNMENT	RECONSTRUCTION, EXISTING ALIGNMENT
Clearway width - absolute minimum - design	 16.0m[a] 21.0m	 12.25m[a] 21.0m	 16.0m 21.0m
Right-of-way width - absolute minimum - acceptable - design	 16.0m[a] 30.0m 50.0m	 24.5m[a] 30.5m[a] 50.0m[a]	 as found[a] 30.0m 50.0m
C_L separation between adjacent HSR and conventional tracks	N/A	4.5m (up to 200 kph) 8.85m (up to 250 kph) 10m (up to 300 kph) 10m+ (300 kph +)	as at left
C_L separation for HSR tracks	4.5m	4.5m	4.5m
a For detailed notes, see Table 3.2.			

Table 3 summarizes our recommendations concerning standards for infrastructure subsystems common to both technology families.

TABLE 3: STANDARDS FOR INFRASTRUCTURE SUBSYSTEMS FOR BOTH TECHNOLOGY FAMILIES					
SUBSYSTEM	New Construction	Reconstruction	Rehabilitation <200 kph	Rehabilitation 200 to 250 kph	Rehabilitation >250 kph
TRACK					
Subgrade	Removal/replacement/ reinforcement of low bearing strength materials	Removal/replacement/ reinforcement of low bearing strength materials	Selective (20%+) replacement or reinforcement of low bearing strength materials	Selective (50%+) replacement or reinforcement of low bearing strength materials	As for reconstruction
Earthworks	Selected washed granular materials laid in courses <1.5m thick with dynamic compaction to 95%+OPM; reinforcement with geomembranes, grids or webs as appropriate	As for new construction	As for new construction where rehab of subgrade is performed	As for new construction where rehab of subgrade is performed	As for new construction
Underbed	0.70m of 25mm crushed rock; dynamic compaction	As for new construction	N/A	N/A	As for new construction
Subballast	0.20m hard crushed rock graded 0/31[5]; dynamic compaction	As for new construction	As for new construction where rehab of subgrade and/or earthworks is performed	As for new constructiom	As for new construction
Ballast	0.35m hard, tough, fine-grained crushed rock; LAA <30, MA <4 and LA + 5MA <40 (LAA, MA as Wt%); CV (MPa) < 1.0 +0.2MA; Mg Soundness (%) < 3; Bulk Specific Gravity > 2.65; Shape Factor < 2; 25/50 grading acceptable but if fines are free-draining prefer 10/50; dynamic stabilization.				
Ties	Concrete monoblock, at 60 cm spacing (250 kph and up); 65 cm (below 250 kph)				
Fasteners	Elastic such as Nabla or Pandrol with 9mm rubber pad or equivalent with 70 kN/mm stiffness; hold-down force 11 kN or more with 8mm deflection.				
Rail	60 kg/m (UIC 60 equivalent) for dedicated HSR track; where track is to be shared with commuter and/or freight, 70 kg/m (140 RE) rail, as used on NEC.				
OTHER					

TABLE 3: STANDARDS FOR INFRASTRUCTURE SUBSYSTEMS FOR BOTH TECHNOLOGY FAMILIES					
SUBSYSTEM	New Construction	Reconstruction	Rehabilitation <200 kph	Rehabilitation 200 to 250 kph	Rehabilitation >250 kph
Electrification	2 x 25 kV 60Hz autotransformer with feeder/overhead system in phase oppposition; contact wire 150mm^2 reinforced cadmium-copper contact wire at 5.1m height. OCS will be tensioned at 7.5 or 10 kN for 200 kph, 15 kN for 250 kph, 20 kN for 300 kph, and 25 kN for 350 kph. 7.5 kn tensioning will be used on sections where curve radii are below 2000m.				
Signalling and Train Control	TVM430 incorporating in-cab displays and automatic speed enforcement; road vehicle detection circuits on grade crossings (where present -- see below), and vehicle intrusion detection circuits at overpasses and between adjacent HSR and conventional tracks will be tied into train control subsystem.				
Grade Crossing Protection	No at-grade crossings where speed exceeds 200 kph; between 160 and 200 kph, public crossings may be permitted on a site-by-site basis provided full barriers with intrusion circuits, road vehicle detection circuits tied to automatic train control and improved crossing visibility are installed; below 160 kph, full-width barriers with intrusion detection circuits and improved crossing visibility will be required. Private crossings will not be permitted if operating speed exceeds 200 kph; below 200 kph, access to the HSR ROW from private crossings must be controlled electronically or manually with interlocking to ATC.				
Station Tracks	All station tracks built as part of the HSR project will be configured to permit access from both sides of a stopped train from high-level platforms. Sizing of station and terminal facilities will be determined by estimated demand requirements.				
Bridges	All bridges are ballast-decked for both families. Bridges are to meet L/4000 deflection limit to ensure compatibility with future generations from either technology family.				
Tunnels	Tunnel cross-sections (for pressure-sealed trainsets): 41m^2, double track, 200 kph; 71m^2 double track, 270 kph; 90m^2, double track, 300 kph; 150m^2, double track, 350 kph; 46m^2, single track, 270 kph.				

Conformity with Safety Standards and Related Issues

The following issues were addressed:

- **conformity with applicable standards:** neither class of technology as currently operated conforms to FRA regulations or industry standards.

- **feasibility of adaptation to North American standards:** however, both ABB and Bombardier have committed themselves to meeting those standards. This requires changes in the TGV power car and the X-2000 power car, coach and driving trailer. Such adaptations appear feasible.

- **feasibility of modifying existing regulations:** the prospects for compliance appear encouraging in the Canadian context, where Transport Canada's Safety Group has been emphasizing performance-based standards and pragmatic reolution of safety issues. With respect to shared track, the position of the Safety Group is based on operating speed, rather than technology type, with progressively more restrictive shared track criteria up to 250 kph.

- **at-grade crossing requirements:** for speeds in excess of 200 kph, no at-grade crossings will be permitted, while at speeds of 160-200 kph, crossings with enhanced protection may be permitted after a site-by-site review.

- **non-regulatory rules and practices:** the main issue here is the differences in operating rules and practices between Canadian and offshore HSR carriers. The review encompassed train crewing, maintenance practices and general skills requirements. The main conclusion was that, while there remain significant differences in operating philosophies, VIA Rail has been taking measures which have narrowed the gap between Canadian and offshore productivity. The training requirements of HSR operators are manageable.

HSR Operations in Canadian Climatic Conditions

Canadian climatic conditions will affect both infrastructure design and construction and achievable performance. The review assessed the effects of rainfall and snowfall (rates, accumulation and icing) on the limits of safe operation and on the behaviour of track, vehicles, catenary, signalling and control systems. It also assessed mitigation techniques, such as the warm water sprinklers used in Japan to reduce snow accumulation, and the effect of adding switch heaters to the reliability of high-speed switches. The major challenge remains the design and construction of stable track structures under the demanding freeze-thaw and geotechnical conditions that exist in the Quebec City-Windsor Corridor. It is recommended that a comprehensive design review for Corridor conditions be undertaken if HSR development is to proceed.

Assessment of R&D Status

The focus of the investigation was on current R&D activities related to the representative technologies of potential relevance to deployment in Canada. Our findings were relatively optimistic concerning high speed trains per se, notably because of the commitment of both suppliers to produce versions of their equipment which conform to Canadian safety requirements. Our assessment is much less optimistic with respect to infrastructure R&D. Most active HSR R&D activities do not target areas of particular relevance to Canada, focussing instead on adding capacity and increasing performance in capacity constrained markets.

It is likely that Canada will have to invest in R&D to solve our own problems, with special attention to three areas:

- **management of the vehicle-guideway interface:**
  - subgrade and track structure stability
  - adhesion management (wheel/rail)
  - vehicle stability and efficiency at high speed
  - improvement in design of structures

- **management of the vehicle-power supply interface:**
  - catenary/pantograph behaviour at high speed in Canadian climate
  - optimization of design for Canadian conditions

- active pantograph control strategies and techniques

o **minimization and mitigation of environmental impacts:**
- during construction
- during operations

Environmental Issues

The review covered noise, vibration, and electromagnetic (EM) fields. The main findings were as follows:

o **vibration** will not be a general problem, provided construction of the infrastructure and maintenance of trainsets, track and catenary are up to standard.

o **EMS fields** data are very spotty. The only controlled data (on TGV) are encouraging, with field strengths and characteristics comparable to those encountered in everyday activities. However, the absence of meaningful standards with respect to biomedical consequences and epidemiological significance make it impossible to draw any absolute conclusions.

o the situation with respect to **noise** is quite different. Noise will clearly be the most important operating impact, and could have a major influence on achievable speed in urban areas. Noise mitigation is possible through barriers and berms, but at a substantial cost. The situation is complicated by the fact that the ambient noise levels in active rail rights-of-way typically exceed statutory limitations imposed by municipalities. Accurate assessment of the incremental impact of HSR operations in these alignments must await availability of data on current noise levels.

TABLE OF CONTENTS

1. INTRODUCTION

This document presents the final report of the preliminary technology review carried out by the Canadian Institute of Guided Ground Transport in association with Canarail, Inc; Swederail; LGL & Associates; and J.H.Parker and Associates.

1.1 Scope

The Steering Committee for the Quebec/Ontario High Speed Rail Project established a requirement for a rigorous and objective assessment of candidate technologies, operating strategies and associated life-cycle costs for delivery of HSR services in the Quebec City-Windsor Corridor, to be structured in terms of two families of high-speed rail technologies that are currently in commercial service outside Canada:

- medium-fast [200-250 kph] technologies incorporating body tilting; and
- very fast [300 kph+] technologies currently without body tilting.

To be considered in this investigation, HSR technologies had to meet three criteria:

- be currently in commercial service;
- be capable of providing inter-city trip times superior to the other [existing] modes serving the Quebec/Ontario corridor; and
- have the potential for development of future generations of equipment capable of operating on the same infrastructure.

Within the set of candidates defined by these criteria, the scope of the preliminary technology review encompassed a wide range of issues and technical considerations, notably:

- description, characterization and definition of each candidate HSR system particularly with respect to rolling stock, service types, and capacity;
- identification of a representative technology from each 'family';
- consultation with suppliers and operators to obtain design standards for each representative technology;
- assessment of potential for and constraints on use of bi-level cars;
- development of design standards for each representative technology for Canadian application to guide the routing consultants;
- a preliminary evaluation of the conformity of the selected representative technologies with applicable Canadian safety standards and regulations, including review of federal regulations and standards in Canada and U.S., plus provincial standards where applicable;

- identification of areas of non-compliance and associated issues with respect to non-regulatory (i.e., industry) requirements and practices (VIA, CN, CP, AAR);
- assessment of feasibility of adaptation of representative technologies to comply with existing regulatory requirements;
- assessment of feasibility and consequences of modifying existing safety regulations;
- identification of potential problems related to HSR operations in Canadian climatic conditions;
- assessment of the ability of future generations of each representative technology to operate without major investments in infrastructure and/or train control;
- assessment of accessibility of technologies for elderly and handicapped;
- review of reliability of representative technologies;
- definition of requirements for at-grade crossings for speeds below 200 kph;
- assessment of the status of current R&D activities related to the representative technologies that are or could be relevant to deployment and operation in the Canadian environment;
- identification of potential environmental impacts arising from construction and operation of each representative technology;
- liaison with the industrial strategy study consultant with respect to components to be produced in Canada; and
- participation in definition of transportation service products and product attributes for the purpose of demand forecasting.

1.3 Organization

In accordance with the direction of the Project Manager, this report is structured to respond directly to each of the objectives called out in the scope above. Where issues have not been resolved, either through the lack of adequate data or because a policy decision is required that is beyond the mandate of this assignment, we have summarized the arguments for each alternative. Note that this report *does not* present complete technical detail in support of each topic. The supporting material is presented in cross-referenced Technical Appendices, which are still in preparation.

Chapter 2 summarizes findings with respect to:

- description, characterization and definition of each candidate HSR system particularly with respect to rolling stock, service types, and capacity;
- identification of a representative technology from each 'family';
- consultation with suppliers and operators to obtain design standards for each representative technology;
- assessment of potential for and constraints on use of bi-level cars;
- assessment of technical feasibility of carrying packages and/or other light freight on high speed trains;
- assessment of the ability of future generations of each representative technology to operate without major investments in infrastructure and/or train control;
- assessment of accessibility of technologies for elderly and handicapped;
- review of reliability of representative technologies; and
- rationale for exclusion of maglev from the orginal set of candidate technologies.

Chapter 3 summarizes finding with respect to:

- development of design standards for each representative technology for Canadian application to guide the routing consultants.

Chapter 4 summarizes findings and characterizes issues with respect to:

- a preliminary evaluation of the conformity of the selected representative technologies with applicable Canadian safety standards and regulations, including review of federal regulations and standards in Canada and U.S., plus provincial standards where applicable;
- identification of areas of non-compliance and associated issues with respect to non-regulatory (i.e., industry) requirements and practices (VIA, CN, CP, AAR);
- assessment of feasibility of adaptation of representative technologies to comply with existing regulatory requirements;
- definition of requirements for at-grade crossings for speeds below 200 kph; and
- assessment of feasibility and consequences of modifying existing safety regulations.

Chapter 5 summarizes findings with respect to:

- o identification of potential problems related to HSR operations in Canadian climatic conditions.

Chapter 6 summarizes findings with respect to:

- o assessment of the status of current R&D activities related to the representative technologies that are or could be relevant to deployment and operation in the Canadian environment.

Chapter 7 summarizes findings with respect to:

- o identification of potential environmental impacts arising from construction and operation of each representative technology.

Supplemental data concerning the findings reported and summarized in each chapter is contained in the corresponding Appendix volume. Appendix TA-1 contains the supporting material for Chapter 2, TA-2 for Chapter 3, TA-3 for Chapter 4, and so on. Most of the material in these Appendices has been presented previously, in working papers, trip reports and/or the Interim Report.

1.4 Acknowledgements

Completion of this review would not have been possible without cooperation from HSR suppliers and operators and from regulatory and safety agencies in Canada and the United States.

The authors wish to acknowledge the cooperation and assistance provided by ABB Canada and ABB International, Bombardier and GEC-Alsthom, Fiat Ferroviara, Siemens, JR-East and JR-Central, AMTRAK and VIA Rail Canada, the national railways of France, Germany, Italy and Sweden, the Offices of Safety and Research and Development of the U.S. Federal Railroad Administration, the Volpe National Transportation Systems Centre, and the Railway Safety Directorate of Transport Canada.

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2. TECHNOLOGY CHARACTERIZATIONS

2.1 Overview

This Chapter addresses the following objectives as specified in the Terms of Reference for this assignment:

- o description, characterization and definition of each candidate HSR system particularly with respect to rolling stock, service types, and capacity;
- o rationale for exclusion of maglev from the original set of candidate technologies;
- o identification of a representative technology from each 'family';
- o consultation with suppliers and operators to obtain design standards for each representative technology;
- o assessment of potential for and constraints on use of bi-level cars;
- o assessment of technical feasibility of carrying packages and/or other light freight on high speed trains;
- o assessment of the ability of future generations of each representative technology to operate without major investments in infrastructure and/or train control;
- o assessment of accessibility of technologies for elderly and handicapped; and
- o review of reliability of representative technologies.

2.1.1 Process

The technology assessment process began with the mapping of HSR technology characteristics and development status against the three initial qualifying criteria established by the Steering Committee. This resulted in identification of five qualified candidate technologies, three in the non-tilting, 300 kph+ family and two in the tilting, 200-250 kph category, as summarized below.

An initial technical characterization of each qualifying technology was then prepared by CIGGT, and sent to each technology supplier and operator for review, comment, and correction. Based on the responses received from the suppliers and operators, the characterization of each technology was updated and used as input to the downselection process. The technology characterizations used for downselection and other supplemental technical documentation are included in Appendix TA-1.

Note that the design specifications and performance capabilities of all candidate technologies -- including the selected representative technologies -- continue to evolve as improvements are made by suppliers and operators. The supplemental data included in Appendix TA-1 reflects this dynamic state, which is a fundamental characteristic of all successful HSR technologies.

In parallel with the supplier/operator review activity, the criteria for downselection were established, based on the functional requirements for execution of the overall Project work plan, and especially for achievement of the objectives of the *Technology Assessment, Operating Strategy and Costing* and *Routing* assignments. These criteria are also summarized below.

Information drawn from each characterization was then mapped against the downselection criteria, and an assessment made of the degree to which each candidate technology met each criterion. Finally, recommendations for the representative technology for each family were formulated and presented to the Steering Committee, which accepted the recommendations.

2.2 Description, Characterization and Definition of Candidate HSR Technologies

This subsection presents the results of CIGGT's assessment of high-speed rail technologies in each of two technology families that meet the initial criteria established by the Project Steering Committee. The objective of this assessment was to identify one representative technology for each family that would form the basis for all subsequent technical and operational analysis and system costing. Note that the objective was *not to select a preferred technology* from each family for procurement purposes, but only to identify a specific technology for purposes of the subsequent conceptual analysis.

2.2.1 Initial Qualifying Criteria

The Steering Committee established three criteria , all of which had to be met for a technology to qualify for consideration as a representative of one of the two families of high-speed rail technologies that are currently in commercial service outside Canada.

To meet these criteria, a technology must:

- o be currently in commercial service;
- o be capable of providing inter-city trip times superior to the other [existing] modes serving the Quebec/Ontario corridor; and
- o have the potential for development of future generations of equipment capable of operating on the same infrastructure.

Why Not Maglev ?

Establishment of the first of these criteria effectively excluded an entire class of high-speed technologies -- magnetically-levitated vehicles -- from consideration. In our opinion, this decision is correct, given the time frame and nature of the decision process to which the current investigation is focussed, and the characteristics of the Quebec City-Windsor corridor.

The appropriateness of this decision stems from 6 key factors:

- o at the time of writing, no high-speed magnetically-levitated technology had entered commercial operation, even in Germany and Japan;

- o the maglev technology which is arguably ready for commercial deployment -- the Transrapid electromagnetic suspension [EMS] system -- requires installation and maintenance of the alignment of guideway-mounted components to very demanding [+/- 0.6mm] tolerances which would pose exceptional challenges under Canadian geotechnical and climatic conditions;

- o electrodynamic suspension (EDS) maglev technologies -- the Japanese 'Linear Express', which has been tested in the form of various experimental vehicles, and the Bechtel, Foster-Miller, Grumman and Magneplane system concepts, which exist only on paper or as very small scale models -- have the potential to overcome the requirements for very accurate guideway component alignment, but are still at least a decade away from readiness for commercial operation;

- o there remain substantial technical and environmental uncertainties associated with EDS technologies, notably the ability to achieved commercially acceptable stability with superconducting magnets in the maglev operating environment, and the ability to shield on-board and wayside DC magnetic fields to acceptable levels;

- o the moderate topographic conditions that prevail in the Quebec City-Windsor corridor do not provide maglev with any particular opportunity to exploit its adhesion-independent traction and braking capabilities; and

- o all studies to date, regardless of corridor, have shown maglev requiring a 25% to 100% capital cost premium over high speed rail.

Given the automobile-dominated markets and relatively short intercity distances in the Quebec/Ontario corridor, a technology that boosts the required initial investment -- even if operating and maintenance costs are as low as maglev proponents assert -- is unlikely to be attractive. This is particularly true of maglev, since a significant proportion of the infrastructure-related investment --about a third of the 85% to 95% of total system first cost -- will likely flow offshore to pay for proprietary technology, as opposed to HSR, where (in our opinion) virtually all infrastructure-related components could be sourced domestically.

While the subject of much recent and on-going attention in the United States, and considerable investment (well over $3 billion in total) in Germany and Japan over the past 25 years, maglev remains a technology in search of an application. While some of its attributes are unique and its potential is sufficiently great to justify continued R&D efforts in those countries where traffic densities and modal congestion are high, it is our opinion that exclusion of maglev through application of the initial criterion is both appropriate and justified.

2.2.2. Candidate Technologies

The two technology families under consideration are:

- o medium-fast [200-250 kph] technologies incorporating body tilting; and
- o very fast [300 kph+] technologies currently without body tilting.

Application of the criteria established by the Steering Committee eliminated all but two medium-fast tilting technologies [the Fiat ETR-450, operated by Italian State Railways; and the ABB X-2000, operated by Swedish State Railways] and three very fast non-tilting technologies [the GEC-Alsthom TGV, operated by SNCF; the ICE, operated by German Federal Railways and built by a Siemens-led consortium; and the Shinkansen Sr. 300, operated by Central Japan Railway Company, which also acts as the general contractor for its construction.

In all cases, these technologies meet all the criteria defined above, although in two instances [ICE and Shinkansen Series 300] the maximum service speed -- but not the maximum achievable speed -- is below 300 kph. Later-generation versions of these technologies are already under development, and the issue of compatibility with infrastructure can be explicitly addressed.

2.2.3 Criteria for Selection of Representative Technologies

The criteria for selection of one representative technology from each family were driven by the key objectives of the *Technology Assessment, Operating Strategy and Costing* and *Routing* assignments. Specifically, these investigations must provide rigorous, credible and objective findings with respect to system configuration (full versus partial double track), system reliability, feasible alignments (new alignment versus co-location in active existing alignments) and life-cycle costs. These findings must be developed at a sufficiently detailed level to permit differentiation between the two technology families.

Achievement of these objectives requires access to substantial operating data for each family, especially as regards failure modes and frequencies, sources of operational delay, and input factor quantities for vehicle and infrastructure construction, operation and maintenance. This requirement gives rise to the first criterion:

- o For otherwise equally qualified technologies, the technology with the longest history of operation at the qualifying speed shall be preferred.

However, HSR technologies are dynamic, and it was considered important to base assessment of the relative and absolute performance of the two families on technologies that are likely to remain relatively stable, at least with respect to key subsystems, over the next five to ten years.

Basing the analysis on a first-generation technology with a longer operating history rather than a newer technology with less operating history but with the liklihood of technological stability in major subsystems could result in a serious bias. Thus, the second criterion established for downselection was:

- o Regardless of the length of operating history, a selected representative technology must reflect current engineering practices at the major subsystem level and offer a reasonable expectation that the subsystems currently in service will continue to be the norm for at least the next five years.

Note that this criterion does not work against continued innovation, especially evolutionary refinements of a qualifying technology (for example, the power rating of the X-2000 a.c. asynchronous traction motor will increase to 1100 kw for the next production batch). It simply provides some assurance that the basis for analysis in this project will remain valid long enough to permit an informed decision to be reached.

2.2.4 The 300 KPH+ Family

There are three technologies under consideration in this family,

- o the GEC-Alsthom TGV, operated by SNCF;
- o the ICE, operated by German Federal Railways and built by a Siemens-led consortium; and
- o the Shinkansen Sr. 300, designed and operated by the Central Japan Railway Company.

Key features of these technologies are summarized in Table 2.1.

In terms of the first criterion, the TGV-Atlantique is the only one of the three technologies to actually operate at 300 kph in revenue service, although all three have exceeded this standard in test. The TGV-A also has the longest operating history, having commenced service in September 1989.

The ICE entered fleet service with German Federal Railroad in June 1991, almost two years after commencement of TGV-A commercial service. The ICE fleet is limited to 250 kph by alignment geometry and superelevation compromises required to allow shared use of track with high-speed freight. However, the top speed on selected portions of the new high speed lines is to be increased to 280 kph in the near future.

The Shinkansen Series 300 EMU equipment entered commercial service with JR Central in mid-1992, and thus has only a few months of service history. As is the case with ICE, the Series 300 equipment has exceeded 300 kph in test, but is restricted to 270 kph maximum in service due to the alignment geometry of the JR Tokaido line on which it operates. As of th time of writing, only a small number of Sr. 300 trainsets are in service, although the fleet size is growing as deliveries continue.

It is clear that the GEC-Alsthom TGV best meets the first criterion, and in terms of actual commercial service at 300 kph+, is likely to be the only technology to do so for some years to come.

TABLE 2.1: CHARACTERISTICS OF CANDIDATE 300+ KPH TECHNOLOGIES			
CHARACTERISTIC	TGV-A	ICE-A	SERIES 300
In Commercial Service	September 1989	June 1991	May 1992
Top speed	515.3 kph (1-3-1)	410 kph	325.7 kph
Service speed	300 kph	250 kph; 280 kph on some track segments	270 kph
Vehicle type	Articulated trainset	Loco-hauled	EMU
Consist	1-10-1	1-13-1 or 1-14-1	16:5(M-T-M) and cab car
Seating Capacity	369 coach;116 first	681 (1-14-1)	1,323
Propulsion	ac synchronous 1100 kw, 8 axles powered	ac asynchronous 3-phase, 1200 kw, 8 axles powered	ac asynchronous, 300 kW, 40 axles powered
Braking	Blended rheostatic, disc and tread brakes	Blended regenerative and discs	Blended regenerative, disc and eddy-current
Power supply	OCS 2 x 25 kV, 50Hz	OCS 15 kV 16 2/3Hz	OCS 2 x 25 kV 60Hz
Axle load	17 tonnes	20 tonnes	11.3 tonnes
Unsprung mass/axle	2.2 tonnes	1.87 tonnes/axle	1.86 tonnes/axle
Fleet Size	105 trainsets in service	90 trainsets in service or on order	4 sets in service; in production

In terms of the second criterion, all three technologies are likley to remain largely stable with respect to major subsystems. While all three will continue to undergo evolutionary development, and while both SNCF/GEC-A (the super TGV) and JR-Central (STAR 21) have longer-term R&D projects aimed at delivering advanced-generation technologies incorporating major changes, the information which is now available to us does not support any strong differentiation among the three candidates on the basis of the 'subsystem stability' criterion.

2.2.5 The 200-250 kph Tilting Family

There are two technologies under consideration in this family:

- o the ETR-450, designed and built by Fiat, and operated by Italian State Railways; and
- o the X-2000, designed and built by ABB and operated by Swedish State Railways.

Table 2.2 summarizes key features of these two technologies.

TABLE 2.2: CHARACTERISTICS OF CANDIDATE 200-250 KPH TILT-BODY TECHNOLOGIES

CHARACTERISTIC	ABB X-2000	FIAT ETR-450
In Commercial Service	September 1990	1988
Top Speed	250 kph	250 kph
Service Speed	200 kph	250 kph
Fleet Size	20 1-4-DT trainsets in service or on order, plus 14 1-2-DT sets on order	15 3(M-T-M) sets in service; 10 ETR 460 sets [also 3(M-T-M) ordered
Vehicle Type	locomotive-hauled with driving trailer	EMU
Consist	1-4-DT (in service) or 1-2-DT	M-T-M-M-T-M-M-T-M (9 vehicles)
Seating Capacity	200 (all Ist class); 281 mixed	402 (9 vehicles)
Propulsion	ac 3-phase asynchronous; 815 kw; 4 powered axles	dc; 312 kW, body-mounted; 16 powered axles/train
Braking	Blended regenerative, discs, magnetic rail brake	Blended rheostatic and discs
Power Supply	OCS 15 kV 16 2/3 Hz single phase	OCS 3 kV dc
Axle Load	18.25 tonnes (max)	12.5 tonnes
Unsprung Mass	1.8 tonnes/axle	1.6 tonnes
Maximum Tilt	8°	10°
Other Features	Steerable powered trucks	Partially active lateral suspension

With respect to the first criterion, the ETR-450 has a longer operating history, having entered revenue service in early 1988. Italian State Railways [FS] now has 15 nine-car ETR-450 trainsets in service. The ETR-450 operates at a maximum speed of 250 kph.

The X-2000 entered service with Swedish State Railways in September 1990, and operations have been expanding as deliveries continue and the fleet grows in size. the X-2000 operates at a maximum speed of 200 kph on SJ lines. An unmodified production trainset has been tested at 250 kph on high-speed track of German Federal Railways, while the slightly-modified trainset leased to AMTRAK reached 248 kph on the North-East Corridor between New York and Washington .

With respect to the first criterion, the ETR-450 would be preferrable, all else being equal. However, that is not the case.

With respect to the second criterion -- 'subsystem stability'-- the ETR-450 does not meet this requirement. The version now in fleet service is equipped with dc traction motors and obselescent power conditioning equipment. The 10 'third-generation' ETR-450 trainsets of 9 coaches (3 x M-T-M) recently ordered by FS incorporate ac traction, GTO converters and a redesigned tilt actuation mechanism, as well as a wider, more aerodynamic bodyshell. Since the shift from dc to ac traction consitutes a 'state change' for a major subsystem, and since several of the other changes will also have, or at least have the potential to have, major (albeit positive) impacts on the reliability and cost structure of the technology, it is our opinion that the ETR-450 should not be used as the representative technology for this class.

The X-2000, on the other hand, already incorporates ac traction and state-of-the art power conditioning equipment, and is unlikely to undergo major alterations at the subsystem level over the time period of interest to the Project. For that reason, CIGGT believes that the X-2000 will be a better representative technology from the perspective of the Project.

2.2.6 Recommendations

On the basis of our assessment of the candidate technologies using the updated information provided by the respective technology suppliers and operators, CIGGT recommended, and the Steering Commmittee accepted:

- o that the GEC-Alsthom TGV-Atlantique/TGV-Reseau technology be adopted as the representative technology for the very fast (300 kph+) non-tilting technology family; and

- o that the ABB X-2000 technology be adopted as the representative technology for the moderately fast (200-250 kph) tilting technology family; and

- o that operating data for subsystems of the ETR-450 and its infrastructure that will not be affected by redesign for the next generation be sought to supplement those for the X-2000.

2.3 Consultation with Suppliers and Operator of Representative Technologies

In accordance with the approach outlined above, GEC-Alsthom, Bombardier (as TGV suppliers) and ABB (as the X-2000 supplier), plus SNCF (as the TGV operator) and SJ (as the X-2000 operator) were asked to provide additional detailed information about these technologies, about the infrastructure over which they are operated, and about the operating and maintenance procedures and operating history of each technology. As well, Fiat and FS were requested to provide selected additional data on specific aspects of the ETR-450, the FS infrastructure and ETR-450 services and operating and maintenance history. Detailed lists of the requested data and the material provided in response by the suppliers and operators are included in Appendix TA-1.

For the most part, the requested material was provided, but the degree of detail provided has varied quite widely, depending on the entity providing the response and the subject matter. In some areas of concern, such as climate, EM fields and noise, some requested material could not be obtained.

In some instances -- electromagnetic fields, for example -- neither the suppliers nor the operators provided data directly. We have been able to obtain sufficient data from other sources to allow us to address most areas of concern affected by this limitation.

In addition to these written requests, senior consultant staff carried out site visting to France, Sweden and Italy, as authorized by the Steering Committee. These visits yielded substantial amounts of valuable information and points of contact. The trip report and supporting documentation has already been issued and will form a stand-alone supplemental document to this report.

The information gathered through the data requests and site visits has been incorporated into the summaries presented in this report and the supporting documentation in the TA-series Appendices.

2.4 Assessment of Potential for and Constraints on Use of Bi-level Cars

At present, JR-East and JR-Central operate high-speed bi-level coaches as part of standard Shinkansen consists, while in France the prototype TGV-Deux Niveau coaches completed their test program in 1992, operating in a modified TGV-A consist. SNCF has placed a firm order for 45 1-8-1 sets of the TGV-Deux Niveau, to be delivered by GEC-A starting in 1994, and has an option on a further 55 sets. The current conceptual design for the next generation of TGV rolling stock -- the so-called TGV-'NG', for *'Nouvelle Generation' -- also calls for bi-level cars.* In all cases, the equipment is or will be fully compatible with existing clearance envelopes, geometric limits and so on.

In both Japan and France, the driving force behind the development and use of bi-level equipment has been the need to add effective capacity without increasing the number of trains or the length of individual trains. Bi-level cars increase the seating capacity per trainset -- thereby adding system capacity without additional departures -- without compromising the total length of the consist, and thus its ability to effectively use existing stations and platforms.

The traffic volumes and capacity problems of the Tokaido and New Sanyo Shinkansen are legendary, while the continued growth of traffic peaks on the TGV-PSE and expected level of demand on the TGV-Nord prompted SNCF officials to examine alternative means of adding capacity. After investigation of conventional and articulated alternatives, SNCF concluded that an articulated bi-level consist would offer the most cost-effective solution and minimize modifiactions to existing infrastructure.

However, while bi-level consists offer a lower cost per seat (according to SNCF and GEC-A and the reported costs for Shinkansen), the ability to exploit this advantage requires a high level of demand in a corridor where infrastructure congestion is threatening to become a problem. A precondition for use of bilevel equipment as a substitute for conventional single-level consists is that the number of departures should not fall below the threshold value for the particular service. Typically for HSR this is in the range of 8 to 10 trains per day per direction. Since the forecast traffic levels on the Quebec-Ontario corridor have historically been marginal for this level of service with short single-level consists and mediocre load factors, there is no obvious case to be made for bi-level equipment from the standpoint of operational economics.

Where bi-level equipment could make sense is in terms of time-sensitive, low-density freight -- packages, letters, any 'high cube, low mass' product -- just as trailers with higher cubic capacity at the same GVW have made truckers more competitive in certain markets. However, pending the completion of the analysis of the market potential for high speed freight, it is unclear whether this idea is worth pursuing.

2.5 Assessment of Technical Feasibility of Carrying Light Freight on High Speed Trains

The movement of low-density, time-critical freight by HSR appears to offer real potential for revenue enhancement with little marginal cost to the HSR operator. Such services are being offered in separate cars on passenger services, e.g. by AMTRAK on its NEC services and in dedicated trainsets, e.g. the Postal TGVs owned by the French Post Office and operated by SNCF during the night-time maintenance window, or DB's express overnight trains with purpose-built freight vehicles.

Technically, there is no problem from an operational point of view provided the track forces imposed by the vehicle do not exceed the limit for passenger operations, and that the light freight rolling stock and cargo containment are maintained and operated in adherence with safety and technical standards of the HSR. After all, it does not matter to either the rolling stock or the infrastructure whether the product is passengers or postal bags.

If one considers the TGV-A consist, with 485 passengers, luggage allowance, and removable fittings, the total payload for light freight would be on the order of 7 to 8 tonnes per car. This is consistent with the 60 metric tonnes reported for the Postal TGVs, although these have specialized internal fittings that increase the tare weight of the consist, and the loads tend to cube out before massing out. For the purpose-designed TGV-Fret concept now under development, the objective is a payload of 10 tonnes/trailer for a 1-8-1, or 80 tonnes total. Lower-speed trains with better weight/power ratios could also be attractive in this role, although this would require a flexible signal system such as ATCS to minimize interference effects.

The major question that will have to addressed before the overall feasibility of light freight operation can be assessed is only partially technical:

> Should the service be provided by one or more dedicated cars in regular passenger consists (a real possibility if demand levels are such that only five or six cars are required to serve ridership), or by complete, specialized consists such

as the TGV-Fret ?

The answer to this question will be determined in large part by the requirements of potential shipper and by modal competetion. At present, it appears that most goods in the 'light freight' category move by truck directly to or from specialized handling facilities and thence by proprietary delivery to the final destination.

The current postal operation in France is based on two dedicated trainsets operating between specialized postal terminals. The plans for TGV-Fret are similar: dedicated consists serving existing and/or new freight handling facilities. However, the French have the great advantage of an extensive electrified network which permits direct access to many existing freight-handling facilities. Unless dual-mode or non-electrified motive power is selected for the corridor operation, this flexibility will not be available even with dedicated consists.

If dedicated cars in passenger consists are to be used, appropriate and acceptable handling procedures compatible with existing and/or new station and terminal facilities will have be established. Speed of handling and shipment security will be of particular concern. Also at issue will be the effect of in-terminal handling on service pricing relative to current operations.

Shipper attitudes and requirements with respect to these issues will largely determine which approach is most practical and the potential light freight volumes.

2.6 Compatibility of Future Generations of Technology with Infrastructure Designed and Built for Current Generation

Development of an HSR system in the Quebec-Ontario Corridor will require seven to ten years from initiation of design to start of operations; once built, much of the infrastructure will have an essentially infinite life, assuming it is properly maintained. As a consequence, the ability to to operate future generations of either representative technology on whatever infrastructure is initially constructed, without need for major new investments, is of particular concern. Indeed, given the substantial lead time between the present and the earliest practical date for initiation of operations, it is likely that for either representative technology, a more advanced generation will be available.

As a starting point, from our discussions with suppliers and operators, there is no question that future generations of either TGV or X-2000 will be fully compatible with the existing infrastructure of SNCF on the one hand and SJ/BV on the other. The design parameters governing the critical wheel-rail and catenary-pantograph interfaces, clearance envelopes and the like will be constrained to ensure that the ability of these HSR operators to exploit service flexibility through operations on their respective existing electrifed networks and increasingly on those of neighbouring countries will not be affected. The limiting feature in all cases will be the geometry and track quality of the existing networks: exploitation of the full performance capabilities of new generations of the representative technologies will require track built to the corresponding geometric limits and maintained to the requisite tolerances for passenger comfort and safety.

The stated objectives for 'next generation' TGV and X-2000 trainsets incorporate two elements of particular interest in the context of compatibility: the top speeds (350 kph and 300 kph, respectively) and the targetted reductions in aerodynamic drag (by 25% relative to the TGV-A and 25% to 30% relative to the current X-2000).

While the 'representative' alignments for the 300+ family have been laid out for 350 kph minimum curves, the alignment for the '200-250' family is laid out for 250 kph curve minima. In view of the higher speed objective for the next generation of X-2000 rolling stock, there should be a close examination of the differential costs between the '250 existing ROW' and '350 existing ROW' representative alignments. It may well be that opting for a common basis (i.e., the '300+') for the 'existing ROW' alignments will eliminate future limitations on effective exploitation of improved speed capabilities for the X-2000.

With respect to the improvements in aerodynamic resistance, there will be two major effects: reductions in aerodynamic noise and energy consumption at a given speed. The former is especially important, given the degree to which noise is expected to limit acceptable operating speed in urban areas. While the importance of aerodynamic noise decreases with speed, the targetted improvements might permit an increase from 160 to 200 kph in some areas. Certainly, the reduction of noise at top speed will be very significant, since many noise components increase as the 6^{th} power of speed.

In the context of the Quebec-Ontario Corridor, where major reconstruction of existing alignments and/or construction of new dedicated high-speed tracks in optimized alignments will be required, the fundamental determinant of compatibility will be the geometric design standards to which such reconstruction and/or new construction are built. The issue here is not physical compatibility but rather the degree to which the superior performance capabilties of new generations can be effectively exploited in operations to deliver improved transportation products. Accordingly, anything that can be done to eliminate speed 'bottlenecks' on the representative alignments will be advantageous.

2.7 Accessibility of Technologies for Elderly and Handicapped

Both technologies have been designed with at least one wheelchair tiedown and a handicapped-accessible toilet. The X-2000 driving trailer is equipped with a wheelchair lift to permit access even from low-level platforms. The TGV does not incorporate a lift but makes use of wayside lifts similar to those used by VIA Rail where high-level platforms are not available.

Based on personal observations, the X-2000 as currently configured is easier to move around in than the TGV; the aisles are wider, and the luggage storage is easier to shift bags into and out of. The fact that the X-2000 is .176 m wider than the TGV contributes to the more spacious interior layout. However, interior layout is an essentially cosmetic issue: either trainset could be configured to facilitate access for handicapped and elderly passengers. The main constraint, in the case of the TGV is the narrowness of the intercar doorway, which is a function of the annular articulation between cars and the requirements of the truck secondary suspension. This constraint could be lifted by building wider cars for North American applications.

What will be required are additional tiedown spaces and accessible facilities on each consist, plus provision of high-level platforms at stations and terminals. This approach will reduce the need for specialized equipment at stations, reduce delays in entraining/detraining (for *all* passengers!) and allow a greater degree of independence for physically disadvantaged travellers.

2.8 Reliability of Representative Technologies

From the information provided to us by SNCF and by SJ, and from our discussions with operations and maintenance experts of both railways, both technologies exhibit a very high level of operational reliability. Neither technology exhibits any dominant failure mode symptomatic of a design deficiency. According to ABB, the reliability of the X-2000 to date has exceeded the contractual standards imposed by SJ to such a degree that ABB are now considering eliminating some of the redundant design features to reduce cost and complexity. (The data supporting these inferences have been provided on a restricted basis and have *not* been included in Appendix TA-1.)

That said, both technologies require systematic preventative maintenance that is 'intensive' by North American standards[1], although commonplace elsewhere. Interestingly, many VIA Rail Canada maintenance practices are beginning to emulate the European model.

The question of overall *system* reliability, including all infrastructure subsystems, is much more difficult to assess, insofar as one must control for track configuration, levels of utilization, operations on shared tracks, climatic conditions, work-related slow orders and so on. The effects of these elements on overall reliability for operation in the Quebec-Ontario Corridor is being explored in some depth in tasks related to development of the operating plans, and will be reported in detail in the Interim and Final Operating Plans. However, as a first-order indicator of system reliability, SNCF report on-time arrival for more than 97% of TGVs operated on dedicated HSR trackage, while SJ cited on-time statistics of more than 95% for 1991.

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1 Comment by Mr. Ed Lombardi of AMTRAK, March 4, 1993, during discussion with Project delegation in Washington, D.C.

3. DESIGN STANDARDS FOR REPRESENTATIVE TECHNOLOGIES

This chapter summarizes the findings with respect to design standards for each representative technology for Canadian application. There are three subsections addressing different aspects of design standards.

Subsection 3.1 summarizes alignment geometry standards for horizontal and vertical curvature, with and without body tilting and for different amounts of superelevation and residual acceleration. Subsection 3.2 deals with clearance requirements for HSR generally and for the TGV and X-2000 specifically, while Subsection 3.3 presents design standards for infrastructure subsystems. Note that in most instances, the specifications for new construction and reconstruction are common to both families. Where there are differences in design specifications between the two families, the differences are related more to speed -- the level of tension in the catenary contact wire, for example -- rather than to technology per se, and have been indicated in terms of speed ranges.

Supplemental information providing additional detail is presented in Appendix TA-2.

3.1 Alignment Geometry Standards.

3.1.1 Alignment Selection Criteria

Selection of an appropriate alignment is an essential step in development of any high-speed ground transportation system. Construction (and subsequent maintenance) to rigorous standards is fundamental to safe and comfortable operation.

The aspects of three-dimensional geometry that define the limiting conditions for the alignment as a whole are vertical and horizontal curvature and gradient, as illustrated in Figures 3.1 and 3.2, plus the local elements that define the orientation of the track at a specific location or for a short segment of an alignment, relative to a set of orthogonal axes [line, profile or level, gauge, superelevation or cant, warp or twist], as shown in Figure 3.3.

Comfort limits for acceleration drive most geometric standards. These limits reflect the levels of lateral and vertical acceleration that the majority of passengers find acceptable -- 0.08g to 0.10g for longitudinal, lateral and downward vertical accelerations, 0.05g for upward accelerations. Most passengers cannot detect accelerations of less than 0.04 g.[2] Because passengers are typically more sensitive to unweighting at crests -- the effect one feels when going over the top of a hill on a highway -- the acceptable acceleration, and thus the minimum radius of curvature, is larger for crests than for troughs.[3]

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[2] See, for example, "*Building the World's Fastest Railway*", Andre Prud'homme, Railway Gazette International, Jan. 1979; "*The Development of a Truck for Narrow Gauge Line Limited Express Vehicles of Next Generation*", Dr. S. Koyanagi, RTRI Quartey Reports, V.26 No.2, 1985; and "*Tilt System for High-Speed Trains in Sweden*", R. Persson, IMechE (Railway Division) Seminar on Tilting Body Trains, Dec. 1989.

[3] Prud'homme, Ibid.

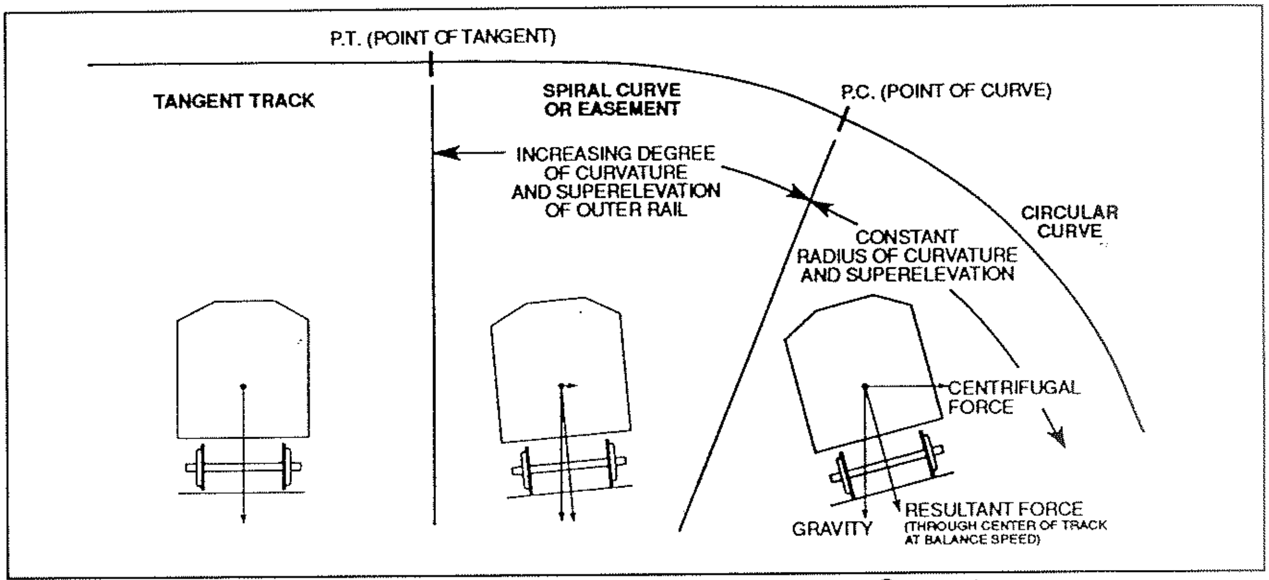


Figure 3.1: Elements of Horizontal Alignment Geometry

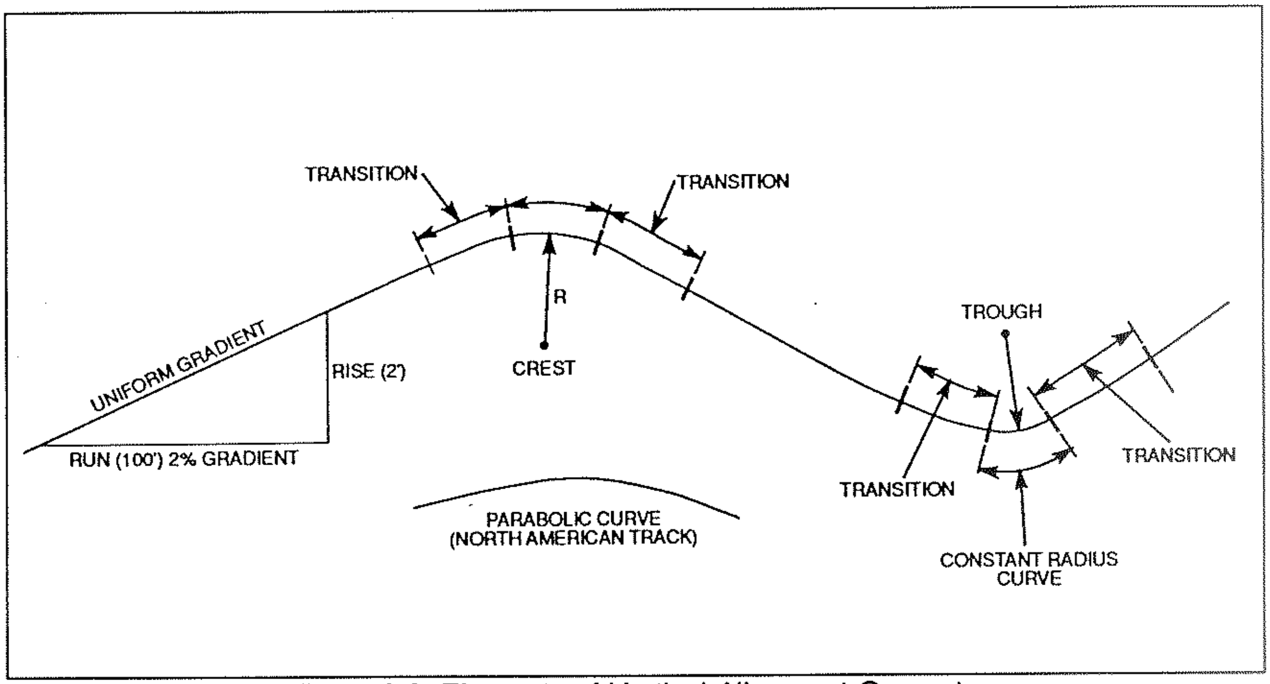


Figure 3.2: Elements of Vertical Alignment Geometry

In contrast, virtually all track in Canada and the United States has been designed to AREA track standards. These standards require larger-radius curves in troughs than at crests, the opposite of the situation for tracks built for high-speed passenger services. This is because the concern with the design of freight track is control of the behavior of cars and locomotives and the inter-vehicle forces, especially in long trains. In passing through a trough or sag, the rear cars tend to crowd in on those in front, with a consequent sudden reversal of stress in the draft gear. To control this phenomenon, troughs are made more gradual than crests.

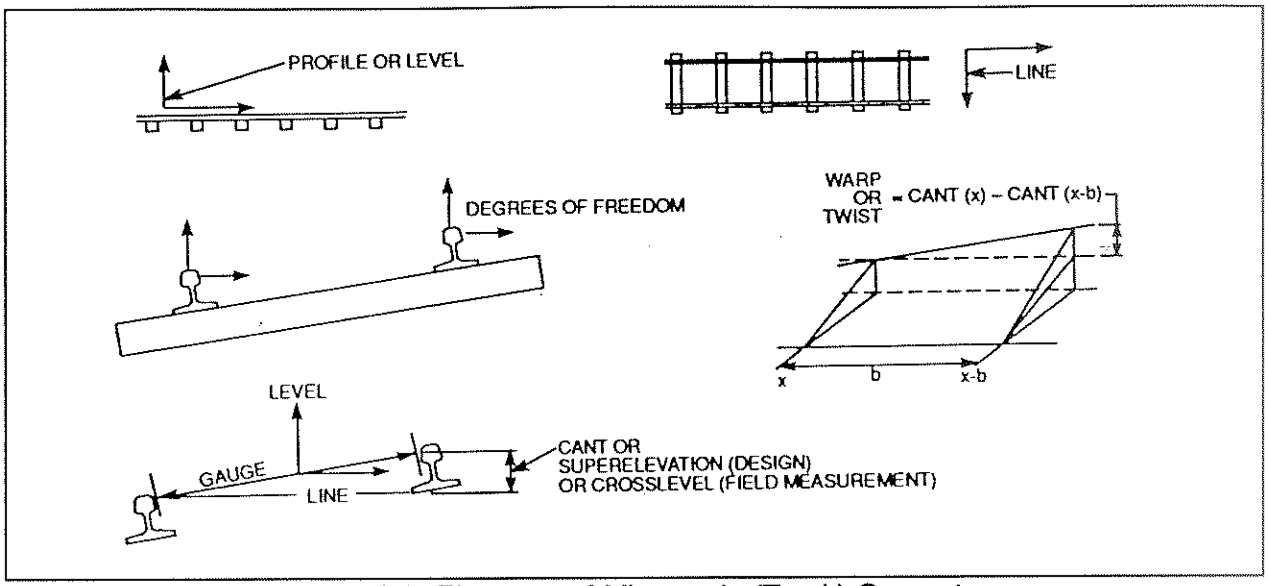


Figure 3.3: Elements of Microscale (Track) Geometry

Compatibility between the characteristics of existing railway [and other] rights-of-way with the geometric requirements of an optimized HSR alignment is an important issue. Most existing mainline railway rights-of-way in Canada were initially selected to serve both low to medium-speed passenger operations and freight. However, the increasing dominance of freight operations in the post-WWII period has resulted in the modification of curve geometry and track configuration to optimize freight railway operations.

The general requirement for a freight alignment is that it minimize route length while permitting operation at a relatively slow but steady speed, with the maximum (controlling) gradient limited by the ability of equipment to start a heavy train from a standing start. To control the costs of track geometry and rail maintenance in curves, freight alignments seek long tangent sections connected by the shortest curves possible, ideally without imposing a restriction on the [relatively slow] planned operational speed. Where topographic relief is a factor, freight alignments sacrifice good horizontal geometry to maintain acceptable gradient with a minimum of tunnelling. This means that most existing rail alignments in Canada have geometric characteristics that represent inherent restrictions on achievable HSR speed.

In contrast to rail freight requirements, an optimum high-speed passenger alignment minimizes achievable trip time through a combination of route length reduction and the elimination of geometric restrictions on speed. This means in some circumstances that a (somewhat) longer route with superior geometry may be preferrable to a shorter but slower alignment. The tradeoffs have to be made among life-cycle costs and incremental revenues arising from improved performance. There are two important points to bear in mind.

First, an HSR alignment can incorporate much steeper gradients [up to 3.5% for wheel-on-rail technologies in service, and potentially 5%] over proportionately longer distances than would be feasible for a freight alignment [where gradients of less than 1% are desired and a 2% grade is exceptional]. The power-to-weight ratio, adhesion control capabilities and trainset momentum of

HSR technologies contribute to this ability. Second, an HSR alignment should be selected so that its geometry will impose as few future speed restrictions as possible, not just accomodate what is now achievable. With respect to curvature, this means that the alignment must minimize total angle, not just be based on some minimum allowable curvature (which will simply become a future speed restriction). For the 300 kph+ family, design curve radius is 6000 m or more, with more restrictive curves accepted only on an exceptional basis, or where other factors -- such as gradient or wayside development -- already require some speed reduction.

Figure 3.4 summarizes the relationship between design speed and curve radius for different levels of track superelevation and levels of residual acceleration without body tilting, while Figure 3.5 shows the same information for operation with body tilting. Figure 3.6 summarizes the required vertical curve radius for different speeds and levels of residual acceleration.

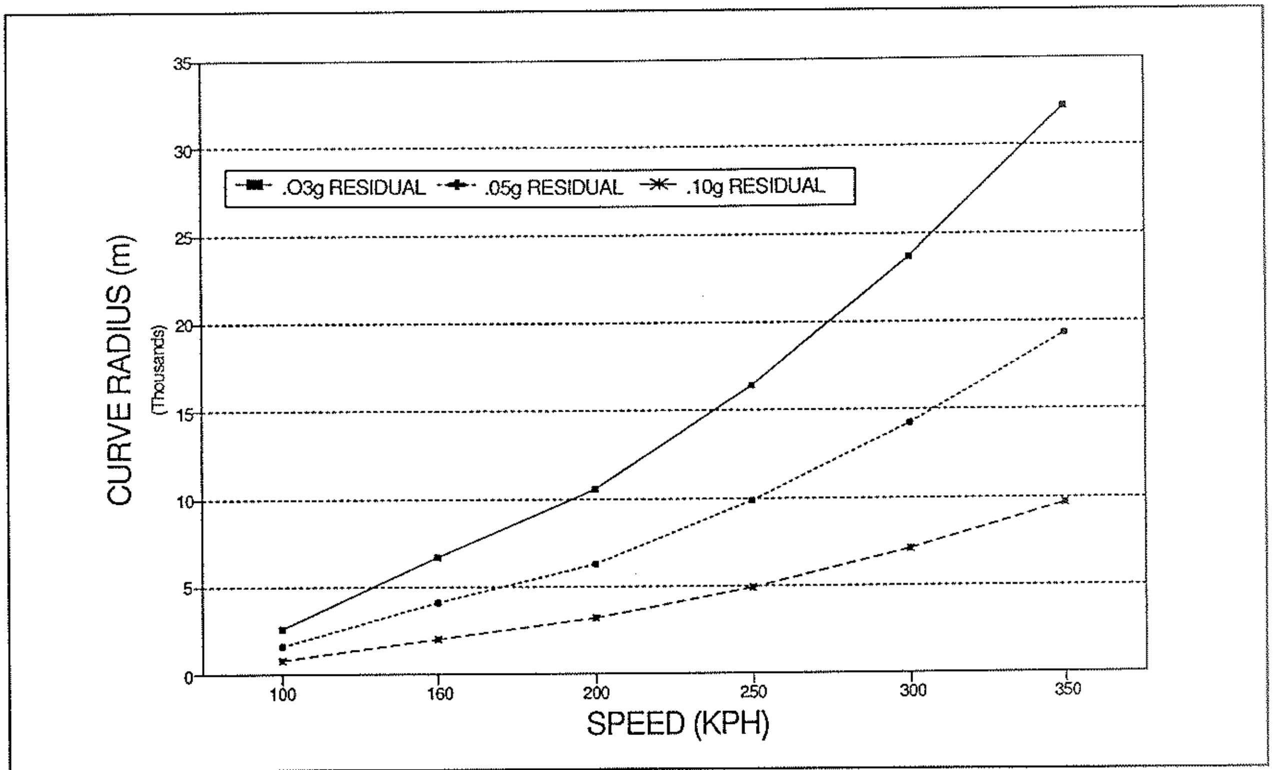


Figure 3.6: Vertical Curve Radius as Function of Speed and Residual Acceleration

Transition Curves

The geometry of the transition curve -- the segment of track linking a tangent (straight) section to a constant-radius curved section -- directly affects the rate of change in superelevation and thus the rate of change in lateral acceleration [the jerk rate]. It also determines the length of transition spiral required to achieve the full amount of superelevation required for any constant-radius curve segment. For non-tilting technologies, the rate of increase in superelevation must track exactly the rate of decrease in effective radius through the spiral, or else the perceived lateral acceleration will increase.

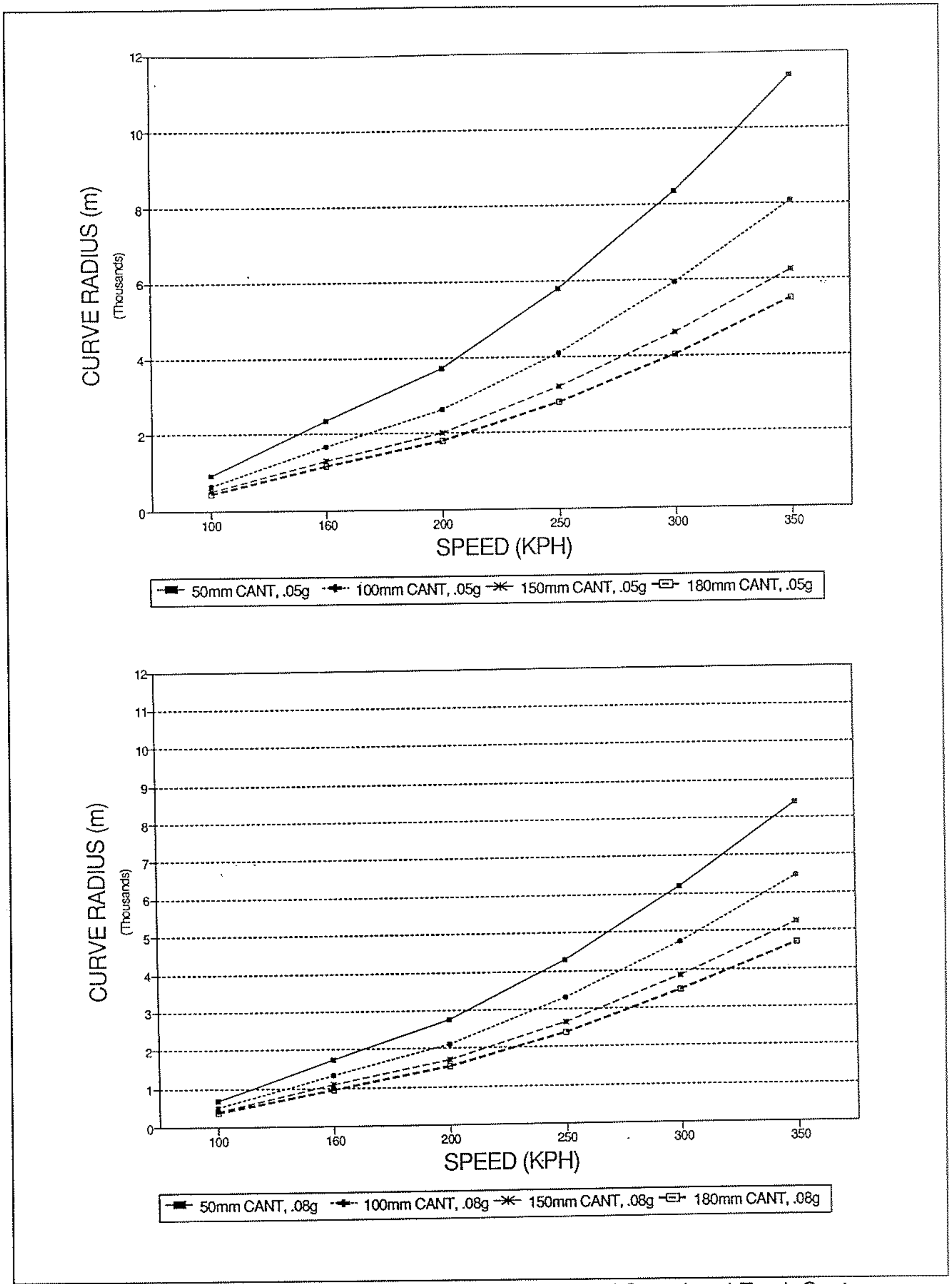
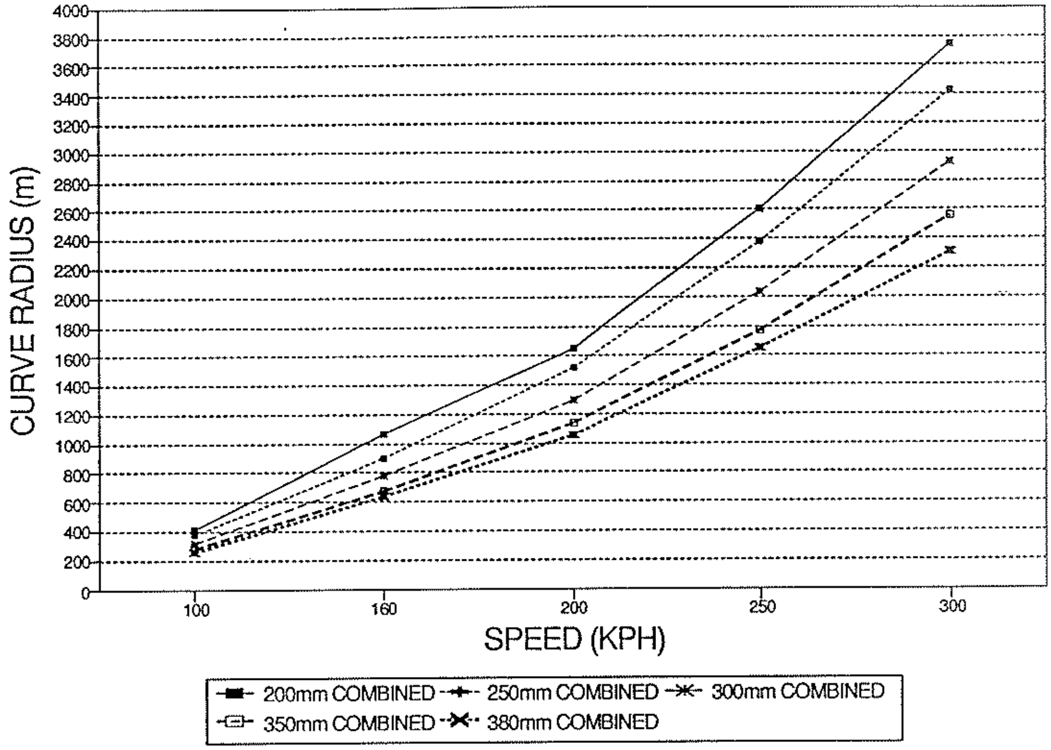


Figure 3.4: Horizontal Curve Radius as Function of Speed and Track Cant for 0.05g (top) and 0.08g (bottom) Residual Acceleration



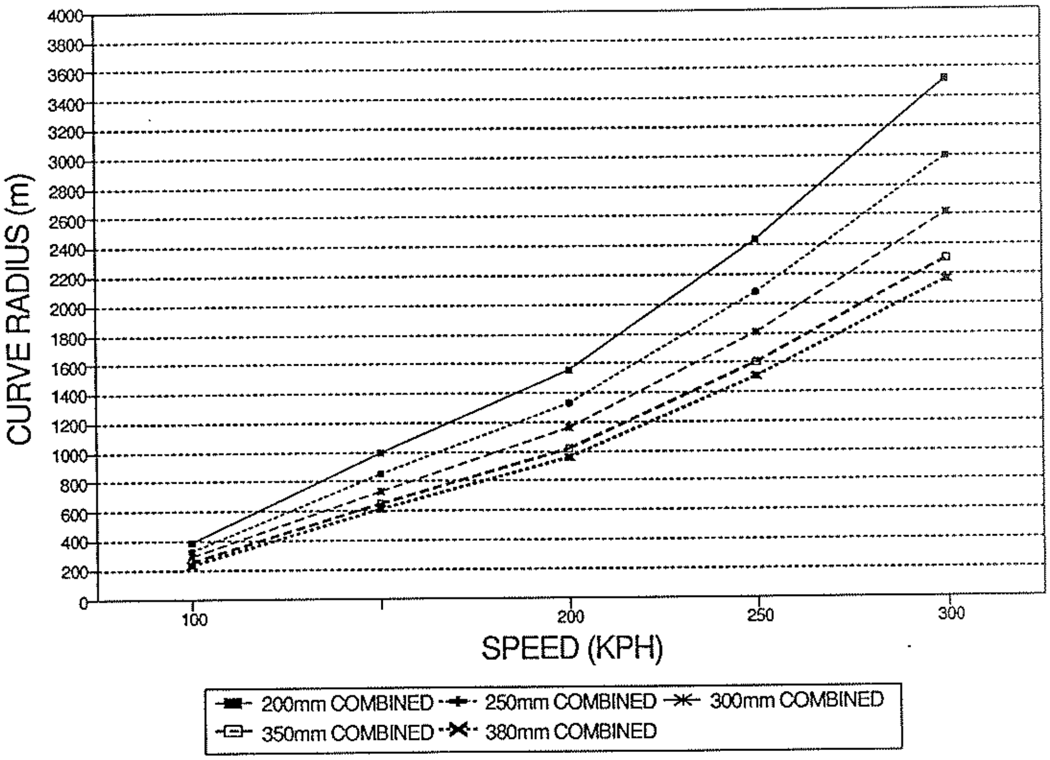


Figure 3.5: Horizontal Curve Radius as Function of Speed, Track Cant and Body Tilt for 0.05g (top) and 0.08g (bottom) Residual Acceleration

Active tilting systems typically sense lateral acceleration at the vehicle truck, and/or the track superelevation, as input signals to the tilting system controller. Accordingly, the vehicle ride quality will be influenced by the transition curve geometry to the extent that these signals affect the rate and magnitude of tilting motion through the system controller.

To control transition effects without imposing unrealistic computational demands, most railway track in North America has been laid out (in the field) using a "cubic parabola" approximation to a clothoid transition. This curve provides a reasonable approximation of the first term of the clothoid transition curve expansion. These tracks typically incorporate linearly-increasing superelevation for all but the gentlest of curves.

Transition curve alignments which eliminate the entry and exit lateral jerk discontinuities of the clothoid transition curve exist and have been used for dedicated high speed passenger track in Japan. The French high speed lines have transitions based on cubic parabolic approximations to the clothoid, while DB high speed lines use a fourth-order (quadratic) parabolic approximation.

Techniques for optimizing railway vehicle passenger ride comfort through transition curves by means of the active car body tilting, not surprisingly, attempt to duplicate the lateral acceleration and lateral jerk variations of the full sine wave/clothoid transition curve geometry.

3.1.2 Recommended Design Standards

Table 3.1 summarizes the recommended standards for transition spirals.

TABLE 3.1: RECOMMENDED STANDARDS FOR TRANSITION SPIRALS

Parameter	Suggested Value
Maximum Superelevation	180 mm, 201 to 300 kph; 150 mm, up to 200 kph
Rate of change in superelevation - normal - exceptional	0.36 mm/m 0.6 mm/m
Minimum Spiral Length	300 m, 300 kph; 250 m, 200-250 kph
Minimum Spiral Separation	150m
Calculation Equation for Cubic Parabola Approximation	$y = x^3/6RL$, where L is the length of the transition curve peojected on the x-axis, and R is the radius of curvature of the constant-radius curve section
Calculation equation for length of transition curve (for maximum jerk of 0.2 m/sec^3)	$L = 0.118\ V^3/R$, where V is vehicle speed in kph and R is as above in m.

3.2 Clearance Requirements

Clearance requirements encompass two distinct aspects: the *clearance envelope* required for safe operation of a particular trainset, and the *right-of-way* requirements that are affected more by safety considerations, operating speeds, construction and maintenance access, catenary support locations and drainage than by technology per se.

3.2.1 Clearance Envelopes

Figure 3.7 shows the clearance envelope for the X-2000; Figure 3.8 presents the TGV clearance envelope.

3.2.2 Right-of-Way Requirements

Required right-of-way width depends on a number of factors, including the structural compatibility of technologies operating in the alignment, the track structure design and track configuration [single, double,...], the geometry of the track at a given point [tangent, transition, constant-radius curve..], the required separation between track centrelines to permit safe operation, the presence or absence of structures [viaducts, bridges, grade separations,...] and topographic relief [cut, fill].

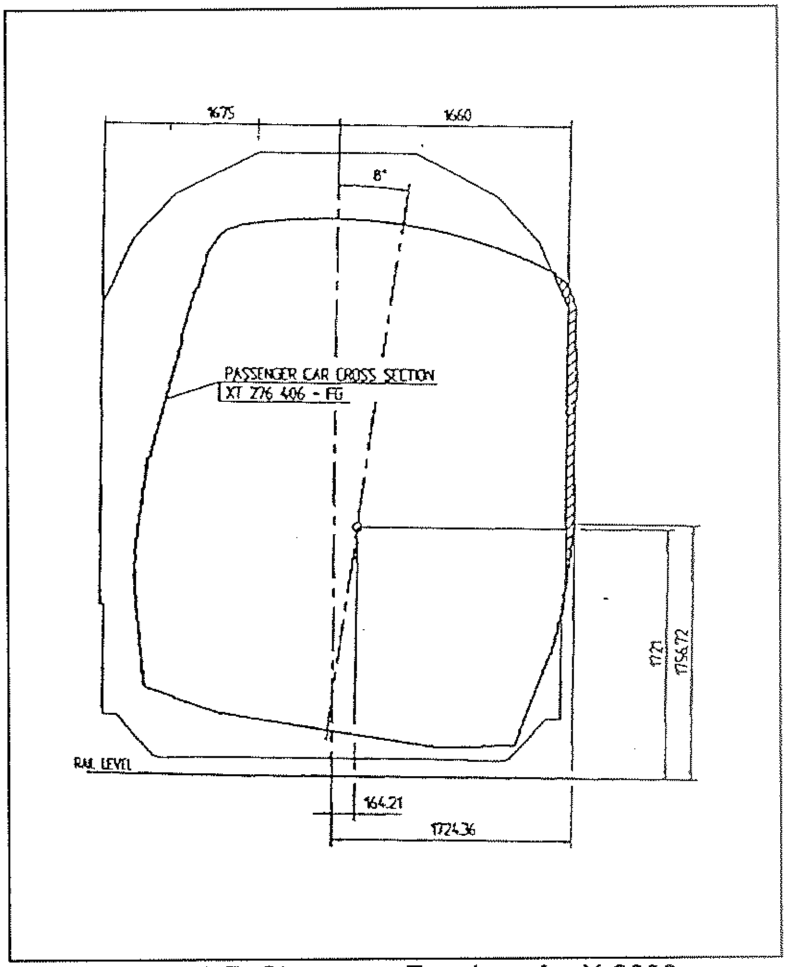


Figure 3.7: Clearance Envelope for X-2000

It has now been established that for a Canadian application, each of the representative technologies would be modified to achieve compliance with existing FRA regulatory standards and AAR industry practices so as to permit shared-track operation with conventional equipment, as well as retaining the superior energy-dissipating capabilities required for safe high-speed operation[4]. This removes technology compatibility as a major determinant of right-of-way requirements and will permit shared-track or

[4] Personal communications, C. Boon with Z. Lendich, ABB, January 21 1993; with J. Pleau, Bombardier, March 18, 1993.

shared alignment operation up to 160 kph at conventional track centres without special conditions[5]. At speeds over 160 kph but below 200 kph, shared-track operation is possible, but TC has stated that special conditions relating to construction and/or maintenance of track, signalling and train control and to operations are likely to be imposed[6].

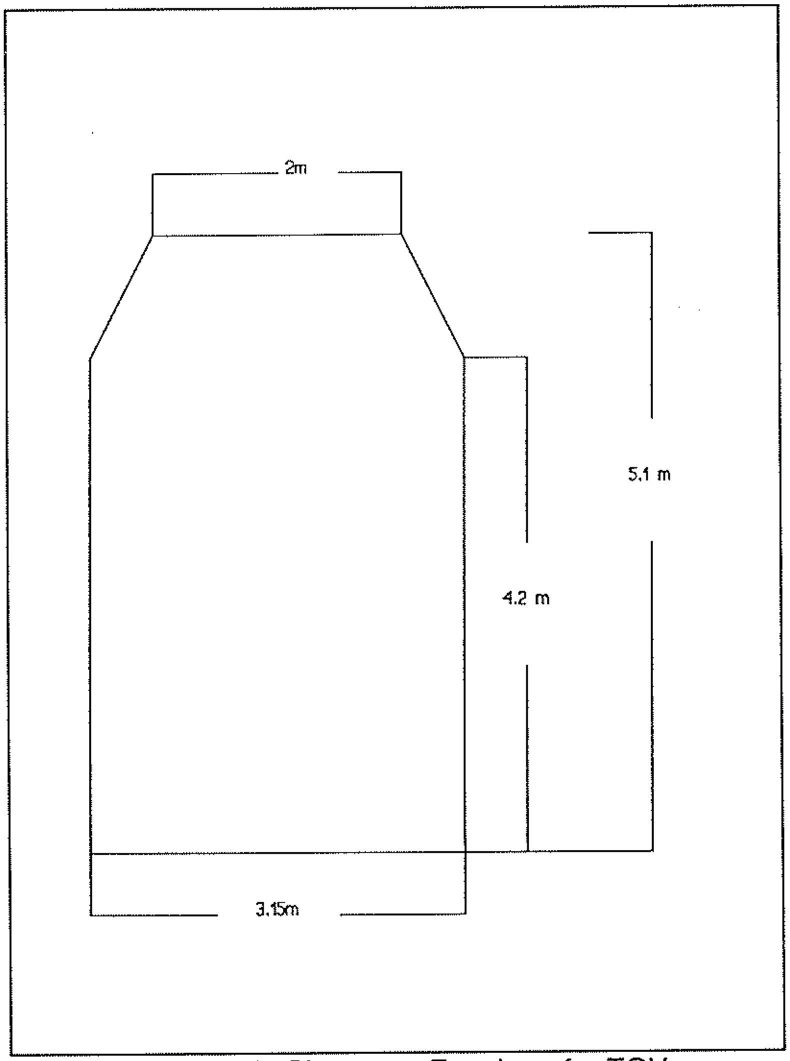


Figure 3.8: Clearance Envelope for TGV

Above 200 kph, shared-track operation will not be permitted, but shared-alignment operation without physical barriers (*but with 8m separation and intrusion detection linked to train control)* will be allowed up to 250 kph. Higher speed operations in a shared alignment will require either much greater separations or some form of passive intrusion barrier[7].

Based on our review of track separation practices employed by HSR operators in Europe and Japan, and in particular those of SJ and SNCF as the operators of the representative technologies, we recommend minimum clearway and other right-of-way-related separation distances as summarized in Table 3.2. These recommendations have been applied by SNC+Delcan to create the typical cross-sections presented in the routing and infrastructure study reports.

5 Personal comunication, C. Boon with C. Churcher, TC-Safety Group, March 22, 1993.

6 Ibid.

7 Ibid.

TABLE 3.2: RECOMMENDED RIGHT-OF-WAY WIDTHS AND SEPARATIONS			
PARAMETER	NEW CONSTRUCTION, NEW ALIGNMENT	NEW CONSTRUCTION, EXISTING ALIGNMENT	RECONSTRUCTION, EXISTING ALIGNMENT
Clearway width - absolute minimum - design	 16.0m[a] 21.0m	 12.25m[b] 21.0m	 16.0m 21.0m
Right-of-way width - absolute minimum - acceptable - design	 16.0m[a] 30.0m 50.0m	 24.5m[b] 30.5m[c] 50.0m[d]	 as found[e] 30.0m 50.0m
C_L separation between adjacent HSR and conventional tracks	N/A	4.5m (up to 200 kph) 8.85m (up to 250 kph) 10m+ (300 kph +)	as at left
C_L separation for HSR tracks	4.5m	4.5m	4.5m

a To edge of ballast shoulder in new Urban ROW, with retaining walls in cut/fill.

b Centre-line of track section to HSR ballast shoulder, for segments with severely constrained additional land availability, with 200 kph limit and intrusion detection.

c Provides 8m C_L to C_L distance between inside HSR and inside conventional tracks; acceptable for up to 250 kph without passive barriers but with intrusion detection. Assumes constrained new land acquisition.

d Provides 31m separation between C_Ls of adjacent HSR and conventional rail tracks or between HSR and edge of highway shoulder to eliminate speed restrictions. Assumes availability of land to widen existing ROW as required. Required width larger for high fills/deep cuts.

e Assumes HSR takes over existing ROW, which is typically 30m wide, +/-. This would permit reconstruction to support new double-track HSR.

3.3 Infrastructure Design Standards

To facilitiate presentation of standards for design and construction of HSR infrastructure, we have categorized this information in terms of its technology specificity (i.e., are differences the consequence of unique technical solutions to specific challenges faced by the representative technologies, or are differences the result of differing customs and practices of the operating railways and/or their operating environments).

In fact, the majority of differences are a function of speed and capacity requirements conditioned by historical precedent (the best technology available at the time of original construction) or geographic practicality (compatibility with the system of a contiguous (and friendly) major trading partner). Once a design is established over a significant portion of a network, major improvements are required to justify alterations. As an example, while the 2 x 25 kV 50Hz autotransformer electrification of the high-speed TGV lines reflects state-of-the-art design practice in the mid-1970s, SNCF retains its 1.5 kV d.c. electrification on its 'conventional' network. The electrification in Sweden follows German practice (15 kV, $16^2/_3$ Hz). Modification of on-board power conditioning for any single set of electrical power characteristics is an essentially routine process, and all the related hardware is well-proven in commercial service.

We believe the real issue should be whether to go to a higher voltage (perhaps even to 50kV, as on the Tumbler Ridge line), not whether standards, quantities and costs for two distinct electrification concepts should be developed. For Canada, with no mainline electrification in the Corridor and with the Montreal-area commuter lines, including the Mount Royal tunnel, undergoing modernization to 25 kV 60Hz, we have recommended that the electrification standard for both families be 2 x 25 kV, 60Hz autotransformer, with examination of the effects of higher feed voltages up to 50kV on life-cycle costs as the principal subsystem sensitivity.

In other instances -- the basic track structure, for example -- there are virtually no differences between the two families with respect to the designs *for new construction*, although the tracks of the existing BV tracks used by the SJ's X-2000 fleet and the LGV-A are quite dramatic. The difference between track construction and maintenance standards for the SNCF conventional lines used by TGV-A equipment and those of the BV are much less pronounced. There are greater differences between any Canadian mainline track and those of either European system.

The only major issue is the extent to which existing Canadian track structures will have to be rebuilt to provide the year-round stability required for safe and comfortable operations at 200 kph and above. Based on our review of track design, construction and maintenance practices and standards for HSR world-wide, and discussion with rail safety authorities in the United States and in Canada, the *absolute minimum* rehabilitation of the track structure that will be required for use of existing track is replacement of existing ballast, ties, fasteners and rails, as specified below. It is far more likely that a significant proportion of the existing track structure below the ballast will require reconstruction to eliminate substandard embankment materials dating from a century or more ago, to reinforce or replace failed or incompetent subgrade, and to enhance drainage. Existing open-deck bridges will require modification to or replacement by ballast-deck structures.

At present, we have no formal basis for estimating the proportion of existing track structure requiring complete reconstruction. Our best judgement is that at least 20% of the affected track-km will be affected for 200 kph operation, but that proportion could equally well be 50% or even 100%. It is probable that Transport Canada will require detailed technical proof of track stability before accepting proposals to operate above 200 kph on upgraded existing track[8]. 250 kph appears to be the cutoff point for this type of rehabilitation. Above that speed, complete reconstruction of all existing track has been assumed and costed.

These standards and our recommendations are summarized at the major subsystem level in Tables 3.3 and 3.4. Additional information in greater detail is presented in Appendix TA-2 and in the reports of the routing consultants.

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[8] Ibid.

TABLE 3.3: STANDARDS FOR INFRASTRUCTURE SUBSYSTEMS FOR BOTH TECHNOLOGY FAMILIES

SUBSYSTEM	New Construction	Reconstruction	Rehabilitation <200 kph	Rehabilitation 200 to 250 kph	Rehabilitation >250 kph
TRACK					
Subgrade	Removal/replacement/ reinforcement of low bearing strength materials	Removal/replacement/ reinforcement of low bearing strength materials	Selective (20%+) replacement or reinforcement of low bearing strength materials	Selective (50%+) replacement or reinforcement of low bearing strength materials	As for reconstruction
Earthworks	Selected washed granular materials laid in courses <1.5m thick with dynamic compaction to 95%+OPM; reinforcement with geomembranes, grids or webs as appropriate	As for new construction	As for new construction where rehab of subgrade is performed	As for new construction where rehab of subgrade is performed	As for new construction
Underbed	0.70m of 25mm crushed rock; dynamic compaction	As for new construction	N/A	N/A	As for new construction
Subballast	0.20m hard crushed rock graded 0/31[5]; dynamic compaction	As for new construction	As for new construction where rehab of subgrade and/or earthworks is performed	As for new constructiom	As for new construction
Ballast	0.35m hard, tough, fine-grained crushed rock; LAA <30, MA <4 and LA + 5MA <40 (LAA, MA as Wt%); CV (MPa) < 1.0 +0.2MA; Mg Soundness (%) < 3; Bulk Specific Gravity > 2.65; Shape Factor < 2; 25/50 grading acceptable but if fines are free-draining prefer 10/50; dynamic stabilization.				
Ties	Concrete monoblock, at 60 cm spacing (250 kph and up); 65 cm (below 250 kph)				
Fasteners	Elastic such as Nabla or Pandrol with 9mm rubber pad or equivalent with 70 kN/mm stiffness; hold-down force 11 kN or more with 8mm deflection.				
Rail	60 kg/m (UIC 60 equivalent) for dedicated HSR track; where track is to be shared with commuter and/or freight, 70 kg/m (140 RE) rail, as used on NEC.				

TABLE 3.4: STANDARDS FOR INFRASTRUCTURE SUBSYSTEMS COMMON TO BOTH TECHNOLOGY FAMILIES					
SUBSYSTEM	New Construction	Reconstruction	Rehabilitation <200 kph	200 to 250 kph	>250 kph
Electrification	2 x 25 kV 60Hz autotransformer with feeder/overhead system in phase oppposition; contact wire 150mm^2 reinforced cadmium-copper contact wire at 5.1m height. OCS will be tensioned at 7.5 or 10 kN for 200 kph, 15 kN for 250 kph, 20 kN for 300 kph, and 25 kN for 350 kph. 7.5 kn tensioning will be used on sections where curve radii are below 2000m.				
Signalling and Train Control	TVM430, incorporating in-cab displays and automatic speed enforcement; road vehicle detection circuits on grade crossings (where present -- see below), and vehicle intrusion detection circuits at overpasses and between adjacent HSR and conventional tracks will be tied into train control subsystem.				
Grade Crossing Protection	No at-grade crossings where speed exceeds 200 kph; between 160 and 200 kph, public crossings may be permitted on a site-by-site basis provided full barriers with intrusion circuits, road vehicle detection circuits tied to automatic train control and improved crossing visibility are installed; below 160 kph, full-width barriers with intrusion detection circuits and improved crossing visibility will be required. Private crossings will not be permitted if operating speed exceeds 200 kph; at and below 200 kph, access to the HSR ROW from private crossings must be controlled electronically or manually with interlocking to ATC.				
Station Tracks and Platforms	All station tracks built as part of the HSR project will be configured to permit access from both sides of a stopped train from high-level platforms. Sizing of station and terminal facilities will be determined by estimated demand requirements.				
Bridges	All bridges are ballast-decked for both families. Bridges are to meet L/4000 deflection limit to ensure compatibility with future generations from either technology family.				
Tunnels	Tunnel cross-sections (for pressure-sealed trainsets): 41m^2, double track, 200 kph; 71m^2 double track, 270 kph; 90m^2, double track, 300 kph; 150m^2, double track, 350 kph; 46m^2, single track, 270 kph.				

3.3.1 Signalling and Train Control

Conventional Practices

Conventional freight and passenger railway signal systems are based on track circuits to detect the presence of trains, and wayside signal lights to display the status of the track block(s) ahead. Permanent and temporary slow orders are given to the engineman as written instructions. There is no system of automatic enforcement for either displayed signals or written slow orders.

High speed rail signalling and train control systems are designed to provide automatic enforcement of both signal aspects and speed limits. The train is protected from human error and thus avoids possible collisions and also derailments from overspeed in curves. Signal aspects are displayed inside the locomotive cab to avoid loss of visibility in fog or snow.

Alternative High-Speed Signalling and Control Systems

There are a number of signalling and train control systems which are either in service or in an advanced stage of development, that are suitable for use on high speed rail systems. The type of signalling system used France, Sweden and other countries for high speed rail passenger service has been governed by the way the respective HSR services have evolved. In the U.S. North East Corridor, in Sweden and in Germany, HSR has developed to make use of existing infrastructure, and continues to share right of way and in some cases tracks with conventional trains. The signalling and train control systems on their respective HSR lines still use the track circuits and other components of the pre-HSR signalling technology, overlain with incremental components to add the (typically) automatic train control features requiremed for HSR.

In the NEC, in-cab signalling with coded track circuits was used prior to the increase to 200 kph. Speed enforcement has only recently been introduced. In Sweden, DC track circuits with wayside signals form the basic signalling system. As part of the upgrading for introduction of the X-2000, SJ/BV added a transponder-based ATC. This signal enforcement system was added by placing transmitters in the track at all signal or control boundaries. The X-2000 locomotive is equipped with an antenna to read the signal aspect and with an onboard computer to display and enforce the speed limits. Slow orders through curves can be protected by locating transmitters on the curve approaches. The crossing occupancy and crossing gate closure detection circuits are tied into the ATC.

In Germany, conventional track-circuit-based signals have been overlayed with a pair of continuous transmission cables laid between the rails along the whole length of the track. The cables cross at frequent intervals to allow the train to locate its position. The cable also transmits signal aspects to the train. Automatic train protection and in-cab display are accomplished with an onboard antenna/receiver and a computer. In cases where tracks are not shared or a new right of way has been built, the cable based signal system may be used on a stand-alone basis.

French Signalling/Control Systems

In France (and Japan), new dedicated lines were built for high-speed operation. The signal systems on these lines were purpose-built for a single type of train, and used the proven technologies of the day. Both use ac frequency-modulated track circuits with in-cab displays and automatic speed enforcement. Both the TVM-300 (which is based on conventional relays) and the TVM-430, which uses solid-state interlockings, are of this type, although the more advanced TVM-430 is capable of shorter headways and higher speeds.

There are a number of limitations associated with track-circuit-based signalling and train control systems, the principal one being lack of flexibility. Track circuit block lengths are fixed (once a system is installed), and the number of messages that can be transmitted to the train are restricted. A change in train type or increase in speed can necessitate major investments in overlay equipment, as has occurred in each of the countries trying to utilize existing tracks for HSR. In addition, track-circuit-based signals are expensive and a source of operating delays, since every signal fault results in a 'fail-safe' shutdown of traffic.

In France, each new TGV line has featured improved signalling and train control performance, reflecting the continuing improvements in the state of the technology. On the Atlantique line, transponders were added to the TVM-300 track circuit system to reduce the delays caused by a fixed block length at switch point approaches. The new Nord line incorporates the TVM-430, which permits an increased number of messages to be transmitted by the track circuits, while the TGV-R and future generations of TGV rolling stock have more on-board computer capability to calculate a continuous deceleration curve based on these data, rather than enforcing stepped speed limits. This allows use of a shorter block length and permits operation at shorter headways

Radio Based Systems

The Siemens LZB system with a continuous antenna laid in the track is a form of radio-based signal system. However, the cable is an expensive communication system and poses problems for track maintenance. The North American ATCS and the French ASTREE systems currently under development are examples of radio-based systems which use intermittent position updates.

These systems utilize many of the principles associated with the overlay technologies already in use with different HSR operations. The main difference is that the track circuit is not required for train location purposes. Instead, passive transponders are located in the tracks at discrete intervals. The locomotive is equipped with an interrogator which reads the transponder to determine its location. This data is used by the train's on-board computer in combination with readings from an axle-mounted odometer to continuously determine its position. The absolute position is updated each time a transponder is interrogated.

The train reports its position by data radio. The central control computer continuously updates train positions on the dispatch display monitor. The dispatcher, aided by the central computer, transmits all speed and distance authorities to each train by the same data radio system. The train's on-board computer compares its position and speed with that authorized in the latest authority, and takes action to enforce the authoized limits, if necessary.

This type of system significantly improves system flexibility, especially in terms of its ability to optimize operations for heterogenous traffic. There are no fixed-length track blocks. Speeds and track configurations can be changed through software and data base changes. With the number of track circuits and relay interlockings reduced, operating reliability should improve. From a cost viewpoint, much of the computer and communications equipment is already part of the existing enforcement system. Both the TGV and X2000 trainsets have antennas to read transponders and on-board computers to calculate brake curves and enforce speed and distance authorities. With ATCS, track circuits and interlockings are only required at track switches. However, a very simple (and less costly) track circuit will still be needed to provide broken rail detection. The communications system will be somewhat more expensive than for existing HSR since better coverage and higher capacity is required. A more expensive central control centre is also required.

ATCS provides benefits to both scheduled run time performance and reliability of run time performance. Figure 4.1 illustrates the implications of a temporary slow order for three systems -- TVM 300, TVM 430 and ATCS. The slow order is assumed to be set at 120 kph, at km 10.5 from the initial position of the train.

With the coarse speed steps built into TVM 300, the closest speed to the slow-order limit that can be signalled to the trainset is 80 kph. This speed must be applied for the full block length of 2000 m and also to the adjacent block, as a precaution against overspeed at the block entrance. The adjacent blocks provide incremental speed steps of 160 km/h, 220 km/h, 270 km/h and 300 km/h.

The TVM 430 system has additional message capacity and we have assumed it will permit an enforced speed closer to the desired 120 km/h slow order. The TVM-430 system monitors brake curves rather than block speeds and thereby allows a 1500 m block length rather than a 2000 m block. It also replaces the 160 and 220 speed blocks with 170 and 230 limits. These characteristics reduce the delay to the train.

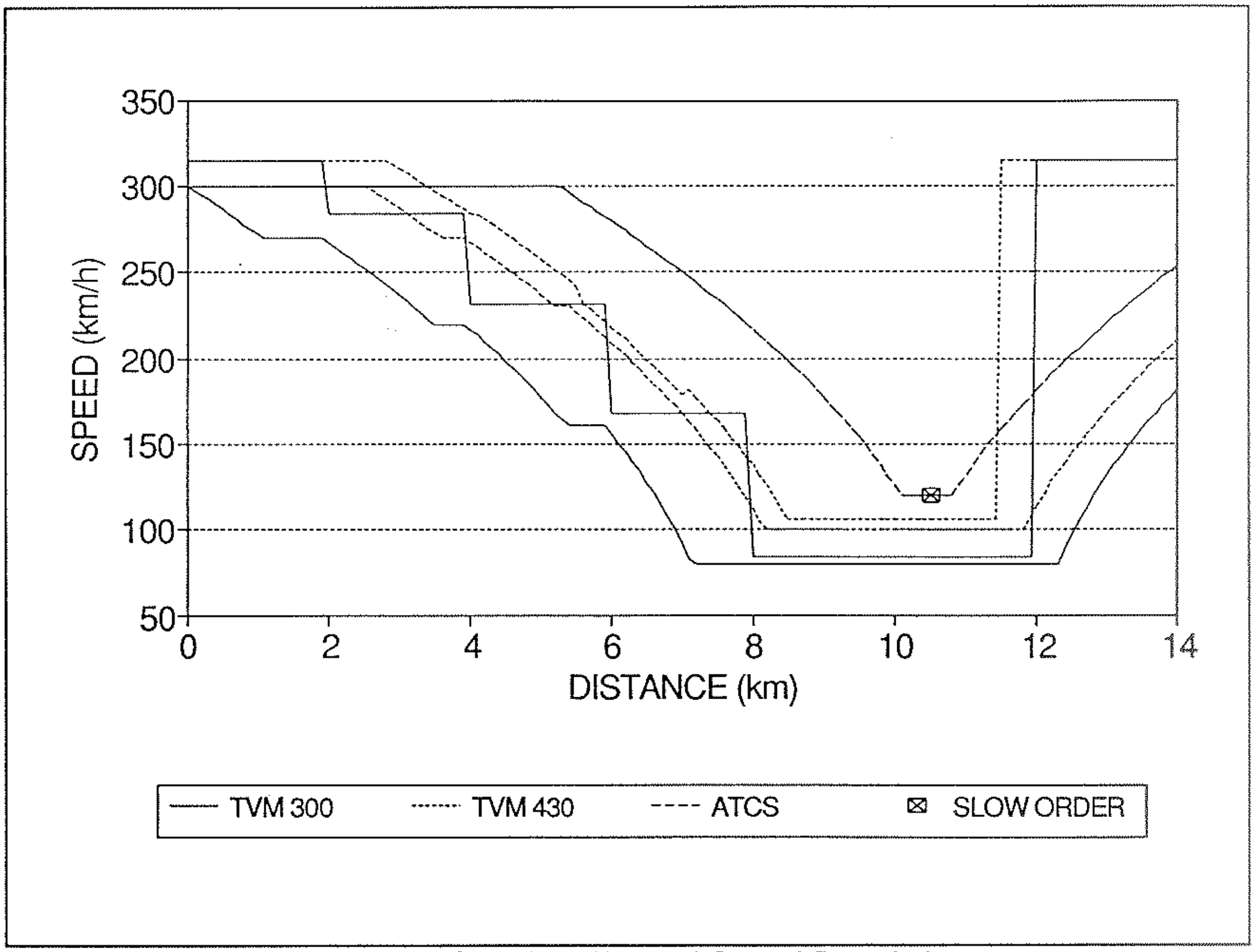

Figure 3.9: Speed Profiles and Control Boundaries
for Different Signalling and Train Control Systems

The ATCS system is totally flexible in specifying slow order speeds and the location is not constrained by fixed track blocks. The deceleration curve is enforced to a point a few hundred metres ahead of the target point. Once through the slow order point it can resume speed whereas the other systems must clear the fixed signal block before resuming speed.

The comparative time lost for the three systems for this one slow order is estimated to be 4 minutes for TVM 300, 2.5 minutes for TVM 430 and 1.5 minutes for ATCS. Even though ATCS is not presently a proven technology, various levels of performance have been demonstrated in prototype installations, and it is reasonable to expect that the required level of ATCS will be in service by the time procurement for a Canadian HSR project could be required. There is also a much higher involvement with domestic suppliers in this type of signal system, which would improve the industrial benefits opportunities.

However, in order to be consistent with the overall criterion that technologies must be proven in commercial operations, the TVM-430 has been designated, as the basis of capital cost estimates, as well as run time and reliability calculations.

4. ASSESSMENT OF CONFORMITY OF REPRESENTATIVE TECHNOLOGIES WITH SAFETY STANDARDS AND REGULATIONS AND RELATED ISSUES

This section summarizes findings and characterizes issues with respect to:

- a preliminary evaluation of the conformity of the selected representative technologies with applicable Canadian safety standards and regulations, including review of federal regulations and standards in Canada and U.S., plus provincial standards where applicable;
- identification of areas of non-compliance and associated issues with respect to non-regulatory (i.e., industry) requirements and practices (VIA, CN, CP, AAR);
- assessment of feasibility of adaptation of representative technologies to comply with existing regulatory requirements;
- definition of requirements for at-grade crossings for speeds below 200 kph; and
- assessment of feasibility and consequences of modifying existing safety regulations.

4.1 Conformity with Applicable Standards

The situation with respect to conformity of each representative technology to applicable safety standards and regulations in Canada and the United States was explored through a series of meetings and discussions with the Transport Canada Safety Group, the U.S. Federal Railroad Administration, ABB and Bombardier.

The representative technologies were designed and built in accordance with safety philosophies that are quite different from those that prevail in the U.S. and until quite recently in Canada. While differing in detail, the approaches to safety adopted by the developers and operators of the representative high-speed technologies share an emphasis on event avoidance through rigorous application of systems safety engineering principles at all stages, supported by energy-absorbing vehicle structures designed to dissipate impact forces through controlled deformation of unoccupied spaces. In contrast, rail vehicles designed and built in North America to comply with AAR interchange standards (an industry standard, not a legal regulation) stress rigidity and overall structural strength, features which work to some degree at low speeds, but which are of questionable value in high-speed incidents.

Equally important, and an integral part of the systems safety approach, are the quality standards for infrastructure construction and the system-level operating and maintainance procedures and practices applied to the representative technologies. These differ substantially from those in common use on Canadian and U.S. railroads, although (as will be seen in Chapter 5 below) VIA Rail has begun moving in the direction of systematic preventative maintenance for its rolling stock.

As currently operated, neither representative technology conforms fully to the FRA regulations and AAR standards that apply in U.S. Studies in the U.S. have identified five safety issues specific to body tilting -- notably the effects of increased curving speed on operating safety, compatibility of clearance envelopes, and impacts of different practices in geometric layout and track construction and maintenance -- and twelve categories of major safety issues that affect all foreign-designed HSR equipment and infrastructure. These latter categories range from primary structural crashworthiness to employee qualifications and training. Additional detail on these areas of incompatibility is provided in Appendix TA-3.

4.2 Feasibility of Adaptation of Representative Technologies

However, this entire class of issues is likely to become moot. As noted above, both ABB and most recently Bombardier have stated categorically that for North American applications, their respective technologies will be modified so as to provide complete safety equivalence both for shared-track operation with conventional equipment up to 200 kph and for operation on dedicated tracks at higher speeds.

In the event of a collision, both the TGV and the X-2000 have been designed to maximize energy dissipation before forces are transmitted to the passenger compartments. This is accomplished first through the controlled deformation of the power car structure (except for a crash cage around the driver) and then by deformation of the unoccupied portions of each coach.

In the case of the TGV, the body structure around the passenger compartment is built to resist a compressive force of over 450 tonnes, much *higher than the* 364 tonne AAR interchange standard. However, the power cars fall short of the required strength limits, and FRA have indicated that some modifications will be required to improve operator safety. Even so, senior FRA staff have expressed the opinion that the adaptations should be possible with minimal impact on performance and cost. We concur that this adaptation is likely quite feasible for 300 kph operation.

The X-2000 power car, coach and driving trailer are built to resist lower forces -- 200 tonnes. Based on the information provided to CIGGT by ABB during our visit to the Vasteras facility in Sweden, there is good reason to believe that the required modifications can be accomplished without adding more than 1 tonne per axle to the maximum static axle load. However, achieving an adequate level of energy dissipation may require a rethinking of the use of passenger-carrying driving trailer. In any event, there is a clear incentive for ABB to accomplish this, as AMTRAK has clearly stated that full compliance will be a condition of purchase should they elect to procure the X-2000. The added power planned for the next build of X-2000 will more than compensate for any additional mass in the trainset.

4.3 Feasibility and Consequences of Modification of Existing Regulations

The decision on the part of the suppliers to achieve full safety equivalence is particularly encouraging in the Canadian context, insofar as Canada has already moved beyond the complex, formal and very time-consuming rule-making process that governs U.S. regulators. Transport Canada's Safety Group operates within a very flexible and (for HSR) potentially advantageous regulatory framework that emphasizes performance-based standards and pragmatic resolution of safety-related issues. Basically, an HSR operator can propose whatever standards and operating procedures are most appropriate for the system and service plan. Standards and procedures used by an off-shore operator can even be proposed by reference, if that is desired. Provided TC judges the proposed procedures and standards to be 'safe', approval will follow in a timely fashion.

Assuming the suppliers are able to achieve full safety compliance, the position of the Safety Group with respect to shared track and shared alignment operation is very practical and based on operating speed, not on technology type. Up to 160 kph (the current speed limit in the Corridor), HSR equipment will be able to operate on shared track with conventional freight and/or commuter equipment without restrictions or special conditions. Between 160 kph and 200 kph, shared track and/or shared alignment operation will be permitted, but with the probable application of special conditions with respect to track construction, maintenance and inspection, signalling and train control requirements, staff training and operating procedures. Above 200 kph, shared-track operation will not be permitted, but shared-alignment operation without physical barriers (*but with 8m separation and active intrusion detection linked to train control)* will be allowed up to 250 kph. Higher speed operations in a shared alignment will require either much greater separations or some form of passive intrusion barrier as well as active intrusion detection sensors.

4.4 Requirements for At-Grade Crossings

With respect to at-grade crossings, the second major concern of the Safety Group from the outset of our discussions, a similar set of speed-related constraints have been suggested. For speeds in excess of 200 kph, no at-grade crossings (public or private) will be permitted. At speeds between 160 kph and 200 kph, at-grade crossings may be permitted, after a site-by-site review, provided the crossings are equipped with crossing-occupancy detection circuits tied into the train control system, full-width barriers fitted with vehicle intrusion detection, and improved signage. Of particular concern will be potentially hazardous road conditions adjacent to a crossing site (for example, a long downslope that could lead to loss of [road vehicle] control under wet or icy conditions) and to inadequate sight lines that prevent crossing recognition in time for a safe stop.

4.5 Non-Regulatory Rules and Practices

4.5.1 Introduction

In addition to compliance with the broad range of topics covered by regulations with the force of law, there is a second important compliance category that could affect the deployability and performance of an HSR system in the Canadian Corridor: the differences between operating rules and practices as embodied in the current collective agreements governing the work forces of VIA Rail, CN and CP, and the equivalent rules and practices that pertain to HSR operations and maintenance for the representative technologies.

While a comprehensive and detailed review of 'conventional' and HSR work rules and practices is beyond the scope of the current assignment, we have discussed these issues with CN and CP, and have examined in some depth practices within VIA Rail that pertain to the running trades (enginemen, conductors, brakemen), shop crafts, and on- and off-train customer service.

To begin, many of the differences in the operating rules and practices that govern operations and maintenance on SJ/BV and SNCF, relative to CN, CP and to a lesser extent VIA Rail, reflect differences in service emphasis (passenger over freight), geographic conditions (relatively short intercity distances compared to Canada) and past investment decisions (electrification of main lines, especially in France during reconstruction after WWII). The effect of these factors should not come as a surprise. However, within the context of their respective labour and management regimes, both SJ and SNCF have been able to establish rules and practices for HSR that are directly related to the functional requirements of the respective technologies. This is of critical importance to achievement of a safe and productive HSR operation: systems safety depends on successful control of complex interactions among many elements. Historical and arbitrary divisions of management responsibility or union jurisdiction must not obscure essential functional relationships.

4.5.2 Maintenance Philosophy of HSR Systems

The operating and maintenance rules and practices for X-2000 and for TGV are based on a systems engineering approach to safety, with very strong emphasis on avoidance of events with undesireable consequences through rigorous preventative maintenance and sophisticated train control, signalling and communications subsystems. Initial training and on-going education of HSR staff is an important component of this overall approach to achievement of safe and cost-effective operations. For example, maintenance workers on the conventional SNCF who are selected for transfer to one of the LGV maintenance teams are given 5 months training, while track maintenance workers receive additional specialized training on switches and crossovers. These workers have already completed the general training program of SNCF, and typically have at least 6 months' experience.

Although the leading North American railroads -- including CN, CP and VIA -- are moving in the direction of programmed maintenance for track and rolling stock, the basic pattern of maintenance is still reactive, while for HSR operations, programmed maintenance activities driven by constant monitoring of track quality parameters amount to between 85% and 95% of maintenance efforts.

For HSR infrastructure and rolling stock maintenance, automated quantitative monitoring of important subsystem and component functions and parameters is increasingly the basis for maintenance activity planning and in-shop diagnostics. For example, the location and scheduling of tamping, lifting and rail grinding activities is based on track quality parameters measured weekly by revenue trainsets equipped with instrumented axles and quarterly by Mauzin track geometry recording cars. By tracking the appearance and growth of geometry defects relative to the historical data, maintenance activities are scheduled to keep all defects within the optimum parameter limits with minimum maintenance cost.

Similarly, rolling stock maintenance is based on elapsed time and/or utilization standards, supplemented increasingly by continuous monitoring of important subsystems and/or components by the on-board computer system. When a TGV-A trainset enters its SNCF maintenance facility, one of the first activities is to download the diagnostic files from the onboard TORNAD computers. These data tell the maintenance staff subsystem status and highlight procedures required during that maintenance activity. The X2000 has similar onboard diagnostic capabilties. The method of maintenance delivery employs facilities that are purpose-built and equipped to permit multiple specialized tasks to be carried out in parallel on an entire trainset. This 'complete consist maintenance' is used both for the articulated TGV trainsets and for the non-articulated X-2000.

4.5.3 North American Practices

Happily, our examination of VIA rules and practices gives reason for optimism. While extensive 'conversion' training would be required to ensure appropriate skill levels and familiarity with either representative family, there does not appear to be any fundamental impediment to safe and cost-effective HSR operation and maintenance in the rules and practices defined by the current collective agreement. This does not mean that HSR deployment and operation will be simple and straightforward with respect to non-regulatory rules and practices: the 'cultural' mindset required for effective HSR operation has more in common with commercial aviation than with conventional railroads. However, there is no reason that the necessary changes cannot be accomplished if unproductive confrontations are avoided.

Turning to rules and practices at VIA Rail, we examined crew size, run-through practices and basis of pay with respect to the Running Trades. The findings are all positive. For example, the size of the operating crew required for either of the two representative technologies -- a 1-4-DT X-2000 consist and a 1-8-1 TGV, each with both first and coach accomodation -- would consist of an engineman, a conductor, and an assistant conductor *under the existing collective agreement.* This is the same as the staffing we have observed on TGV-A and TGV-PSE trainsets, although SNCF has indicated that an additional assistant conductor is assigned to the longer TGV-A during peak periods when load factors are very high. Staffing on the X-2000 operated by SJ is not directly comparable, as they are running trains configured with all first class accomodation, with an attendent per car, plus a conductor and an engineman.

As far as run-throughs are concerned, the current collective agreements allow crews to operate between adjacent seniority districts (Quebec City-Montreal, Montreal-Toronto) but not through a second district to a third. Toronto-Windsor trains appear to be within a single district. This means that within each of the three major corridor segments, all crews can operate terminal-to-terminal, which is what is required for HSR for either family. However, with higher operating speeds, it may be attractive to operate trains through Montreal and/or Toronto, perhaps serving Quebec City-Ottawa or Windsor-Montreal. In view of the fact that CN, CP and VIA have been uniformly successful in negotiating other run-through agreements (CN, for example, runs GO-Train crews from Hamilton to Whitby), we do not believe that there will be any problem to achieve such run-throughs with either HSR technology. The practical consideration that for current operations the crews must be familiar with the tracks over which they are to operate will be largely eliminated with equipment featuring cab signals and ATC. In our opinion, an HSR operator should be able to make decisions regarding run-throughs based on operational and market considerations.

Basis of pay is a less clearly defined issue, partly because VIA has not focussed on this area in its negotiations to date. In Canada mileage is still the basis of pay for running trades employees operating in road service[9]. The contractual basis for mileage-based pay is now 150 miles per day, where the word "day" means a minimum amount of pay. The guarantee for a 28-day pay

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[9] In the U.S., Amtrak has negotiated an hourly or other time-related basis of pay for most of its running trades..

period is 4,200 miles, which is 150 miles per day, **with no days off!** Earnings at the minimum would be $47,700, which is equivalent to running 210 miles five days per week. To put this in context, the basic pay for a yard foreman is approximately $40,000, for 260 eight-hour shifts.

In recent years, VIA has negotiated a 'ticketless' system for train crews. Under this system, a "normal" Toronto-Montreal trip is rated at 360 miles, including an allowance for terminal time. This system reduces the administrative and clerical workload and provides incentive for the crew to operate in a timely manner since there is no pay to be gained through minor terminal delays.

4.5.4 Assumptions concerning HSR Crewing

What should be assumed for an HSR system? We believe the idea of applying the current mileage-based rates is unrealistic, as with a three-hour Toronto-Montreal trip time, annual earnings of $60,000 would require working four hours a day four days per week. There are two alternatives which we believe are worthy of consideration:

- o Maintain the level of annual earnings and adjust hours worked to achieve a 40 hour work week, averaged over a multi-week period, as VIA has been done with its on-board service (OBS) staff; or
- o Assume the daily yard rate applies for eight hours work, perhaps with some increment for operation away from home and so on, so as to retain some distinction between yard and road work.

Under modified operating rules, which could well apply to a new rail operator, it would be reasonable to aim at a solution based on one of the alternatives. However, ther are some practical obstacles to changes in the basis of pay. If HSR operations share alignments or especially track with conventional services (a situation analogous to those in France and Sweden), it is unreasonable to suggest that HSR train crews be paid on a basis substantially different from that of conventional crews, particularly if the same individual may be employed on both conventional and HSR trains, as is the case in France.

To permit assessment of the impact of these alternatives, we will develop crew costs using the existing basis of pay with minor modifications, plus the alternatives defined above. The alteratives may require one-time payments to existing VIA train crew employees, depending on the institutional scenario. Such payments will not be included in the crew cost estimates.

4.5.5 Skills and Training Considerations

Train Crews

Conversion from conventional to HSR equipment will require a considerable investment of time and effort in skills upgrading and familiarization. The following discussion pertains to the TGV family of trains. The design principles of these trains were evolutionary: the French National Railways sought to "modernize driving practices by comparison with those for other trains", while ensuring "operating continuity" between the TGV and other trains[10]. This 'operating continuity' is important, because the French National Railways have sought to avoid the creation of specialist TGV drivers. TGV drivers are required to be able to run TGV equipment over conventional lines; TGV drivers also operate conventional trains where it is efficient for them to do so. Hence, the French have so far resisted the notion of automating driving, with the operator as a manual back-up; the operator continues to drive the train, with computer assistance and monitoring.

The main changes in the work of a TGV driver compared to the driver of a conventional train are summarized by Houillon as follows:

- cab signalling, instead of conventional wayside signalling;
- higher operating speeds: this "will require drivers to adopt a new driving method with shorter reaction times; driving according to orders received consists of braking to comply with the speed indicated as soon as the restrictive speed indication is given, and this replaces the method...of braking to comply with the speed indicated on entry onto the next block section";
- a new 'art of driving' because of the steeper grades and the possibility of exploiting the kinetic energy of the train to a much greater extent than on conventional lines;
- isolation and monotony, because of the fewer number of stations[11].

In conclusion, the skills requirements of a TGV driver are attainable for drivers of conventional trains with proper training. The SNCF generally allows a two-month training period for TGV training of staff with ten years' experience on conventional trains. A longer training period may be required since the difference between the present corridor service in Canada and the proposed high-speed service may be greater than that between the best of the SNCF "conventional" service and the TGV. The French National Railways has begun to make extensive use of driver's simulators (so as to avoid taking trainsets out of revenue service for training purposes) — a practice pioneered by Canadian railways and hence familiar to all VIA, CN and CP enginement. The dissemination of driver skills required for a technology similar to the TGV -- or the X-2000, which differs in detail but not in principle with respect to train control and operation -- should not pose serious problems for a Canadian operator.

Shop Crafts

With regard to the Shop Crafts and equipment maintenance, the most important issues for an HSR operator will be the impact of traditional craft-based organization on maintenance productivity, and the predominance of diagnostic and preventative approaches to HSR equipment maintenance. There may also be opportunities to contract out some or all maintenance activities.

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10 Houillon, J.-P., "The TGV or the opportunity for a new approach to railway vocations" in *Canada-France Symposium: TGV System Developments, 25-26 March 1992.*

11 The fewer number of stations argument would not be applicable to most of the Corridor runs.

The workforce in Canadian railway equipment maintenance facilities, both passenger and freight, has traditionally been divided along craft lines. For example, in recent years the 1,652 VIA equipment maintenance employees have been represented by five unions. VIA management has successfully argued that the existence of multiple bargaining units has lowered labour productivity because it has hindered flexibility in job assignments. This argument was recently accepted by the Canada Labour Relations Board, which stipulated the creation of a single bargaining unit for equipment maintenance employees. The CLRB supported the arguments of VIA management that it required the ability to make assignments in order to operate with efficiency, and that the existence of multiple bargaining units was an impediment to this. It should be noted that even under existing collective agreements, VIA has some discretion in work assignment.

With respect to compatibility of existing VIA maintenance practices with HSR requirements, our main findings are positive:

- Equipment maintenance at VIA now reflects some of the characteristics of maintenance in an HSR system, notably the increased use of diagnostics and servicing in consist; and

- By the year 2005, if the strategy of VIA management is successful, the most important institutional barriers to efficient equipment maintenance practices will have been overcome.

The main issues for HSR equipment maintenance will be training the work force and management in the new skills and attitudes required to maintain the new equipment, and the degree to which HSR management wishes to pursue the option of contracting out maintenance activities.

Other Employees

Customer Service includes ticket sales; station staff and on board service (OBS) staff. There appear to be few labour issues related to Customer Services that are a function of the deployment of an HSR system rather than a function of decisions as to what level of service to offer.

No specialized skills or knowledge of operating practices over and above what is already available within VIA's Customer Service staff are required for high speed operations. Given present staff skills, all that would be required would be training on the specific features of the rolling stock and other equipment to be used. Such training would appear to be no different than that currently required when new or rebuilt equipment is introduced into VIA service.

There is significant flexibility in the present Customer Services staffing regieme. There are few residual workrule limitations. On-train staff are paid on the basis of a 40-hour week, averaged over a multiweek period, with considerable variation in the average hours worked per day. Part time employment is allowed, provided that it constitutes no more than one-fifth of employment within a specific facility. Split shift employment is allowed for off train employees. There are no contractually required staffing levels for either group of employees.

Customer Service issues that must be addressed relate to the potential for contracting out and to the size and makeup of individual station and train crews. The former issue is discussed in

Appendix TA-3; the latter will be addressed in the Operating Plan.

5. HSR OPERATIONS IN CANADIAN CLIMATIC CONDITIONS

Canadian climatic conditions on HSR system design and operation will impact both infrastructure design and construction and achieveable performance. The effects of rainfall and snowfall rates and accumulations and of icing on the limits of safe operation, and on the behaviour of track, vehicles, catenary and signalling and control subsystems have been assessed, together with possible mitigation techniques such as the warm-water sprinklers used in Japan to reduce snow accumulation, and the effect of adding switch heaters to the reliability of high-speed switches. The major challenge remains design and construction of stable track structures under the demanding free-thaw and geotechnical conditions that exist in the Quebec City-Windsor corridor.

Other climatic issues that have been addressed include temperature-induced longitudinal stresses in rails and the adequacy of lightning protection for substations, catenary, signalling, train control and communications. Some quantitative comparisons of climatic conditions in the Quebec City-Windsor Corridor with the conditions prevailing in France and Sweden have been made, but the data provided for those countries is very limited.

Table 5.1 presents the adverse climatic conditions considered in this assessment and the abbreviation which is used in the impact matrix. This list contains those climatic conditions which occur in the Quebec-Windsor corridor and which pose a greater hazard here than in Sweden and/or France. These conditions and recommended mitigation are discussed below.

TABLE 5
ADVERSE CLIMATIC CONDITIONS

ITEM	CODE
FREEZE-THAW CYCLES	FTC
EXTREMELY LOW TEMPERATURES (-50°C)	ELT
WIDE TEMPERATURE VARIATIONS DAILY/SEASONALLY	WTV
TEMPERATURES NEAR FREEZING	TNF
FREEZING RAIN	FR
WET SNOW	WS
SNOW ACCUMULATION	SA
ELECTRIC STORMS	ES
HEAVY RAINFALL	HR
SALT SATURATED MOISTURE	SSM
HIGH WINDS	HW
ICE ACCUMULATION	IA

Freeze-Thaw Cycle

Water which is trapped in the ballast, subballast, earthworks and/ or subgrade because of inadequate drainage will freeze during the winter and expand in volume. This will cause, to some degree, a heave in the support structure and ultimately misalignment of the rails in one or more dimensions. This process is exacerbated during spring thaw, when daytime temperatures and frequent precipitation result in penetration of the support structure and potential accumulation of water in localized zones of saturation. The result is significant distortion of the track geometry at least to the degree that it causes poor ride comfort and frequently to a degree where significant wheel unloading with attendant risk of derailment will occur, necessitating a slow order.

From discussions with our track structures expert [Raymond] avoidance of this situation will require careful geotechnical investigations to identify subgrade types that are particularly vulnerable to freeze-thaw action and removal or application of other mitigation strategies such as cementation or lime stabilization to improve subgrade bearing capacity. Fouled or poorly-draining materials must be removed from existing rights-of-way, and geowebs or other reinforcement used to establish containment cells in the substructure strata. As well, geogrids or geomembranes and carefully graded courses of granular material should be used to encourage lateral drainage and provide additional subgrade reinforcement. Every effort must be made to ensure that the track structure and earthworks remain free-draining, especially with respect to material characteristics and grading specifications, compaction standards and techniques, and provision of adequate slope and drainage clearway.

Finally, Dr. Raymond stated that he felt it would be much easier to engineer a monoblock tie with the same level of lateral resistance as the duo-block tie used by SNCF than to overcome the tendancy of duo-block ties to pump ballast if there is any moisture in the section. This is reflected in our tie specification.

Extremely Low Temperatures

Temperatures below -50°C are experienced in the Quebec-Windsor corridor, although rarely and usually as a result of wind-chill effects. The rolling stock must be capable of operation and storage at such temperatures.

Extremely low temperatures lead to changes in material properties such that certain plastics become extremely brittle and subject to fracture. Oils and greases increase in viscosity to the degree that they no longer perform the required function. Also, components with residual stresses, such as continuous welded rail, or which are already under tension, such as overhead catenary support wires, are subject to greater tensions as a consequence of extremely low temperatures.

More pragmatically, trains need more thermal insulation or increased thermal capacity for heaters in order maintain passenger comfort. This problem is exacerbated at high speed where the effective heat transfer coefficient is much greater than at conventional speeds. Maintenance of acceptable on-board temperatures in the event of a loss of OCS power under worst-case conditions (winter and summer) must be addressed, in conjunction with emergency procedures to ensure appropriate response from rescue agencies in the event power is lost..

Wide Daily Temperature Variations

Electronic components inside enclosures are subjected to wide daily variation of temperature. When such equipment is operating, the temperature could reach in excess of 50°C. This causes air to expand and pressurize the enclosure. If the enclosure is vented, or if it is not properly sealed, air will be forced out. If the trainset is then stored in typical winter nighttime conditions (-20° to -30°C), the air cools and shrinks and outside air containing suspended salts, acids and other conductive or corrosive chemicals will be drawn in. Accumulation of these contaminants can lead to ground faults or shorts resulting in unusual and unpredictable failures. Since the trainsets will be pressure-sealed to prevent passenger discomfort in tunnels, this problem can be mitigated without major design changes if care is taken in locating equipment.

Ambient Temperatures Near Freezing

Ice or snow exposed to sunlight in ambient temperatures near freezing will melt. The resulting meltwater will refreeze when it comes in contact with cold metal, particularly surfaces exposed to air flow at high velocities. Components of either the bogie or suspension system that are not exposed to either large forces or large motions can accumulate ice on their exposed surfaces. Ice accumulation can lead to the component becoming inoperable, or can alter significantly the dynamics of the bogie and suspension system. The wheels can flick water against the underframe of the car so that the accumulation of ice can interfere with equipment mounted there. Chunks of ice that break loose at high speed are themselves hazardous, and cause pieces of ballast to fly up, resulting in damage to vehicles or injuries to bystanders. This is an on-going problem on SJ with the X-2000 and with conventional equipment. So far, their response has been to reduce the level of the top surface of the ballast 5cm below the top of the ties. Investigation of low-friction paints or other coatings to reduce ice adherence may be worthwhile.

Wet Snow

Many cooling systems for electrical components and the air intake for HVAC systems employ fibre or paper filters to remove debris and dust from the air. Wet snow tends to accumulate on such components and often causes them to collapse or to become clogged, leading to overheating due to reduction of airflow and/or short circuits or corrosion due to moisture being ingested into electronic or mechanical equipment.

Snow Accumulation

Almost all of the Quebec-Windsor corridor experiences occasional heavy snowfalls[12], and some sections are in or adjacent to zones of frequent heavy snow [e.g., the 'lake effect' snowbelt along the northern boundary of Prince Edward County]. With relatively frequent and long freight trains plus conventional passenger trains on existing lines, all but the heaviest snowfalls tend to be quickly dispersed, so that snow plows are required only occasionally, and then typically for problem areas such as rock cuts.

In the case of HSR, the trains will be shorter and lighter, may have longer headways and will likely not operate between [say] midnight and 0600. Consequently, there is a greater probability that train operations will be inadequate to keep the line clear and that snow plowing will be required. In contrast to the present situation where the right-of-way is essentially clear of obstructions, HSR has an overhead catenary and support columns, plus possibly one or more noise barriers which would interfer with snow clearing operations. Thus, snow clearance on high speed lines will require some consideration beyond simple provision of equipment. It is possible that some additional setback on the catenary masts and/or on noise barriers may be required.

The snow-related slow-order rules of the Tohoku and Joetsu Shinkansen, which typically get over 600 cm of snow per year with daily accumulations of as much as 100 cm, are an iteresting example of speed adaptation to snow conditions: with 17cm or less, speed is held to 240 kph (275kph is the maximum at some locations); between 17 and 19cm, the limit is 210 kph; between 19 and 22 cm, 160 kph; and between 22 and 30 cm, 110 kph. If accumulations exceed 30 cm, operations are shut down.

Another major problem caused by both wing plows and rotary plows is that the snow below the top of the rail is progressively compacted into solid masses which are then pushed laterally and longitudinally by subsequent snow clearance. This compaction forces snow into switches and can exert rather severe shear loads, both longitudinal and transverse, on any equipment, such as transponders, that might be attached to the ties. This will have design implications for track circuits such as the SNCF use with between-rail capacitors located every 100m, for the German LZB system with continuous cables between the rails, and

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12 Between 1975 and 1991, every major meteorological recording station in the Corridor had at least one snowfall of 10cm or more each year; Quebec City and Kingston share the 'worst' with an average dump of 23.4cm, while Windsor has averaged 'only' 16.9cm in its heaviest snowfall.

to a lesser extent, the Swedish ATC and even ATCS, with discrete transponders.

Finally, the very long scarph joints in 160 and 220 kph high-speed turnouts invite problems with snow accumulation and compaction during actuation. The electrical resistance heaters used in France will not be adequate under Canadian conditions. At a minimum, conventional switch heaters and/or blowers at relative close intervals will be required to avoid switch problems. These components are themselves not especially reliable and require substantial on-going maintenance.

Electrical Storms

There is known to be a higher incidence and greater severity of electrical storms in North America[13] than in Sweden or France, although we were unable to obtain quantitative data for France and Sweden to permit comparison. Canadian utility practices, which are well-proven under all conditions, will be followed in design of lightning protection for OCS, substations and communications facilities.

Heavy Rainfall

Heavy rainfall 'downbursts' [and high winds] occur frequently in conjunction with electrical storms. This situation presents special challenges to HSR operations due to the effects of high rates of rainfall on wheel-rail adhesion and also the potential for washouts and flash flooding if adequate drainage channels are not provided. This represents a service reliability issue in that it could affect schedule adherence and equipment utilization. Since the incidence of high rainfall rates will likely correlate closely with that of electrical storms, such situations may occur more frequently in the Corridor than in France or Sweden. For example, Windsor has averaged over 34 days with thunderstorms yearly since 1955, while Kingston has averaged just under 30 days, Ottawa 23 days, and Trois Rivieres fewer than 14 days.

Salt Saturated Moisture

In cities and on major highways a significant volume of salt is used to help de-ice roads in winter. Thus, HSR tracks and trainsets will be exposed to salt-saturated moisture in urban areas, at highway crossings (grade separated or not) and when colocated adjacent to major highways. Being a conductive medium, salt laden moisture can lead to tracking across high voltage insulators, flashovers and deterioration of conformal coatings of printed circuit boards. Again, this is essentially preventable with proper attention during the detailed design phase.

High Winds

High winds have several adverse effects on HSR operations. Cross-winds, and especially cross-wind gusts, may affect curving safety, and can also result in instability in the overhead catenary. SNCF restricts operating speed on the PSE line to 220 kph when wind speed exceeds 70 kph, due to an incident in the early months of operation that brought down several kilometres of catenary and also prompted a redesign of the pantograph. Head winds will affect running resistance and energy consumption. Both the magnitude and direction of wind are important, as are direction and magnitude of gusts. These data are presented in Appendix TA-4.

Modifications to both the catenary support and the pantograph on the Atlantique line have allowed operations without speed restrictions during high winds on this line. Similar modifications to the catenary are being implemented to the PSE line and thereafter speed restrictions will be lifted.

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[13] Personal Communication, Dr. J. Lever, CRREL, December 17, 1992.

Ice Accumulation and De-Icing Methods

Large-scale ice storms occur relatively infrequently in the Corridor, but localized freezing rain is a more frequent occurrence in the fall and spring months. Freezing conditions can also result in frost adherence to rails. If ice accumulates on the wires of the overhead catenary or on the pantograph, it will affect both current collection and also the dynamic behaviour of both elements.

There are three basic methods of ice removal (or prevention) that have been employed, either individually or in combination by electrified railways:

- o application of preventative agents;
- o heating of the wires; and
- o mechanical methods.

The most likely choice for the Canadian Corridor is preventative electric heating through phase imbalance introduced in adjacent substations, although mechanical methods may be necessary in yard or station areas with multiple tracks. This matter is discussed in greater detail in Appendix TA-4.

Other Issues: Material Selection

The climatic conditions prevailing in the Quebec City-Windsor Corridor are challenging but should not pose any insurmountable problems, provided system and subsystem suppliers are aware of the conditions and their implications for design adaptation. An example of this is the selection of materials. The reduction in the elasticity and increase in brittleness of some materials at low temperatures are obvious design issues. The increase of hardness of rubber may prevent the draft free sealing of doors. The increased brittleness of the sheaths of cables could lead to cracking. Increases in viscosity of oils may lead to the effective loss of lubrication of rotating parts during a cold start.

A comprehensive design review for Corridor conditions will eventually have to be done if HSR development is to proceed. Without attention to such material selection details, there will unquestionably be avoidable failures and equipment breakdowns and a concomitant loss of service and inconvenience to passengers.

Comparison of Climatic Conditions

Table 6 presents a comparison of selected climatic conditions for the Quebec-Windsor corridor with those prevailing in the areas served by the TGV high-speed lines in France and by the X2000 in Sweden. Very little of the requested climatic data were provided by either operator or supplier, and we have had very limited success obtaining these data from public sources.

Table 7 summarizes the impact of various climatic conditions on the major subsystems of a HSR system. By segregating the climatic issues into distinct and different adverse conditions, it is possible to systematically examine the impact of each of these on any item of equipment. In fact, during a proper design review, these different conditions should be examined at much greater levels of detail, down to individual components, to ensure that these are adequately designed to handle these various adverse conditions.

TABLE 6
COMPARISON OF KEY CLIMATIC CONDITIONS

CANADA	Degree-Days	Avg Days Wind >64 kph	Avg Days with gust > 60 kph	Greatest Snowfall (cm)	Avg Total Snowfall (cm)	Avg Total Rainfall (mm)	Mean Max Temp (July, ° C)	Mean Min Temp(Jan, ° C)	Extreme Min Temp (° C)	Extreme Max Temp (° C)	Days Freezing Rain (Avg)	Days with Thunderstorm (Avg)
Que City	1130	6.5	29.8	33.0	319	836	25.2	-16.7	-28.7	31.2	14.8	22.4
Trois Riv	1045	N/A	N/A	27.2	224	853	25.4	-16.2	-30.3	31.3	6.8	13.5
Montreal	826	4.9	32.0	30.7	218	750	26.5	-14.6	-26.7	32.0	11.9	23.5
Ottawa	941	3.0	20.9	26.7	216	652	26.6	-15.5	-27.7	32.6	16.6	23.5
Kingston	600	2.7	29.3	30.0	187	750	25.0	-11.7	-24.7	30.7	9.5	29.5
Toronto	483	8.9	38.6	39.9	140	675	26.7	-10.3	-22.1	33.1	9.0	31.4
London	466	N/A	N/A	40.6	225	808	26.1	-9.6	-21.3	32.2	13.9	N/A
Windsor	275	6.1	34.9	36.8	127	803	27.6	-7.5	-17.2	34.0	10.9	34.4
FRANCE												
Paris	N/A	M/A	N/A	N/A	All precipitation: 564 mm		24.4	+0.6	N/A	N/A	N/A	N/A
Lyon	"	"	"	"	N/A	N/A	N/A	N/A	"	"	"	"
Tours	"	"	"	"	"	"	"	"	"	"	"	"
SWEDEN												
Stockh'm	1000	N/A	N/A	N/A	All precipitation: 569 mm		22.0	-6.0	N/A	N/A	N/A	N/A
Goteborg	700	"	"	"	All precipitation: 736 mm		20.0	-3.0	"	"	"	"

CLIMATIC IMPACT SUMMARY MATRIX

EQUIPMENT NAME/DESC	CLIMATIC CONDITION CODE											
	IC	HW	FTC	ELT	WTV	TNF	FR	WS	SA	ES	HR	SSM
Locomotives		X		X	X	X	X	X				X
Coaches		X		X	X	X	X	X				X
Signalling & Train Control	X			X	X				X	X	X	X
Power Supply & Distribution	X	X		X			X	X		X		X
Overhead Catenary	X	X	X	X	X		X			X		X
Track	X		X	X	X		X		X		X	
Ballast & Subgrade			X		X				X		X	
Viaduct	X		X	X	X				X		X	X
Maintenance Facility			X	X	X		X		X	X	X	

Legend: IA = ice accumulation; HW = high winds; FTC = freeze/thaw cycles; WTV = wide temperature variations; TNF = temperatures near freezing; FR = freezing rain; WS = wet snow; SA = snow accumulation; ES = electrical storms; HR = heavy rainfall; SSM = salt asturated moisture.

6. ASSESSMENT OF R&D STATUS

Chapter 6 summarizes findings with respect to the status of current R&D activities related to the representative technologies that are or could be relevant to deployment and operation in the Canadian environment. R&D topics related to the deployment of HSR in Canada that could be or are being pursued by Canadian researchers are also summarized.

There are a quite broad range of corridor-specific, regulatory and institutional issues that will have to resolved before any of the candidate technologies can be deployed and operated in the Quebec-Ontario Corridor. Accordingly, it is clear that there is considerable R&D work that could contribute to the successful transferrence of these technologies.

As part of the Technology Review, the status of current R&D of particular relevance to design, implementation and operation in the Canadian corridor has been assessed. Emphasis was being placed on identifying activities intended [or with the potential] to reduce capital costs or improve the cost-effectiveness and efficiency of the representative systems, and on estimation of the potential impact of these activities on required investment. Site visits to France, Italy, Germany and Sweden facilitated exploration of on-going and planned R&D activities in greater depth.

Our findings are relatively optimistic with respect to the high-speed trains per se, but much less so with respect to infrastructure. Clearly, the fact that both suppliers intend to produce versions of their equipment that will provide full safety equivalence in the Canadian railroad operating environment will have a major impact on overall system cost, insofar as it will permit lower-speed operation on shared track for urban access and shared-alignment operation at higher speeds without deflection barriers. Lower-speed operation through at-grade crossings, while still not desireable, will at leat be acceptable under some circumstances.

That said, it should be emphasized that most *active* R&D initiatives affecting HSR in general and the two representative technologies in particular do not target areas of particular relevance to Canada. The current initiatives in France focus almost entirely on adding capacity and increasing performance, which may well improve the financial returns for additions to the existing network by providing better-positioned transportation products, but do litle or nothing to reduce first costs in a stand-alone corridor with difficult terrain and climatic conditions and marginal market prospects.

In Sweden, there is quite a broad range of R&D projects that have either been recently completed or are on-going on behalf of SJ and/or BV, sometimes in conjunction with other agencies of the Swedish government. Table 6.1 summarizes these activities.

It is entirely likely that Canada will have to invest in R&D to solve our own site-specific problems. The High Speed Surface Transportation Research Consortium has been created to that end, although as yet it includes only TGV technology, with no tilt train representation. A representative selection of research areas and topics and the rationale for their importance to HSR deployment in Canada is summarized below. We expect that at least some of the proposals based on these topics will be funded and will result in important and valuable developments that will enhance the deployability of HSR in the Quebec City-Windsor Corridor.

TABLE 6.1
RECENT AND ON-GOING
SWEDISH NATIONAL RAIL ADMINISTRATION
R&D PROJECTS

AGENCY	STATUS	SUBJECT
Swedish Road and Traffic Research Institute	Complete	Risk analysis/evaluation in railway sector (Jointly funded with SJ and Railway Inspectorate
	Complete	Assessment of effectiveness of plastic foam insulation
	Complete	Development of Computer Program to calculate track and turnout geometry
	Active	Risk analysis of dangerous goods transport on road and on rail (Jointly funded by SJ and Swedish Nationa Rescue Authority)
Lulel Technical University	Complete	Assessment of effects of different rail metallurgies on brittleness and fatigue life
	Active	Investigation of tunnel boring machine designs and cost-effectiveness under Swedish conditions
Royal Technical University	Active	Investigation of soil and rock mechanics in railway embankments and cuts
	Active	On-going investigations in railway-related engineering problems
	Active	Development of dynamic track structure behaviour simulation program
Chalmers Technical University	Active	Investigation of track-train dynamic interactions
Swedish National Geotechnical Institute	Active	Investigation of Swedish and EEC standards for bridges/other structures
	Active	Detection and warning system for landslides
	Active	Investigation of techniques for measurement and analysis of point and pore pressures

The research areas and projects are categorized in terms of three major themes. This categorization emphasizes the relationship of these activities to the two critical interfaces in high-speed operation:

- o between the vehicle and the guideway; and
- o between the vehicle and the power supply.

6.1 Management of the Vehicle-Guideway Interface

Justification: Achievement of cost-effective control over interactions between the vehicle and its guideway is fundamental to delivery of a safe and comfortable transportation product at any speed, but especially for high-speed ground transportation technologies. This theme, in combination with macroscale alignment geometry and microscale guideway geometry, encompasses ride comfort, suspension design, consist configuration, vehicle structure design, propulsion, braking, adhesion managment, subgrade and track structure stability, and design of bridges, tunnels, and other structures. It also directly affects a number of environmental issues, most especially noise generation at low to moderate speed.

6.1.1 Research Areas

Subgrade and Track Structure Stability

Cost-effective achievement and maintenance of a uniform and consistent running surface [the wheel-rail interface] demands an inherently stable subgrade and track structure. Existing railway tracks are subject to substantial seasonal deformation and misalignment due to freeze-thaw action, erosion by running water, pumping action due to inadequate drainage, the effects of seasonal moisture content variations on expanding-lattice clays and organic soils such as peat, and long-term effects of application of instantaneous loads in excess of the subgrade bearing capacity. None of these problems are beyond the current capability of geotechnical engineering to overcome, but the life-cycle cost implications of doing so are likely to price HSR systems out of consideration. This is especially true if co-location in existing railway or other rights-of-way is desired, inasmuch as some or all of the conditions listed above affect virtually all such alignments in the Quebec City-Windsor Corridor.

Possible Projects:

- o Improved non-invasive techniques to locate and characterize subgrade conditions and especially track sections subject to one or more stability-reducing failure modes

Payoff: Ability to reliably determine what segments of existing alignments require mitigation of specific problems that reduce track stability. Will permit explicit cost/benefit tradeoffs between new and existing alignments, and also among alternative existing alignments where such exist. If fully reliable, could result in significant reduction in life-cycle costs for subgrade engineering, track construction and maintenance. Should also have broader applications in geotechnical engineering.

- More cost-effective mitigation techniques to overcome subgrade and other defects causing track structure instability

Payoff: Improvement in system costs, system constructability and maintainability. In situ techniques that do not require, or at least minimize, requirements for excavation, removal and replacement of existing materials may offer greatest payoffs, especially for construction in existing (active) alignments. Could also offer decrease in (at least) construction-period environmental impacts.

- Improved track structure design to minimize effects of frost action, saturated soils, other sources of subgrade instability while retaining/improving cost-effectiveness

Payoff: Reduced life-cycle costs; improved track availability for operations; enhanced compatibilty with higher-speed operation in future.

- Improved techniques for achieving and maintaining uniform track modulus at transitions on/off structures such as viaducts, bridges and tunnels, through turnouts and crossovers, etc.

Payoff: Improved ride quality; lower dynamic track force increments at transitions, and thus improved safety and reduced maintenance costs; enhanced compatibility with higher-speed operation.

<u>Adhesion Management</u>

Justification: This research area affects propulsion and braking of the vehicle or consist, and thus is fundamental to operational safety, achievable performance (in terms of acceleration and deceleration rates and maximum speed), maximum train weight, minimum headway, and controlling gradient. While great progress has already been made in this area over the past 20 years, the effects of Canadian climatic (rain, snow, ice) and other conditions (e.g., wet leaves in fall, caterpillar or other insect swarms) on adhesion must be addressed. Proof of safe operation under Canadian conditions will be a precondition to commercial service.

Possible projects:

- Improved Wheel/Rail Metallurgy

Payoff: One strategy for improving available adhesion for acceleration and braking is to improve the tribological fit between wheel and rail, recognizing that there will be tradeoffs between minimization of rolling resistance and maximizing adhesion. However, there may be scope for substantial improvement in the high-speed [200 kph+] regime, given the predominance of aerodynamic drag as the source of running resistance at and above that speed. Improvements, especially with respect to retention of useable adhesion under adverse climatic and other environmental conditions, could offer substantial benefits in terms of system safety and reliability.

o Non-Adhesion-Limited Braking Techniques

Payoff: The braking techniques used for service braking on HSR technologies, including rheostatic braking, are all adhesion-limited. Eddy-current brakes which employ magnetic force acting on the rails are not adhesion-limited, but induce rail heating and -- with repeated applications over a given segment of track -- can result in loss of rail strength and thus create a hazardous condition. Eddy-current brakes are thus used only as an emergency brake on some technologies. However, access to braking which is not adesion-limited and which is effective at high speed is very attractive from a system safety viewpoint and could overcome potential climatic and/or environmental limitations on system operations.

o Improved Brake Design

Payoff: This is already a major research focus in Europe, notably the work being done on brakes for GEC-A as part of the 'Super-TGV' initiative. The key dimensions are improved rates of energy dissipation, improved tolerance for short-cycle application, decreased mass and physical dimensions, and decreased aerodynamic drag.

<u>Vehicle Stability and Efficiency at High Speed</u>

Possible projects:

o Reduction in vehicle/truck/unsprung mass

Payoff: As speed increases, control of vehicle mass and especially partially sprung and unsprung mass becomes very important. The TGV family operate with 17 tonne maximum axle load and about 2.2 tonnes of unsprung mass per axle. The Shinkansen Series 300 EMU has a maximum axle load of just 11.3 tonnes, and an unsprung mass of 1.86 metric tonnes per axle, albeit with a less rigid vehicle structure. Clearly, there is scope for mass reduction. However, this must be balanced against the cost of sophisticated light-weight materials, especially composites, which are typically more expensive than metal components both initially and on a life-cycle basis. Also, research to reduce vehicle mass must be cognizant of regulatory compatibility and system safety issues.

o Improved secondary suspension

Payoff: Provision of acceptable passenger ride comfort at very high speed requires maintenance of track to tolerances considerably more stringent than those dictated by operational safety. Improvement of the secondary suspension -- especially the use of an active secondary suspension -- could permit a relaxation of some construction tolerances and a reduction in maintenance effort for operation at current speeds, and/or the ability to achieve higher-speed operation with the same construction tolerances and level of maintenance activity.

o Improved truck stability at high-speed

Payoff: The key to safe high-speed operation is stable truck behavior (the elimination of hunting and other unstable modes). Most current high-speed trucks depend on hydraulic dampers to control yaw at high speed. The performance of these dampers under Canadian conditins will need to be demonstrated. Also, achievement of improved yaw stability by adding more dampers (as was done on the TGV-A 325 trainset for the 515.3 kph record run) increases truck complexity and maintenance requirements and also decreases the curving performance of the truck. One of the major tradeoffs in truck stability is between the rigidity needed to control yaw at high speed and the flexibility required for improved curve negotiation.

o Body tilt control and actuation for very high speed operation

Payoff: To permit exploitation of the performance potential of future generations of equipment on high-speed infrastructure built for current or near-term future speeds, without the need for major modifiations to the infrastructure, while maintaining passenger comfort, improved acceleration compensation will be required. There are two possible strategies that come to mind immediately: use of an active secondary suspension to compensate for differential suspension compression during curving, which would provide an additional 25 to 75 mm of effective superelevation relative to the current situation, and/or the addition of active body tilting, which could provide up to 200 mm of effective superelevation. The key issues would be control of the added mass and complexity of tilt control and actuation subsystem, verification of acceptable vehicle stability when in the tilted position and under possible tilt failure modes, and determination of an acceptable tilt control strategy.

o Improved vehicle aerodynamics

Payoff: Aerodynamic drag dominates all other sources of running resistance at speeds above 200 kph. It also is the primary source of noise above this speed, and many aerodynamic noise components increase as the 6^{th} or higher powers of speed, so this is a major issue for future generations of technology. Any modifications to reduce drag will contribute significantly to the overall cost-effectiveness of the technology, in terms of energy consumption, required installed propulsion power, sizing of power supply and conditioning subsystems and noise mitigation requirements. Also, if the vehicle cross-section can be reduced, tunnel sizing may also be reduced.

<u>Improvement in Design of Structures</u>

Possible projects:

o Improved cost-effectiveness through standardization of design(s) for grade separations

Payoff: Development of HSR in the Quebec City-Windsor Corridor will entail closing, detouring and/or separating well over a thousand highway, county road and private crossings. There are about 365 public road crossings on the Montreal-Ottawa-Toronto spine alone. Even if HSR is able to treat these crossings in the same fashion as a limited-access highway, there will be hundreds of grade separations. The cost of construction for these separation must be minimized through development of a small number of standardized designs, the components for which can be mass-produced in specialized facilities and field-erected. This approach will also allow the field erection teams to become more efficient.

6.2 Management of the Vehicle-Power Supply Interface

Achievement of reliable, cost-effective transmission of MW power from wayside to vehicle is a major challenge to continued speed increases for wheel-on-rail technologies. The perceived inability to do so is the major reason that maglev designs have adopted active-guideway linear drives, which result in a much more costly guideway than would be the case with active vehicles and a passive guideway. The major issues are achieveing and maintaining continuous contact between the pantograph and the catenary, the minimization and damping of vehicle-induced motion in the catenary, minimization of peak power requirements through improved vehicle design and operations optimization, and minimization of life-cycle power supply, conditioning, and consumption charges through improved subsystem design and construction.

Possible Projects:

o Investigation of behavior of catenary and pantography at high speed under Canadian climatic conditions

Payoff: This is fundamental to deployability of HSR in Canadian corridor. Icing, heavy snow and rain, electrical storms, and high winds all must be taken into consideration. Experimental and analytical investigation of cat/pant behavior will be required. This can build on low-speed investigations that have been on-going.

o Optimization of catenary and pantograph designs for Canadian conditions

Payoff: Issues here will be life-cycle cost minimization and enhancement of constructability and maintainablity. Experience with Tumbler Ridge electrification will be relevant.

o Investigation of active pantograph control strategies and techniques

Payoff: This is another major research area for high-speed suppliers and operators world-wide. Improved control of cat/pant contact means reliable power transfer, lower wear on catenary and pantograph, and reduced noise due to arcing. This is one of the enabling technical improvements for 350 kph and above operation.

6.3 Minimization and Mitigation of Environmental Impacts

Minimization of environmental impacts and effective mitigation of impacts that cannot be avoided through careful siting and good design and construction practice will be essential to the acceptability of any HSR project in the Quebec City-Windsor Corridor. There are two principal grouping of impact:

o Construction-period impacts, which will be largely common with those of any major linear-facility project; and

o Operating-period impacts, which will be more or less technology- and operating-strategy-specific.

The former impacts -- on water and air quality, habitat, and so on -- will be contentious, and will require a great deal of conscientious effort on the part of designers and constructors, but are not likely to require substantial new technical innovations.

The latter category of impacts -- noise and vibration, electromagnetic fields, localized air quality degradation around stations and terminals, increased traffic noise and congestion around stations and terminals -- will require the same attention to detail, but are also likely to require new technical investigations.

EM fields are a good example. Although as yet there is no irrefutable [or even reproduceable] evidence linking exposure to ac fields to any kind of epidemiological consequence, there is a great deal of public misinformation and hysteria about EM fields. There is also a paucity of hard data on the nature and magnitude of the fields associated with 25 kV 60Hz catenary and with HSR technologies themselves. At a minimum, rigorous measurements of electrical and magnetic fields under the catenary and within different types of vehicles will be needed, to dimension the problem and put it in context with respect to field exposure in everyday life.

Noise and vibration, although better understood in a theoretical sense, also suffer from a lack of readily-available and credible data. Again, technology and site-specific measurements to provide baseline information will be needed, followed by design of appropriate mitigation measures where such are necessary.

Possible Projects:

o Measurement of EM fields under catenary energized at different voltages and current types [single-phase 2x 25 kV 50/60Hz, three-phase 25 kV 60Hz, 15 kV 16 2/3 Hz, 1.5 kV dc, etc.]

o Measurement of EM fields in HSR vehicles and at wayside [TGV, ICE, Shinkansen Sr. 300, ETR 450, ETR 500, X-2000, etc][14]

o Measurement of noise and ground-borne vibration adjacent to lines carrying high-speed and conventional technologies, independently and in shared operation, at speeds between 50 kph and full operating speed.

o Investigation of the Technical and Cost-Effectiveness of Different Noise Mitigation Strategies for Operation of Conventional and High-Speed trains in Urbanized Areas.

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[14] A project to do exactly this is now under way with funding from several agencies of the U.S. government. Measurements on-board the TGV were completed in the fall of 1992, and the report on that portion of the investigation is due to be released in the near future.

7. ENVIRONMENTAL ISSUES

We initially expected that there would be three major technology-related environmental impacts associated with operation of HSR systems: noise, vibration, and EM fields. We have obtained such data as are available about these subjects relating to the two representative technologies, but even with the cooperation of suppliers and operators, these data are quite sparse.

However, despite this limitation, it has become clear that vibration will not be a general problem provided construction of the infrastructure and maintenance of trainsets, track and catenary are up to standard. There may be some very localized vibration-related issues (for example, if the HSR alignment ran adjacent to an analytical laboratory dependent on very sensitive instrumentation), but experience with transit systems and other domestic operators indicate that mitigation is possible at reasonable cost. We suggest a lump-sum allowance for this aspect of mitigation.

Similarly, there are very few data on EM fields associated with either of the representative technologies, but some data on TGV are now available. ERM, a contractor to the U.S. National Maglev Initiative, recently (mid-September 1992) completed controlled field measurements within the TGV power car and coaches and at various wayside sites including a power substation. We have a copy of the contract officer's trip report, some very preliminary results that were developed for presentation to the French, and also a copy of a paper prepared by SNCF on this subject. This material is covered by CIGGT's confidentiality agreement with NMI and so cannot be circulated until it is formally released (which should occur in the near future).

The preliminary results look very encouraging, with field strengths and characteristics comparable to those encountered in everyday activities. We also reviewed this material and found no evidence of any unusually high field strengths at any locations in the coaches or power car. We have requested a copy of the final report as soon as it becomes available.

In any event there is no irrefutable [or even reproduceable] evidence linking exposure to ac fields to any kind of epidemiological consequence. However, there is a great deal of public misinformation about EM fields. There is also a paucity of hard data on the nature and magnitude of the fields associated with catenary and with HSR technologies themselves, although this latter deficiency is now being addressed.

The situation with respect to noise is quite different. Noise will clearly be the most important operating impact, and could have a major influence on achievable speed in urban areas. Noise mitigation is possible, but at a substantial cost. The situation is complicated by the fact that the ambient noise levels in existing (active) rail rights-of-way typically already exceeds statutory limitations imposed by municipalities, but only very limited data are available on the magnitude and characteristics of the ambient environment. This makes accurate assessment of the incremental impact of HSR operations in these alignments an impossibility.

Existing Noise Standards and Bylaws

LGL & Associates, our specialist noise consultant, identified four relevant noise standards or guidelines, as summarized in Table 7.1. Note that many pre-existing activities, including conventional railroad operations, may be non-compliant.

TABLE 7.1: APPLICABLE NOISE STANDARDS AND GUIDELINES		
AUTHORITY	SOURCE	NOISE LIMITS
Montreal Bylaw 4996	As at left	$L_{Aeq.7h}$ of 60 dBA between 0700 and 2300; 50 dBA between 2301 and 0659[a]
Province of Ontario	Model Municipal Noise Control Bylaw-Final Report (publication NPC-131)	$L_{Aeq.16h}$ of 55 dBA between 0700 and 2300; $L_{Aeq.8h}$ of 50 dBA between 2301 and 0659[b]
Province of Quebec	Ministry of Environment	$L_{Aeq.24h}$ of 55 dBA for new mobile sources
CMHC	Road and rail Noise: Effects on Housing.	$L_{Aeq.24h}$ of 55 dBA for outdoor recreation areas

a The values cited are for the maximum noise level of intensity of a normalized noise as defined in the Bylaw. The normalized noise is determined according to the level of background (ambient) noise, the duration of emission of the measured intermittant noise and the type of noise.

b The cited publication refers to the noise environment on the site of proposed residential or other sound-sensitive development in an urban area; the limits are for outdoor sound levels.

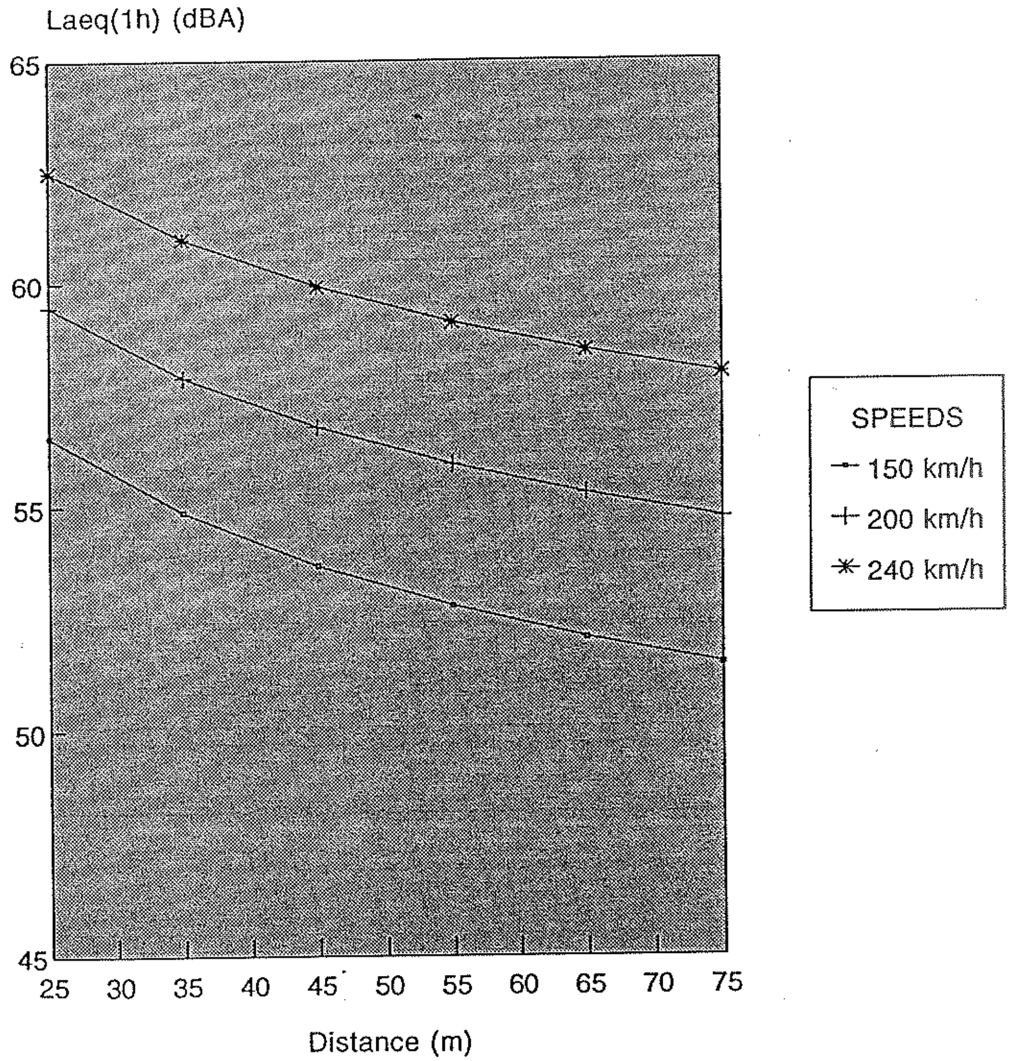
Estimated HSR Noise Levels

Subsequently, LGL were able to calculate the $L_{Aeq.1h}$ noise levels for the X-2000 and for the TGV, making use of data provided by the respective suppliers and drawn from the literature. The results of these analyses are shown in Figures 7.1 and 7.2, respectively. Note that the top speed for X-2000 is 240 kph, while that for TGV is 300 kph. the results shown are for one passing train per hour and do not take directivity into account. Additional detail is included in Appendix TA-6.

These results should be interpreted with caution, for the following reasons:

- o the maximum noise level L_{Amax} depends on the quality of the wheel and rail runing surfaces (poor track geometry or defective wheels cause more noise), the type of track structure (ballasted track versus slab, concrete ties and elastic fasteners versus wood and cut spikes), and the train length and configuration (i.e., power car forward or at rear);
- o the equivalent noise level $L_{Aeq.1h}$ of a train pass-by is dependent on the L_{Amax}, the train length, the distance from the track of the noise receptor, the train speed, and (for a time period other than 1h), the value if T in $L_{Aeq.T}$;
- o the results are estimated for a free sound field, and are valid for 25 to 75m distances over flat reflective ground; and
- o for multiple trains per hour, $L_{Aeq.1h}$ (x trains) = $L_{Aeq.1h}$(1 train) + 10 log x.

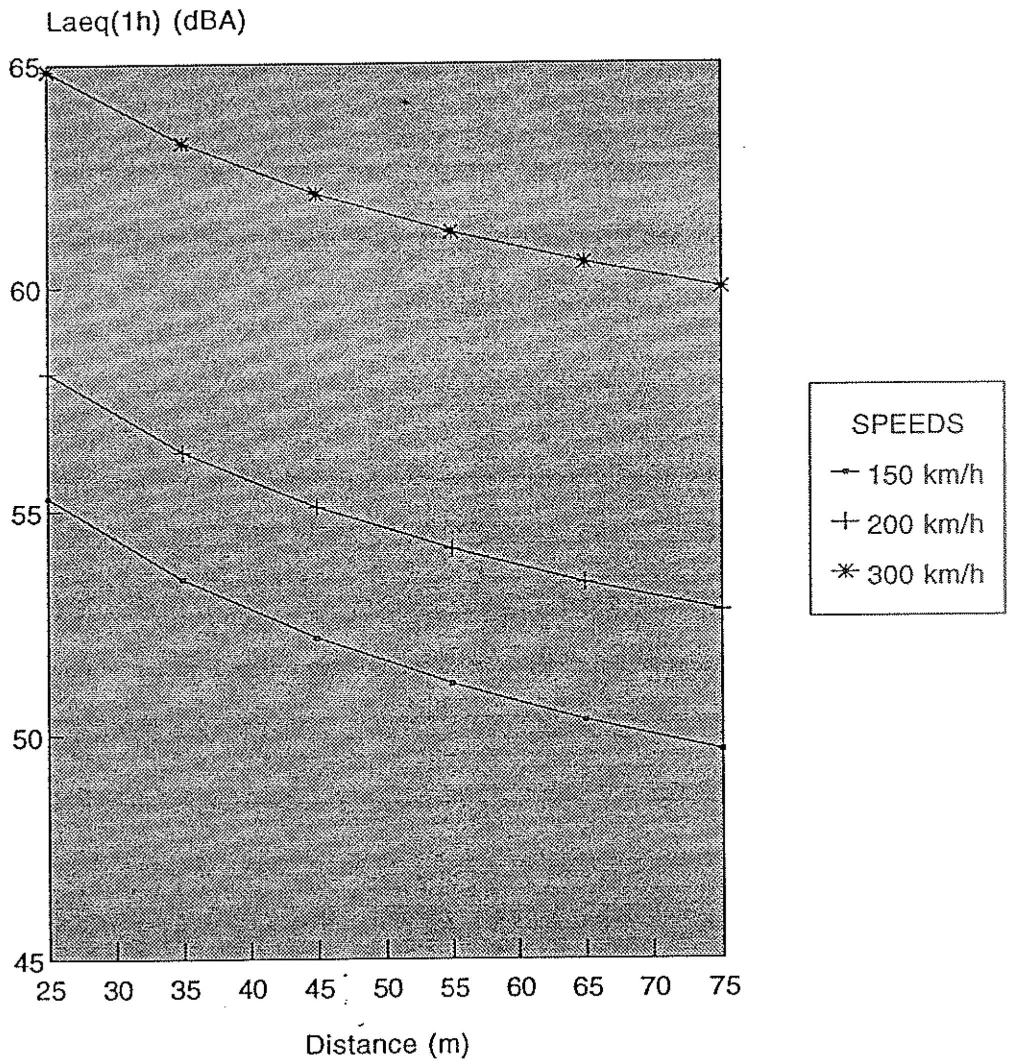
ACOUSTIC EQUIVALENT LEVELS Laeq (1h) FOR 1 PASSING TRAIN
X2000 Length : 140 m
Train configuration: 1 power car 2003 + 4 cars, track: n/d



1. The Laeq,(1h) are based on the formula in the SOFRERAIL article.
2. La, max from figure 2 of rep. no. TR P9213 (Noise test runs on Neubahnstrecke in Germany) except for the speed of 150 km/h (see SOFRERAIL article)

Figure 7.1: Passing Noise Level $L_{Aeq,1h}$ for X-2000

ACOUSTIC EQUIVALENT LEVELS Laeq (1h) FOR 1 PASSING TRAIN
TGV Length : 240 m
Train configuration: 2 power cars +2 transition cars+ 8 coaches, track: ballast and tie at-grade



1. The Laeq,(1h) are based on the formula in the SOFRERAIL article.
2. La,max from figure 4 of rep.no.291550-1 by C.HANSON
   except for the speed of 150 km/h (see SOFRERAIL article).

Figure 7.2: Passing Noise Level $L_{Aeq,1h}$ for TGV-A

Noise Mitigation

While noise reduction at source is the most elegant mitigation technique, more pragmatic approaches are often needed. Noise barriers and/or berms located adjacent to the track are an effective technique that is widely used in France and elsewhere. In particularly circumstances, such as the alignment of the LGV-A into Paris-Montparnasse and a number of locations on new high speed lines in Germany, placement in deep cuts or even cut-and-cover tunnels may be required.

Generally, a 2-m barrier or berm is sufficient to control noise generated by the wheel-rail interaction and other noise sources located below the top of the barrier. However, if aerodynamic noise is the principal concern, as it will be at full speed for the TGV, higher barrier will be required. This is particularly true if noise caused by poor pantograph-catenary contact is a problem, as it has been on the Shinkansen.

This topic is dealt with in greater depth in the reports of the Routing and Infrastructure consultant.