Shared Use of Railroad Infrastructure with Noncompliant Public Transit Rail Vehicles: A Practitioner's Guide

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TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 130

Shared Use of Railroad Infrastructure with Noncompliant Public Transit Rail Vehicles: A Practitioner's Guide

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TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), Transportation 2000, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

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The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

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FOREWORD

By Gwen Chisholm Smith
Staff Officer
Transportation Research Board

TCRP Report 130: Shared Use of Railroad Infrastructure with Noncompliant Public Transit Rail Vehicles: A Practitioner's Guide includes a business case for the shared use of non-FRA-compliant public transit rail vehicles (e.g., light rail vehicles) with freight operations and offers a suggested business model for such shared-use operations. The *Guide* also identifies the advantages and disadvantages of shared-use operations and the issues and barriers that can arise in the course of implementation.

The *Guide* includes a section that identifies and evaluates available and emerging technology, operating procedures, and techniques that could be used to minimize the risks associated with sharing of track between non-FRA-compliant public transit rail vehicles and freight railroad operations. Finally, the Guide includes descriptions and sources of real-world examples of these applications.

This *Guide* will be helpful to transit managers, transit operations planners, transportation consultants, state safety oversight agencies, and federal rail and transit oversight agencies.

There are two methods by which railroad corridors can be shared between public transit and freight rail operations. The first consists of public transit rail vehicles using existing railroad corridors, but not sharing the same track. The second method involves public transit rail vehicles sharing the same track with freight rail operations. The focus of this research is on the second method of shared-use, solely as it relates to sharing track with lighter public transit vehicles (e.g., light rail vehicles) that do not meet current Federal Railroad Administration (FRA) crashworthiness regulations. This "co-mingled" use of track has enormous potential for public transit expansion because freight rail corridors that crisscross the nation often provide the only transportation corridors left to connect suburban development to many urban communities. Each prospective shared-use corridor will give rise to a unique set of operating issues that requires development of new techniques, operating rules, and technology applications to allow the safe sharing of privately owned corridors that are becoming increasingly attractive as a latent community asset. In other instances, transit agencies have acquired rail corridors but are required to maintain pre-existing freight services, or public transit operators have been able to reach shared-use agreements (under "temporal separation" restrictions) with existing railroads. In either case, the FRA maintains jurisdiction and oversees use of the corridors based on regulations, laws, and policies developed during a century of safety oversight of the railroad industry.

To assist in the development of the *Practitioner's Guide,* the research team identified and evaluated the suitability of existing train-control applications for promising shared-use opportunities. Also, the research team evaluated the effectiveness of available and emerging technologies, operating procedures, and other techniques that could be used to address signals, grade crossing warning systems, and corridor intrusion detection appropriate for "co-mingled" shared-use train control. Based on this evaluation, the research team developed a baseline of common communications and control elements that would enhance the safety for applicable shared-use operations.

The *Practitioner's Guide* is intended as a tool-kit and handbook for identification of candidate corridors and implementation of a cotemporaneous shared-track operation. The report develops analytical techniques, notably a business model and business case, and strategies to overcome the barriers of safety standards and regulatory restraints.

CONTENTS

SUMMARY

Shared Use of Railroad Infrastructure with Noncompliant Public Transit Rail Vehicles: A Practitioner's Guide

Research Objective

A. Over the past decade, highway and urban congestion have garnered the attention of commuters as well as government entities. Facility joint-use, by expanding public transit using existing rail corridors, is one approach to solving the constellation of problems occurring as offshoots of congestion. Such routes are especially attractive because they appear to have available capacity and utilize an existing connection between high trip generating origins and destinations. The potential and feasibility of shared use of rail corridors, between light rail vehicles (associated with public transit) and freight railroads, to function compatibly are still being investigated, even as current "near shared-track" operations are evolving.

B. A number of operating issues need to be addressed, including the relative safety of shared-track, and practicality of the operational concept. Other questions that remain to be answered include:
   - How to mitigate joint use risks? What accommodations are necessary to make commingled shared-track workable in a variety of situations?
   - What are the viable business models?
   - How would shared use affect a current freight carrier and the rail corridor operations? Can track sharing be made attractive to the freight operator?
   - What are its advantages to the public?
   - How do public agencies develop policies and strategies to enable the use of an existing freight track for public transit?
   - What are the capital, maintenance, and insurance costs elements?
   - Finally, the most significant unknown is determining what is necessary to satisfy the FRA to obtain approval for this mode of operation.

C. The intent of the research project is to initiate a pragmatic investigation whose end product is a guidebook for transportation and other practitioners, and to assist them in finding answers to the questions raised above. Part of the goal is pedagogic: to provide a means to expand knowledge and understanding of strategies to ensure safety in rail transportation. The information and analysis should form a basis for informed discussion, analysis, and decisions in the environment of shared-track of infrastructure, including approaches to an assessment of benefits and costs; and demonstrate current practical processes and applications of different scopes.

D. Valuable and cost-effective projects of opportunity are available in some of the larger urban and suburban areas in the United States. Consequently, a secondary goal is to formalize and standardize an American approach to concurrent shared-track operations.

Summary of Research Tasks

The research program was divided into a series of tasks. The results of these task efforts were assembled and condensed for this final report.

Phase I Tasks 1–5 describe current and state-of-the-art technology and vehicles, and inventory the status of shared-track projects in North America. This narrative forms the context for the anticipated guidelines to commence a shared-track operation. A requisite preliminary was a literature review, data collection, and analysis. Identification of relevant information helped to focus on the most critical issues, avoided duplication of previous efforts, built on that prior work, and ensured access to the most current knowledge and thinking. The Task 6 Report summarizes the results from Tasks 1–5.

(1) Command and control (C&C) systems are a cornerstone of FRA approved safety procedures used on freight railroads to avoid collisions, and their principles are significant to development of any shared-track operations involving noncompliant rail transit vehicles. Techniques and technologies of the three major branches of C&C—train control, communications and Rules and Procedures—underscore the goals of redundancy and other measures to ensure a fail-safe environment.
(2) Information on current and new classes of railcar equipment was assembled and supplemented with descriptions of special attributes, such as crashworthiness and enhanced braking capabilities, needed in shared-track. Emphasis is on those features that will compensate for vehicle structural deficiencies. Such features will be part of any successful Waiver Petition and a small wedge towards gaining FRA acceptance for "equivalent safety" decisions.
(3) North American shared-track operations and programs have been identified and inventoried to provide a reference resource.

The findings, exposition, and analysis contained in the earlier tasks make a coherent case for Phase II, development of analysis tools and products to further future shared-track operations. Phase II Tasks 7–12 examine characteristics of freight railroads, financing, and parameters and metrics for a business model, a business case template, a risk analysis template and a demonstration project recommendation. Task 13 encompasses the findings and analyses of Tasks 1–5 and 7–12 to prepare a comprehensive final report and guidebook for the practitioner.

Report Output

The report contains examples of North American shared-track operations and describes progress to date. A business case template illustrating the use and interpretation of business case data, including sample worksheets, is included, as is a risk analysis template and an explanation of how the results impact the business case and ultimately project viability. Incremental steps to move beyond "rigid temporal separation" are reported as evidence of evolutionary progress in shared-track operations. Finally, concrete actions are proposed to help project planners develop a shared-track operation with a freight railroad. Ultimately the research suggests ways to increase the interest and potential of shared-track systems:

- A list of possible candidates and preferred conditions for a demonstration project;
- Highlighting the advantages and disadvantages of shared-track to broaden its service and practical economic appeal; and
- Reflection on the barriers and obstacles to adoption of the shared-track concept.

Research insights and conclusions are tempered by first-hand experience gleaned from preparation of an FRA Waiver Petition and direct involvement in all aspects of initiating a shared-track operation.

Findings

Alternative Approaches to New Starts

Major investment studies for shared-track systems should reflect trade-offs between the shared-track alternative and other investments that might equally serve mass-transit needs. At a planning level, four types of alternatives are distinguished:

- **The "Nonrail" Alternative:** represents the status quo or nonrail investments including carpooling facilities, bus route rationalization, transit priority lanes, or bus rapid transit investments.
- **The "Separate System" Alternative:** requires construction of dedicated track for non-compliant rail vehicles. The service uses a new right-of-way, shares a right-of-way (but not track) with conventional trains, or uses a highway alignment.
- **The "Compliant Vehicle" Alternative:** can establish commuter rail service on a railroad. Modernization of signal systems and infrastructure, and new passenger facilities are required. Railroad equipment can share track without restrictions. However, high platforms could cause clearance issues for freight equipment. Downtown street running also may be precluded.
- **The "Shared-Track" Alternative:** entails seeking special FRA approval to allow light rail vehicles (noncompliant) to share track with conventional railroad equipment. The infrastructure requirement can be similar to the compliant alternative, but the resulting service would be more flexible. Light passenger rail cars can continue off-the-rail alignment onto city streets. Low floor cars avoid conflicts between freight and passenger operations. There are two methods of operations:
  a. Temporal separation is possible where all freight activity can be constrained to a short overnight period without adversely impacting freight operations; and
  b. Concurrent operations are required where most freight activity can be moved into the overnight period with some overlap in the fringes of the service day. Occasional mid-day moves may occur in response to shipper needs.

Planners and stakeholders can use the "Alternatives Analysis" process to evaluate the primary advantages and disadvantages of a proposed shared-track system (shown in Table 1).

Business Model

If the advantages lead to the selection of a shared-track alternative, then the business model should guide the subsequent decision making. While there is no standard business model for shared-track operations, there are features and attributes that nearly all shared-track operators exhibit summarized in Table 2.

Business Case

The business model parameters then can be incorporated and quantified in the business case. In an exercise for this report, the team's research indicates that shared-track methods may reduce the capital development costs for rail transit system by 40% to 66% when compared

Table 1. Shared-track advantages and disadvantages.

Advantages	Disadvantages
Increase accessible passenger market; public transportation available in new, less served areas	Conflicts with growth in freight traffic. Temporal separation can be a "zero-sum" game, with winners and losers
Potential for route extensions, connections and passenger growth. Flexibility for test services	Capacity limitations, not suitable for high density, high volume passenger movements
"Walkability" to and from stations	Stations require parking and improved highway access; and generate traffic
Downtown distribution	Noise generated by horn warnings when trains traverse grade crossings
Lower cost than light rail	Increase in noisy freight movements that will likely shift to night
Quieter and with lower emissions than traditional commuter rail	A lightly used freight line must exist. The concept is applicable in selective circumstances
Induced growth may be economically beneficial to locality	Existing freight corridor may not be optimally placed to generate ridership. Growth may be induced where inappropriate or constrained by other factors. Ridership may be induced rather than mode shifted
Shorter, faster trains	A cooperative freight partner is required
Viable in "edge cities" and suburban neighborhoods	Extended and complex bureaucratic process; success not assured
Additional utilization of an existing railroad asset	Requires added systems and technology to protect passenger traffic from freight-based accidents
Reduced social disruption construction relocation, and environmental disturbance by using existing facility	Route will likely include a large number of grade crossings. Realistic or not, concern is increased with noncompliant vehicles
	Disparate speeds and weight, structural incompatibility of vehicles increases risk
	Each incremental change requires approval from the FRA

Table 2. Business model for shared-track.

Business Issue	Transit Agency	Freight Railroad
Track Ownership	Purchase, improve, and assumes control	Sell and relinquishes control
Track Maintenance	Pays all costs and defines standards subject to FRA regulation	Identify needs for continued freight service
Track Access	Manages freight and passenger schedule interactions	Perpetual and exclusive trackage rights, subject to per-use fee
Liability	Assumes all risks over-and-above the old status quo	Provides suitable insurance for own employees and operations
Capital Financing	Uses traditional public transit financing mechanisms	Pays for freight-specific improvements on an incremental basis
Incident & Emergency Management	Leads the incident site and recovery effort	Assists as necessary if freight equipment is involved
Operating Rules	Maintain railroad-like rules for both freight and passenger operations	Coordinate with transit agency and FRA to identify rules necessary to preserve and operate freight service
Employee Training	Trains transit employees and provides cross-training where needed	Trains freight employees for operation on transit territory
Breakdown Recovery	Retrieves disabled passenger equipment and evacuates passengers	Quickly retrieves disabled freight equipment to allow resumption of transit service
Labor Laws	Avoids rail labor laws	Operates under railroad labor laws
Command and Control	Combined command-and-control system with either temporal separation or "fail-safe train separation"	

to a new and entirely separate system. Concurrent shared-track light rail operations provide a mechanism to offer a higher frequency of service than commuter rail, while keeping the capital costs affordable and enhancing urban passenger and freight rail service. Where shared-track is the preferred option, the business case should consider:

1. The main reason to consider noncompliant equipment is the improved flexibility it offers. Constraints in curvature radius, grades, clearance envelopes, limits of acceleration and deceleration make a lighter rail vehicle a superior choice for a regional service that traverses both urban and suburban environments.
2. A willing freight partner is essential.
3. Temporal separation while adequate, limits both using parties, and can be unacceptable for freight customers, and restrict special events services for transit. It is also more difficult to schedule maintenance-of-way (MOW) windows on a temporally-separated system.
4. A strong oversight function and negotiation skill is essential.
5. Local governments should deal with the railroads as peers in negotiations and in business transactions. However, state or local authorities may have the right of first refusal if the freight operator proposes abandonment.
6. All planned improvements should benefit both the freight and passenger operation.

A business case for improved technology is more easily made where risk to passengers can be significantly reduced. A freight operation also receives benefits, but the business case for the use of state-of-the-art technologies on a freight branch line is not particularly strong.

Train Control Technology

Systems to back up the operator have existed for over 100 years. The rapid development of new processor and communications technologies has vastly increased enforcement options, and more importantly, safety capabilities. Conventional signal systems rely on train operators correctly observing and conforming to wayside signals, plus applicable radio messages and written operating rules, timetables and bulletins for safe train separation. Modern signal systems, standard to many high-density transit systems, employ different ways in which signal aspects and other instructions can be transmitted to the train and enforced, even if the operator fails to observe these instructions. The most important factor in choosing a train control system is to ensure an adequate level of collision safety.

However a shared-track train control system that permits progress beyond "rigid temporal separation" and allows a true concurrent train operation should incorporate other desirable features and capabilities:

- Short block lengths;
- Multiple signal aspects;
- Automatic train stop to override operator error and prevent rail vehicle collisions;
- Prevent/protect track to track crossing conflicts and siding roll outs;
- Accommodate different performance characteristics of passenger and freight equipment;
- Provide for operator alerts and a visual transition zone when going from signaled track to street running territory;
- Provide hazard warning and avoidance systems; and
- Accommodate equipment that may not be recognized by the train control system on the line.

A shared-track operation requires no advanced or exotic technology to provide adequate safety when the preceding guidelines are applied. The benefits and advantages of the latest technology may reduce operating costs, or provide life cycle savings, but well thought-out and appropriate applications of common train control technologies can furnish acceptable safety and fail-safe train separation. Conventional intermittent or audio frequency cab signals are sufficient for a new installation.

Technologies for Achieving Fail-Safe Train Separation

The single most important requirement in a shared-track system is to provide active safety. An active safety system is fail-safe, in that an inevitable human operator failure should not result in catastrophic consequences. Two currently available classes of train control technologies can meet that requirement.

1. Inductive warning system with stop enforcement. Inductive warning systems provide intermittent wayside-to-train communication via a series of electro-magnets or transponders installed at periodic intervals in the right-of-way. The train speed or warning can be acknowledged, but the system must slow down or stop the train regardless of whether the warning was acknowledged.
2. Coded-track circuit cab signal with speed enforcement. Coded track circuit systems provide continuous wayside-to-train communication via a pulse code or an audio frequency signal. The on-board microcomputer restricts train speeds and issues brake commands automatically based on the maximum permissible speeds or stop, indicated by the code.

Operating rules govern the movement of equipment with failed train control apparatus. Typically, movement is not permitted without on-site supervision. Movement of conventional trains with failed train control apparatus would not be permitted except under temporal separation.

Intrusion accidents and derailment risks are a threat to safety. Intrusion risks are greater in areas of close clearance. Derailments could lead to intrusion accidents. To provide safeguards against these accident scenarios, designs featuring wider track centers and downward sloping industrial sidings should be adopted where possible. Active detection also may be necessary:

1. Proven railroad technologies: hot bearings, high-and-wide equipment, and brittle wire detectors;
2. Hazard detection technologies: optical or newer laser technologies for intrusion detection and other temperature sensing devices for hot bearings;
3. Interlocked derails: prevents runaway loose cars from fouling mainlines; and
4. Electric locks and switch position indicators: minimizes facing-point derailments.

Together, these technologies provide a safe operating environment. Application of these technologies to mitigate identified hazards would be viewed with favor by regulatory authorities.

Grade Crossing Hazards

Grade crossing collisions with highway vehicles are a serious problem for all passenger and freight rail operations and some light rail systems. Crossing accident risks are not changed by either concurrent or temporally separated shared-track. Waiver applicants should emphasize the crossing safety benefits of lower vehicle mass, shorter trains, lower speeds and more powerful brake systems of light passenger rail cars compared with conventional commuter trains. There can be no objective technical justification for applying a higher grade crossing safety standard to shared-track than to light rail operations.

Integrating Technology for Effective Command and Control

- Freight carriers and passenger operators must be able to communicate when using the same track. This is fundamental to joint operation regardless of the type of railroad equipment in service. This capability is relatively easily served by conventional technology, at an acceptable cost.
- Regardless of the choice and capabilities of train control and communications technologies, these will have to be integrated with Rules and Procedures to complete the framework of C&C. Both the freight and passenger operator need to use a unified rulebook and receive movement authority from one control center, preferably the passenger operator.
- The current variety of vehicle choices necessitates that each new or unique vehicle must be analyzed from a safety perspective, increasing overall system deployment costs. Standardization can facilitate the incorporation of Crash Energy Management (CEM) features by avoiding or limiting the structural and risk analysis necessary for each railcar. Further reduction of the number of standardized vehicle categories and models will contribute to lower unit costs and facilitate acceptance by agencies and regulators.

Requirements for Concurrent Shared-Track Operations

Under the current North American regulatory framework, each shared-track operation must be approved by a waiver exception. Each such shared-track operation must incorporate measures that are safe, verifiable, and achievable when regulatory exceptions are sought. Detailed engineering or safety criteria allowing routine approval of standard shared-track system designs appear unlikely in the near future. Analysis and research experience to date indicates that shared-track operations that meet the following criteria have an elevated likelihood of achieving approval in the federal process.

1. Light Density Freight Operation (less than 1.5 million gross tons per annum)
2. Medium Density Transit Operation at Limited Speeds (no more than 20 minutes off peak headway, and at speeds of less than 60 mph)
3. Adoption of Railroad-like Rulebook for Transit Operations
4. Fail-Safe Train Separation Technology for Both Light Passenger Rail Cars and Freight train consists (variance from 49 CFR Parts 234 and 236 must be justified)
5. Common and Shared Communications Network
6. Full FRA Compliance and Reporting, Except:
   a. Transit Vehicle Design (49 CFR Parts 221, 223, 229, 231, 238, 239)
   b. Transit Operators are not FRA Engineers (49 CFR 240)
   c. Minor Variance on Hours of Service (49 CFR 225, 228)

Waivers: The waiver process puts the applicant at the whim of authorities that may identify additional requirements due to unforeseen local circumstances or new lessons learned from novel accident scenarios. FRA may require specific risk analyses for the proposed operations. However, planners should be confident that if the proposed operation meets these requirements, the risk of regulatory stall is much reduced.

Equipment: Given the disparity in structural capabilities and weights of light passenger rail cars and conventional railroad equipment, the light rail cars cannot be expected to provide primary passive protection in an accident. A dominant role for train control clearly emphasizes crash avoidance over crashworthiness.

Command and Control: From the outset the train control system should be designed with concurrent shared-track in mind. This allows the designer to account for high service braking rates of the light passenger rail car and design appropriate block lengths and signal aspects.

Additionally, the lower freight speeds on branch lines with shorter train lengths can be accommodated too.

- Ultimately the vehicle should be considered one part of an integrated 'system' of safety that relies on crashworthiness, train control, training, and Rules and Procedures.
- Whatever Command and Control and vehicle technology forms the basis of the shared-track operation, it should provide some capacity for service growth by both the passenger and freight operator.

Practical Shortcuts

1. Pursue "near compliance" wherever possible. The system has to look, feel, and sound like a railroad to the FRA, while applying transit technology and most important, assume that an FRA waiver will be necessary.
2. Control of movement authority is the key to safety and regulatory compliance. Consider that the choice of a train control system can contribute to a positive review of the Waiver Petition, improve the freight operation, and provide a faster, safer passenger operation.
3. A fail-safe train separation system with the capacity to override the train operator is necessary to prevent a potentially catastrophic collision and essential for concurrent operations. Cab signals can provide speed enforcement and reduce risk.
4. Where possible, incorporate CEM features on rail cars to reduce risk of potential injuries and fatalities.
5. Analyze nature of freight traffic and the physical configuration of track; modify track separation and/or elevations to protect against derailment accidents where possible.
6. Consider measures to mitigate risk:
   Recognized Risk Parameters
   - Accident rate variability with volume and type of rail traffic.
   - Frequency, nature and proximity of freight traffic.
   - Single or double tracks, yard operations.
   - Account for the operating speeds of the light passenger rail equipment.
   - Secondary collisions (effects on standees is a particular concern).
   - Note reduced fire hazard from less fuel and improved protection for the fuel tank on typical DMU equipment.
   - The number of cars in the consist.
   - Collision effects on the articulated joint.
   - Collision effects on power module or propulsion components.
   - Number of grade crossings, volume and nature of highway traffic.

   Potential Risk Reduction Actions
   - Upgrade the track maintenance class to reduce the likelihood of a derailment.
   - Lower the operating speeds of freight, time of day track restrictions.
   - Add intrusion detection and other hazard detection devices.
   - Failsafe train separation.
   - Protection from freight siding roll-outs.
   - Automatic Train Protection.
   - Grade crossing warning system technology.
   - Extremely high braking rates and redundancy of brake system on DMUs and LRVs.
   - Well developed operating rules and procedures with training and enforcement program.
   - Provision of CEM design including frangible and crush-zone elements in vehicle, in addition to interior features that offer more protection for passengers.
   - Anti-climber features for carbody and roof.

Barriers to Implementation

Research for this project has highlighted some of the advantages and disadvantages of the shared-track concept. None of the disadvantages is insurmountable, if shared-track is the right fit.

Some of the more prominent barriers, however, have subjective elements. These cases require convincing regulators and policy makers that shared-track operations are both possible and advantageous to the public. The tactic requires stronger and more irrefutable objective arguments to overcome the necessarily conservative approach to safety. On one hand, more research on and experience with shared-track operations may be essential to effect a change. On the other, existing impediments are the primary reason that the concept has not been more readily embraced, as evidenced by the number of transit agencies that have opted for conventional rail systems, or other projects that were simply stopped.

While there are a number of impediments to broader application of this form of service, risk analysis may be the primary obstacle. The interpretation of risk analysis methodology and results is somewhat esoteric. Validated data to quantify risk is lacking; modeling risk events is a complex affair; some have a natural inclination to dismiss risk concerns while some display a tendency to overstate them. One school of thought places excessive faith in risk management, while another has insufficient faith. The probabilistic aspect does not satisfactorily address a "nightmare scenario" event. There is simply less comfort in calculating a one-in-a-billion chance of an accident event every 10 years. Regulators can more easily understand the idea that if an event occurs, passengers are protected.

Advancing the Shared-Track Concept

Track sharing between mainline trains and light passenger rail cars serves a niche market between commuter rail and a stand-alone light rail system. It is clear that advances in this service concept are contingent upon shared-track operations being affordable, and achievable without sacrificing safety.

The shared-track transit systems currently operating in San Diego and southern New Jersey should be designated as demonstration systems for further development, as templates, for an American approach to shared-track transit operations.

Use existing shared-track systems to initiate demonstration or pilot programs for concurrent operations of light passenger rail car and conventional rail equipment in the United States. A shared-track demonstration project without temporal separation could be useful:

- To gain experience in design and implementation of such a system;
- To demonstrate the feasibility and safety of such an operation; and
- To quantify the benefits of shared-track operations.

Results of a demonstration could offer the potential for relief from a significant operating constraint on current temporally-separated operations.

CHAPTER 1

Shared-Use: Background and Rationale for the Research

Introduction

The focus of this investigation is shared use of track by lighter weight rail transit vehicles (e.g., light rail vehicles) that do not meet current FRA crashworthiness regulations with standard freight railroad rolling stock. "Commingled" use of track has significant potential for public transit expansion because rail freight corridors that crisscross the nation often provide the only transportation corridors to connect suburban development around urban communities. In the context of this research the terms "shared use or shared-track" imply cotemporaneous and/or concurrent use of a track by both freight and these lighter, non-FRA-compliant public transit vehicles.

Transportation planners may view an existing freight rail corridor as a potential community asset with a prospect for shared-use. Each corridor has a unique set of operating issues. Whether publicly or privately owned, to realize this potential each requires development of new techniques, operating rules, and technology applications. For example, transit agencies have acquired rail corridors but are required to maintain pre-existing freight services, or public transit operators have been able to reach shared-use agreements with existing railroads. In either case, the FRA maintains jurisdiction and oversees use of the corridors based on regulations, laws, and policies developed during a century of safety oversight of the railroad industry.

Research is essential to create a better understanding of the business case for shared-track by public transit and freight operations, to develop suitable business models for shared used, and to understand how technology, operating procedures, and techniques can be applied to address the key risks associated with these shared-track operations.

This Final Report (originally designated as Task 13 of the work program) was prepared using the results of Tasks 1 through 5, the approved version of the Interim Report, and results of Tasks 7 through 12 (listed below). Further detail and in-depth analysis for specific inquiries may be available in one of the task reports prepared as part of this research. A summary description of each research task is in Appendix 3 "TCRP A-27 Research Task Descriptions."

- Task 1 and 2 Consolidated Report—Current and Emerging Train Control Technologies
- Task 3—Command and Control Systems
- Task 4—Light Rail Passenger Vehicles for Shared-track
- Task 5—Shared Track Operations and Appendix
- Task 6—Phase I Interim Report
- Task 7—Freight Railroad Characteristics
- Task 8—Business Model
- Task 9—Business Case and Practical Guide

– Task 10—Hypothetical Case Study
– Task 11/12 Consolidated Report—Demonstration Program and Recommended Practices

As mandated, the report includes the output of the project tasks, synthesizes prior research on related topics, and describes advantages and disadvantages of shared-track operations, and fulfills the project objectives:

1. Provides a business case for shared use of non-FRA-compliant public transit vehicles (e.g., light rail) with freight operations;
2. Suggests business models for such an operation;
3. Identifies and evaluates available and emerging technology, operating procedures, and techniques that could be used to minimize the risks associated with sharing of track between non-FRA-compliant public transit rail vehicles and freight railroad operations; and
4. Serves as a guide for identifying the issues that may be faced by new project sponsors of a shared use operation.

This Practitioner's Guide is designed to be accessible to a variety of users of diverse expertise, background, responsibilities, and interests. The reader is supplied with a "to-do" list of specific actions and guidelines that can serve as a "primer" for the development of a transit system that shares track with a freight operator. A checklist includes advantages and disadvantages of different options and notes the constraints, barriers and pitfalls that might impede progress.

Defining Shared-Track

The focus of this research is "shared-track". This phrase implies cotemporaneous use of the same track and corridor by light rail transit vehicles and conventional freight equipment. The terms "shared use" and "shared corridor" are apt to be used interchangeably, but "shared-track" and "shared use" will be utilized here to describe concurrent train operations with these two different categories of equipment. In the context of this research the terms incidental corridor or route sharing is implied also, but the defining characteristic is true commingled operation of these two types of equipment on the same track.

Reader's Guide to the Final Report

The guide below is intended as a tool to assist in locating or selecting specific topics and issues for review. The work program task products are condensed and organized into five sections. This portion of the report is preceded by an Executive Summary, which concentrates and highlights the key findings. The Appendices, which contain specific information, or details that illustrate or expand on report content, follow the report itself. Information is displayed in five major groups: background for the research effort, institutional elements, the technological and operational facets, a practitioner's guide, and suggestions on advancing the concept.

Chapter 1—Shared-Use: Background and Rationale for the Research

Introductory and background material. Includes this "Reader's Guide", followed by brief contextual information about shared-track. The section defines the operational concept, discusses the typical freight characteristics and lists attributes that make a route an attractive candidate for shared-track operation.

A description of the research approach recounts its aims and focus, and the results of the team effort to identify, obtain, and organize the information used to prepare this handbook. The preparatory work includes a literature search; contacts with vendors and operators; and surveys and interviews with operators, suppliers, and regulators.

Chapter 2—Shared-Track: Laying the Foundation—Policy and Strategy

Policy and strategy. This section explains the policy and strategic underpinnings of a shared-track operation. It discusses the broader institutional aspects including the business model, the outline of a business case and the safety case. It reviews the FRA Waiver process, the role of State Safety Oversight, and the contribution of Risk Analysis to the safety case.

Chapter 3—Enabling Shared-Track: Technology, Command, and Control

Technical elements. This is a straightforward summary of train control technology, communications, Rules and Procedures and current and new vehicle designs, and how each contributes to a viable shared-track operation. It notes the influence of each on safety and the practical application and integration with both the passenger and freight operation. The influence of technology on the safety case is described.

Chapter 4—Shared-Track: A Handbook of Examples and Applications

Practitioner's guide to shared-track. This section serves as the practical manual. It is an account of North American shared-track operations and progress to date. A business case template illustrating the use and interpretation of business case data (sample worksheets are included) follows next. The guide contains a risk analysis template and an explanation of how the results impact the business case and ultimately project viability. Incremental steps to move beyond "rigid temporal separation" are reported as evidence of evolutionary progress in shared-track operations. Finally, concrete guidelines are suggested to help project planners develop a shared-track operation with a freight railroad.

Chapter 5—Shared Use: Progress and Evolution

Future directions for the shared-track service concept. What realistic approaches can be employed to increase the interest and potential of shared-track systems? Candidates and appropriate conditions are recommended for a demonstration project. The advantages and disadvantages, and their effect on the potential market are reviewed. This segment points out barriers and impediments to broader application and acceptance of this mode of operations. Finally it suggests area or research and efforts likely to enhance the practical appeal of this operational concept.

Bibliography

Appendices

1) Abbreviations
2) Glossary
3) TCRP A-27 Research Task Descriptions
4) Relative Cost Comparison of Train Control Systems
5) Sample Operating Rulebook Table of Contents
6) Vehicle Cost Drivers
7) Some Examples of Current Vehicle Production LRV and MU Vehicle Types
8) Shared-Track System Status
9) Shared-Track Configuration and Operational Alternatives

Research Effort

Scope of Work for Project A-27

TCRP issued its Research Project Statement for Project A-27, "Shared Use of Railroad Infrastructure with Non-FRA-Compliant Public Transit Rail Vehicles" on March 29, 2005. Thirteen tasks broken into two phases (summarized previously and shown in the Appendix) constituted the scope of work and defined the research effort. The principal aim of the investigation, reiterated here, is taken from the Project Statement.

> The objective of this research is to develop a guide for practitioners that (1) provides a business case for the shared use of non-FRA-compliant public transit rail vehicles (e.g., light rail) with freight operations; (2) suggests business models for such shared-use operations; and (3) identifies and evaluates available and emerging technology, operating procedures, and techniques that could be used to minimize the risks associated with sharing of track between non-FRA-compliant public transit rail vehicles and freight railroad operations.

The research program was not conducted in isolation, and was complicated by the need to be coordinated with a parallel program sponsored by the FRA. This was titled, "Intelligent Transportation Systems Technologies for Integrated Rail Corridors" (No document reference number because it is not published at this time) and was under the auspices of the USDOT Joint Program Office. Representatives of the FRA, FHWA, and FTA made up the panel for that project. Their objective, while similar, was not entirely the same in approach, scope, and deadlines; nor was the audience they wished to reach.

Additionally this report had to incorporate information generated by previous research including *TCRP Report 52: Joint Operations of Light Rail Transit or Diesel Multiple Unit Vehicles with Railroads,* TCRP Research Results Digest Number 43 and TCRP Research Results Digest Number 47, and build on those efforts to advance the breadth of knowledge and adapt it for practical application.

The unwritten element guiding the research was its audience. The immediate audience consists of the review Project A-27 Panel, assisted by the TCRP Program Manager. The second and ultimately larger audience comprises the transportation professionals, consultants, regulators, vendors, advocacy groups, public or government agency officials, private sector representatives and academic specialists who are professionally interested or simply curious about this novel approach to transit services. The A-27 Panel's makeup was intended to represent a cross-section of the larger audience to assure that a broad perspective and differing views were considered in pursuit of the objectives.

Research Approach

The team's first effort was to identify the most important issues to define and focus the research. They also examined prior work and documentation and selected the most valuable outputs for use in the project. Once this was accomplished members went on to establish and prioritize the primary obstacles to true shared operations.

Information acquired for each task involved conventional research methods.

- Literature survey and review of available research and internet search;
- Surveys of supplier/vendor representative and Operating Agencies;
- Interviews with supplier/vendor representatives and Operating Agencies; and
- Site visits, inspections, and discussions with Operating Agencies.

Although primary interest lies in true shared-use operation of track and infrastructure, the team had to review parallel operations on adjacent tracks and operations on same track with temporal separation to establish characteristic operating categories and parameters. These categories were confined chiefly to shortlines and low-speed and low-density routes rather than to high-volume and high-speed freight corridors where risk assessment and mitigation would be extremely difficult.

Finally, the products of the research were used and then integrated into a risk assessment process along with a business case and a business model. This could then be packaged and rolled out to the transit industry as a practical guide on planning and implementing a shared-track operation.

All work was reviewed by the A-27 Panel:

Submission of each of the 13 Task Reports to A-27 Panel for review and comment. Each report was submitted as a draft. The Panel members provided comments that were forwarded to the team. The revised Task report was then resubmitted to the A-27 Panel.

Panel meetings. The team met with the Panel members on two occasions, to review progress, brief them on available results or issues requiring guidance and to receive direct comments regarding the Task reports.

This report reflects those efforts; however, the insights and conclusions are tempered by first-hand experience gleaned from preparation of an FRA Waiver Petition and direct involvement in all aspects of initiating a shared-track operation.

Shared-Track—The Operating Environment

Currently mixed operations of light rail transit vehicles and conventional freight trains are permitted only under restrictions established by the FRA using the principle of "temporal separation". Ironically this is how railroads were run back in the early to mid-1800s, before the advent of electrical train control systems.

Characteristics of a Shared-Track Corridor

A route that reflects most of these general physical or operating characteristics is an attractive candidate for shared use:

- It is a light density short line used by freight. The freight operation is a small, relatively self-contained operation with limited volumes of traffic, not a far-flung system with connected facilities and traffic in many states and the technical systems and infrastructure to support such an enterprise;
- Freight traffic is a mixture of short through trains and some switching operations, with some delivery schedule flexibility;
- Highway/rail grade crossings and industrial or customer freight sidings are present;
- The route is presently dark territory or has very few signals, and no centralized traffic control (CTC), with simple radio communications between a freight dispatcher and train or MOW crews;
- The route is end-to-end and has the potential for downtown distribution via exclusive light rail passenger car street running on at least one end; or possibly an intermediate street running segment;
- Dedicated passenger and freight crews familiar with route physical characteristics are available;
- Light rail passenger car performance is the same for all cars and consists do not exceed two cars. The passenger equipment is "captive" and dedicated;
- Passenger service frequency is no greater than 10-minute headways in peak and 30 minutes in off-peak. Freight operations may have an exclusive operating window for 4 to 6 hours after midnight and before the start of the morning rush hour;
- Relatively low top speeds (not exceeding 60 MPH) are feasible for passenger equipment with limited requirements for civil speed enforcement; reduced freight speeds possible;
- Existing operating rule books, practices, and procedures are tailored to freight operations;
- Upgrades to the infrastructure such as improved track, train control, C&C system, stations, and the like, suitable for a light rail passenger operation, are feasible.

Presence of the characteristics outlined above can guide a planner towards a potential shared track project. However, multiple or extreme deviations from these characteristics may justify closer scrutiny of the plan, or render a true shared-track operation infeasible.

Freight Operations Perspective

Project planners are encouraged to concede a legitimate interest by freight operators to service customers. That service may support local business enterprises that contribute to economic vitality in the region. The planner should understand the perspective of the freight operator. In this way, the freight operator's objections can be anticipated and respected, and perhaps certain needs can even be accommodated. It is essential that the public sector representatives be capable of asking the right questions and appreciating the response.

Railroads in North America are primarily privately financed, owned, and maintained. For-profit concerns have focused capital investments in the most profitable traffic lanes and rationalized unprofitable track. Branch line tracks have low traffic density and high per-unit fixed costs. There are 545 short-line or regional railroads in the U.S., with in excess of 50,000 miles or 30% of the network. Such smaller railroads only account for 9% of the industry's revenue. These railroads are assets that offer opportunities for future passenger rail and freight railroad growth.

Class I railroads generally operate long distances over a multi-state network and on corridors with high traffic densities. Shortlines provide feeder or distribution service to or between Class I, other railroads, customers, and suppliers. There are four major types of ownership arrangements for these shortlines: Class I, shipper, government, or private ownership. Shipper and government owned lines typically contract their operation to a designated freight rail operator who may be one of the large holding companies that operate a variety of multiple shortline holdings. Of the private shortlines, some are owned by national holding companies, some are established regional roads, but a significant proportion of shortlines are truly small and independent. These lines are at higher risk for abandonment if the traffic base becomes unstable.

To operate light density lines, the shortlines need to lower their unit-costs to below Class I levels. The typical shortline expends about 70% of its revenues on above-the-rail expenses. This leaves 30% for fixed-plant (infrastructure) maintenance, overhead, and return-on-investment. In 2004, the shortline industry expended $264 million in maintenance. The annual track maintenance costs turn out to be between $5,000 and $10,000 per mile. There are limited federal programs for funding the rail freight industry. The Short-Line Tax Credit provides up to $3,500 per mile to qualified railroads. Railroads generally finance their operations and their capital needs using revenue derived from operations.

Shortlines tend to be the sole track user and are usually centrally dispatched via radio. Carloads are the dominant type of shipment on shortlines. Carload shipments are typically less "urgent," but require consistent timing. Temporal separation is often unacceptable for freight customers who demand specific car delivery, pick-up and spotting times. It is also more difficult to schedule MOW windows on a temporally-separated system.

The FRA "Intelligent Transportation Systems Technologies for Integrated Rail Corridors" [unpublished; ITS Technologies for Integrated Rail Corridors, FRA Office of Research and Development Contract No. DTFR53-01-D-0030 (2006)] concluded that local transportation officials should be encouraged to work with the owners of urban low density freight lines to share facilities and infrastructure, creating synergies in urban passenger and freight mobility that would not be possible without cooperatively sharing scarce transportation resources. Preservation of urban rail freight service offers economic development and congestion mitigation opportunities not otherwise possible. The shortline rail industry provides an alternative to highway based urban freight services, while allowing some business operations to remain viable in congested urban areas. In summary:

1. Low density branch lines are an important part of the nation's freight system;
2. Low density branch lines are low speed, low volume operations;

3. Insufficient revenue to cover fixed costs (maintenance of plant) is a continuous and ongoing threat to the sustained operations of low density freight lines; and
4. Shared-track provides a mechanism to defray fixed cost expense over more units of traffic, or provide an incentive for sale of the right-of-way that enables the preservation of the shortline and improves its financial position.

The first two points underlie the appeal of shared-track. The last two points are primary incentives for a freight operator to consider shared-track.

CHAPTER 2

Shared-Track: Laying the Foundation—Policy and Strategy

Introduction

The evolution of a shared-track project from concept to an operating system is likely to be tedious and extended. Planners should anticipate as much as 6 to 10 years from start to finish, with a potential for unanticipated delays. The way forward is littered with seemingly burdensome requirements, extended procedural steps, and the possibility of failure. The research challenge was to identify a series of necessary and sufficient steps, along with effective actions, to provide a reasonable certitude of project fruition.

This guide should enable originators to navigate the process to advance a proposed shared-track system, to better direct their efforts and to address the inherent ambiguities common to many public/private sector, multi-party endeavors involving bureaucracies and competing demands for limited resources.

Part II explains the key policy and strategic factors essential to achieve the sharing of track by a freight operator and a passenger operator using light passenger rail cars. These are broadly categorized as "*Institutional Issues*"; a complex panoply of policy, organization, administration, regulatory, liability, access, private, public, and other stakeholder perspectives, funding and business considerations. Coordination and integration of these myriad aspects is critical to success. A strong oversight function and negotiation skills are essential.

Why Share Track?

A convincing answer to this fundamental question is essential. The strongest reason for shared-track occurs in situations where a transit need that would go otherwise unmet is made possible by track-sharing. In cases where conventional solutions might be acceptable, it is almost always cheaper and faster to start a commuter rail service, and from a regulatory point of view less burdensome to construct a stand-alone light rail system. The transit needs that require shared-track tend to fall into three distinct categories or combinations of these categories:

1. The need to expand the reach of an existing light-rail system by using radial railroad rights-of-way, but the existing freight operation cannot be completely moved into the night-time nor abandoned.
2. A transit or planning agency wants to use an existing radial or conveniently linked branch line connection, but also wants to fulfill a downtown distribution function by traveling on city streets to reach major downtown destinations not proximate to the railroad terminal.

3. A transit or planning agency wants to use an existing radial or conveniently linked branch line connection, where the right-of-way has been 'hemmed in' by development and cannot support more tracks than absolutely necessary for a shared freight and light passenger rail service plan.

In each case, neither commuter rail nor a stand alone light rail system would be entirely satisfactory. A commuter rail operation would result in lower ridership, in unattractive end-to-end transfers, or noise and vibration impacts in the downtown or is simply physically unsuitable for the alignment. A stand-alone light rail system would result in duplicative facilities and thus much higher capital costs, or a poor at-grade alignment choice. There is then a very real possibility that the initial ridership would not justify any construction.

Shared-track represents projects of opportunity where a potential transit corridor need occurs along a strategically located, active rail freight branch line. In those cases track sharing offers many advantages over other solutions by: providing interoperability with existing light rail systems; street running to improve proximity to demand generators and contribute to economic revitalization in blighted areas; reducing negative environmental impacts and construction costs; preserving economically important branch line freight service; and offering an intermediate level-of-investment between a stand-alone light rail system and a commuter rail alternative.

Creating a Strategic Foundation

Track sharing between short or branch line trains and light passenger rail cars serves a niche market between commuter rail and a stand-alone light rail system. Viable operations in North America typically entail allowing a small number of branch line freight trains to operate over a line that is converted for medium-frequency light passenger rail use at limited speeds. To ascertain whether shared-track is the ideal or preferred solution, it is necessary to develop effective strategies that work within the confines of existing policy:

- Identifies these "projects of opportunity"
- Quantifies their costs and benefits
- Provides examples of successful projects
- Describes a business model and defining a business case
- Discusses the safety case
- Reviews effective technologies
- Examines the role of regulatory agencies

The institutional issues are the most complex, but the first step is development of a business model to help guide the approach.

The Business Model

The research objective clearly expressed the need to prepare a business case and identify the business model for shared-track. The model is the more strategic facet of the two and forms the skeleton of the business case. It is therefore addressed first. The business case is the tactical constituent that is applied to a specific situation to analyze and evaluate factors that shape the economic, technical, and operational decisions.

A business model is a guide to the conversion of technology to economic value, and is vital to advancing the concept of shared use:

> A business model is a conceptual tool that contains a set of elements and their relationships to express the business logic of a specific firm or service. It describes the value of a company to its customers and of the architecture of the firm and its network of partners for creating, marketing, and delivering this value and integrating financial and institutional resources to generate profitable and sustainable revenue streams.

While the business model for public agencies and the private sector will differ, the fundamental principle prevails. The public sector now may have to contend with more stakeholders and players. Overall, there may be more competing interests in the public domain, and financial considerations may not be the primary driver in resolving these rival objectives. A model can facilitate an agency's pursuit of the shared-track concept by laying out the framework for a business case.

Business Model Structure

The emerging American business model for concurrent shared-track physical asset shares many elements with the current American shared-track state of practice under temporal separation, but differs in detail to accommodate the needed changes from concurrent operation. The key differences lie in the areas of Command and Control, track access, liability, operating rules, employee training, and emergency recovery.

- The transit agency should plan to install a train control system, including train-stop apparatus on-board freight locomotives if deemed necessary. That eliminates the potential for collision between transit and freight trains sharing the same tracks.
- For track access, the transit agency must develop a capability for managing potential schedule conflicts, both for planning purposes and in real time. This may entail a schedule that reserves spare freight train slots within its operating schedules.
- For liability, the transit agency may assume more liability than in a temporally-separated regime (assignment of fault can be complex in a concurrent operating environment).
- The transit agency can expect to adopt operating rules of a railroad heritage, even though transit operators are not FRA certified engineers. The transit agency will be responsible for promulgation of some freight related rules.
- In terms of employee training, some cross-training would be expected to ensure smooth interface between freight train crews, their transit counterparts, and the transit agency dispatcher.
- The freight railroad and transit operator need a plan for emergency recovery of disabled freight equipment on a timely basis, so that transit service is not disrupted by a freight train malfunction, and vice versa.

Presently, the number of cases where conventional railroad rolling stock and light passenger rail cars share tracks is limited; public passenger transportation and private freight operations do share track. The recommended business model borrows heavily from the current practices in concurrent shared-track operations for both light passenger rail cars and conventional commuter rail.

While there is no single business model for shared-track operations, some common features and attributes exist for nearly all shared-track operators.

1. The transit authority generally purchases, controls, improves, maintains, and dispatches the infrastructure. Transit agency pays all related costs.
2. The freight railroad selling the low-density line retains "perpetual and exclusive" freight trackage rights for an agreed per-use fee.
3. Transit agency assumes all risks, liabilities, and insurance requirements over-and-above the old status quo, including the risks to freight operations due to presence of passengers.
4. The transit agency uses various financing mechanisms for infrastructure improvements that are unavailable to the freight operator.
5. The transit agency assumes responsibility for accident and incident management, maintaining operating rules, and training for transit agency staff.
6. The freight railroad must retrieve inoperative freight rolling stock (should it fail) and train their employees on transit territory.
7. Transit agency works to avoid legal and administrative classification as a railroad for the purposes of employment laws, to avoid higher labor expenses and related costs.

8. Where all freight operations can be shifted into the overnight period, a temporal separation approach to shared operations is adopted; where the volume of freight service, the needs of freight customers or the sensibilities of neighboring residents prevents overnight freight operation, an investment in train control technology that features "fail-safe train separation" is required to ensure that human failure does not result in a collision between a light passenger car and heavier freight rolling stock. A wide variety of technologies are available to provide this extra margin of safety.

Strategic elements of the business model should be quantified as parameters for a project specific business case. Table 3 displays a checklist of key issues and suggested resolutions that have previously shown to be acceptable to both the transit agency and the railroad.

The Business Case

A business case is a tool that supports planning and decision making, including major investment decisions. Business cases are generally designed to answer the question: what will be the financial consequences of each choice among multiple options? A good business case shows expected economic consequences of the decision over time and includes the rationale for quantifying benefits and costs. Critical success factors and significant risks are discussed. The case also describes the overall impact of a proposal in terms that can be understood by policy makers.

Business cases can range from the comprehensive and highly structured, as required by formal project management methodologies, to the informal and brief. Information included in a formal business case could be the background of the project, expected business benefits, options considered (with reasons for rejecting or carrying forward each option), the expected costs of the

Table 3. Recommended business model parameters for shared track.

Business Issue	Transit Agency	Freight Railroad
Track Ownership	Purchases, improves, and assumes control	Sells and relinquishes control
Track Maintenance	Pays all costs and defines standards subject to FRA regulation; define limits of agency ownership	Identifies needs for continued freight service; define limits of freight ownership
Track Access	Manages freight and passenger schedule interactions	Perpetual and exclusive trackage rights, subject to per-use fee
Liability	Assumes all risks over and above the old status quo	Provides suitable insurance for own employees and operations
Capital Financing	Uses traditional public transit financing mechanisms	Pays for freight-specific improvements on an incremental basis
Incident Management	Leads the incident site and recovery effort	Assists as necessary if freight equipment is involved
Operating Rules	Maintains railroad-like rules for both freight and passenger operations	Coordinates with transit agency and FRA to identify rules necessary to preserve and operate freight service
Employee Training	Trains transit employees and provides cross-training where needed	Trains freight employees for operation on transit territory
Emergency Recovery	Retrieves disabled passenger equipment and evacuate passengers	Retrieves disabled freight equipment so that transit service can resume
Labor Laws	Avoids rail labor laws	Operates under railroad labor laws
Command and Control	Combined Command-and-Control system with either temporal separation or "fail-safe train separation"	

project, a gap analysis, and the expected risks. Consideration also should be given to the option of doing nothing, including the costs and risks of inaction. The result of a review may be justification, termination, or amendment of the project.

Using a good business case in a complex environment requires assumptions, arbitrary judgments, and the development of new data—new information unique to the particular undertaking—that goes beyond existing budgets and business plans to address less tangible or more ambiguous issues.

Shared-Track—A Practical Business Case Structure

There is a strong national business case for shared-track operations. There are valuable and cost-effective “projects of opportunity” available in some suburbs and medium to high-density cities in the United States. Consequently, an appropriate national business case leading to adoption of a routine method and standardized American approach to concurrent shared-track is useful.

The practical business case for shared-track operations using non-FRA-compliant public transit rail vehicles and conventional railroad equipment identifies the costs and benefits to the freight railroad, public transit agency, and others associated with establishing new or enhanced rail transit service and regional goods movement. The business case for a shared-track system generally requires three separate components.

- Presence of appropriate business drivers suggesting a shared-track solution.
- Agreement among three major classes of stakeholders that benefits are fairly shared and costs equitably apportioned, producing a win-win-win scenario.
- Site-specific alternatives analysis demonstrating best economic return-on-investment for a shared-track approach.

The process for concurrent shared-track operations starts with negotiation between a public transit agency and a private freight railroad to share the target freight line for a combination of transit and freight applications. Conditions likely to lead planners to a shared-track solution include:

1. A suitable route, origin-destination linkages, and traffic level on the freight branch line;
2. A desire for a start-up transit service;
3. A desire for sections of street-running or a core section shared with an existing light-rail system;
4. A paucity of good parallel alternatives; constrained right-of-way width; and
5. A willingness to convey the rail right-of-way to a public entity.

Shared-track projects are feasible once these conditions are met. Valuable and cost-effective projects of opportunity are available in many of the larger urban and suburban areas in the United States.

There are three main groups of stakeholders in any shared-track project.

- The freight branch line owner will be concerned about operating costs, freight service quality, ease of operations, perpetual and exclusive rights of access, and safety.
- The transit agency will be concerned about service quality, ease of operations and management, and capital and operating costs.
- The main concerns of the government regulators and sponsors are to ensure safety and cost-effectiveness.

Within the framework of the business model, it is clearly possible to balance the interests of all stakeholders to produce a win-win-win situation among the stakeholders.

Three of the four key business case issues are:

- Key business drivers: these prerequisites should be met;
- National business case: the standardized "American approach to concurrent shared-track" should be understood and accepted by federal authorities; and
- Stakeholder analysis: all must reach agreement on cost and benefit sharing to produce a "win-win-win" scenario.

Where the first three conditions are present, the fourth and final step is to determine whether shared-track makes sense for a specific site or proposed operation by explicitly enumerating all of the costs and benefits trade-offs in an alternatives analysis. The four main classes of possible conceptual alternatives are:

1. Non-rail alternatives;
2. Shared-corridor options with minimum freight-passenger interactions (e.g., Parallel track operations);
3. Compliant commuter rail alternatives; and
4. Temporally-separated or concurrent operating regimes in shared-track scenarios.

When contemplating a new shared-track operation, whether it is a conversion of an existing low-density branch line freight railroad, or a 'concurrent upgrade' to an existing temporally separated line, building the business case typically follows the format of an alternatives analysis that considers other options to satisfy the business needs. Typically a four-step process is employed.

1. Identify service needs;
2. Define alternatives;
3. Choose shared-track operating regime; and
4. Analyze cost effectiveness.

All four steps are necessary to form a complete practical business case for a specific shared-track proposal. Practitioners wishing to build a business case for a concurrent operation should carefully study the difference in costs and benefits between the temporally separated and the concurrent alternatives. One point common to any business case is that freight operator must concur with the plan. Since they become tenants and the transit operator becomes the host, the nature of that relationship will be reflected in the business case.

Planners should be aware that although the freight operation benefits from improved infrastructure and technology, the business case might not be as strong. Freight adapts more slowly because costs have to show a return on investment. Freight operators also may be reluctant to adopt new technology because of its limited benefit to them and unanticipated interoperability issues.

The next section provides a template that will guide the user through specific steps. A unique practical business case can be built by substituting the appropriate geography and local variables. However, while the business case is necessary to justify a project, it is not sufficient. The safety case also must be made.

The team's research indicates that shared-track methods may reduce the capital costs to develop a new rail transit system by 40% to 66% when compared to a new separate light rail system. Concurrent shared-track light rail operations provide a mechanism to offer a higher level of service than commuter rail, while keeping the capital costs affordable and enhancing urban freight rail service. Indeed, there are a number of operating examples (San Diego Trolley, NJ Transit River LINE, and Newark City Subway, Utah TRAX) of substantial shared-track in North America where stakeholders have been able to reach agreement and the transit systems are in operation.

The Safety Case

To advance the business case, the safety stakeholders must be satisfied. The business case identifies stakeholders with the most significant impacts on a project and then puts in place a win-win-win scenario. Simultaneously planners are guiding the resolution of various institutional, operational and technical issues. However, safety regulators can be the "deal breakers" for a planned project. Even if the freight operator, transit operator, and state and local interest groups and authorities are "on-board" and the purchase, liability, and track access agreements are completed, progress is not guaranteed.

The FRA must be convinced that the project fulfills its safety requirements. Any shared-track project will require an FRA Waiver Petition, and invite the scrutiny of both the FRA and State Safety Oversight Organization.

FRA—Obtaining a Federal Waiver

Typically, a project involving concurrent operation of light passenger rail cars and conventional railroad trains triggers the need for a federal waiver due to the presence of cars that do not conform to full federal crashworthiness standards for passenger-carrying equipment. A waiver petition details specific conditions that render federal requirements inapplicable and describes alternate means of providing equivalent safety. The information in a waiver application typically includes:

- Description of the proposed shared-track operation on the general system of railroads;
- Proposed light passenger rail car characteristics;
- Proposed application of alternate technologies for signals, communications, train control, and other elements of the infrastructure;
- Required deviation from federal requirements for vehicle design, train control system, operating rules, practices, documentation, training, and maintenance procedures; and
- Explanation why the deviations do not compromise the level of safety, and how equivalent safety is achieved.

In pursuing a waiver, the agency examines each regulation and compares it to project design to ascertain the extent of compliance. The FRA will review plans and documents, inspect facilities, and interview technical, operating, and management staff as part of the approval process. All project elements that deviate from the current regulations must be addressed. If the FRA Office of Safety is satisfied, then a conditional waiver is granted, allowing operation of the proposed system. Approval is likely to be subject to specified terms and conditions, and is granted for a fixed term.

There are two levels of federal involvement. The FRA Office of Safety headquarters is in Washington, D.C., where the Safety Board convenes with respect to waiver petitions. The second is regional FRA offices, staffed by local experts and specialist who meet directly with project participants (designers, operators, agency managers), to review plans, and inspect facilities. Their reports are forwarded to the FRA Office of Safety and influence the Safety Board's review.

Since the FRA plays such a dominant role in the project's implementation, initiators are encouraged to engage the agency early in the planning stage and keep local and headquarters representatives apprised of plans, developments or changes. It is advisable to maintain a dialogue between train control system designers and appropriate Federal officials from concept and design throughout testing and startup.

Role of the Designated State Safety Organization

Rail transit projects generally come under the jurisdiction of the state agency responsible for State Safety Oversight (SSO). The state is ultimately responsible for ensuring the safety of the rail transit system. As with conventional transit projects, the SSO usually requires a project System Safety Program Plan (SSPP) and safety certification. Typically Federal waiver approval will be contingent upon the approval of the SSPP by the SSO.

The likely model of state safety oversight of shared-track operations should be basically identical to the framework for conventional rail transit projects. The difference is a Federal waiver is required to operate under shared-track conditions.

Federal regulators rely on state oversight for certain matters and vice versa. It is useful to distinguish those elements that fall within FRA or FTA purview and those reserved for the SSO. Research indicates that the federal authorities provide oversight for issues directly related to track-sharing with the general system of railroads, i.e., all of the issues explicitly mentioned in the waiver request. The SSO should furnish safety supervision in all areas not covered by the contents of the waiver request as well as those cited within the petition. In addition, the SSO must supply oversight where the waiver application explicitly requests exemption from federal regulation on the basis of the state regulatory framework.

Project planners are advised to engage the FRA, FTA, and SSO to confirm limits of jurisdiction and establish communications among all participants and coordinate provisions of the Waiver Petition for SSO participation.

It is likely that transit agency will be asked to communicate separately to the SSO for the shared track operation. Major accidents have to be reported to the federal and state regulatory agencies separately. Typically, freight and transit operators would file separate reports, if the incident involved transit and freight trains. A jointly acceptable reporting format that satisfies the requirements of the FRA, FTA, and SSO could be developed by prior agreement. It also will be necessary to develop an acceptable (to both the FRA and FTA) protocol to control, monitor, test, and discipline violations of drug and alcohol use policies.

Typically states with large or extensive commuter rail or public rail transit systems are actively monitored by an SSO. Some examples include:

- New York—New York State Public Transportation Safety Board
- New Jersey—New Jersey Department of Transportation Office of State Safety Oversight
- California—California Public Utilities Commission

In many states, SSO responsibility is delegated to the Highway Department.

Methods for Risk Analyses

Federal regulations state that an applicant must demonstrate an equivalent or acceptable level of safety. Safety equivalency is established by comparing the proposed operation with an "acceptably safe" conventional operation. Federal regulations and policies do not define the relevant quantitative safety measure(s), nor do they identify comparisons of operating models deemed acceptably safe. The applicant proposes these measures and comparisons for consideration by the FRA. Such a process may involve a number of iterations to satisfy the safety authorities. Two such methods of risk analysis approaches are safety measures and comparisons of systems.

- Safety Measures—Estimated accident casualties among passenger train occupants, or a measure of total harm combining current standard DOT values for injuries and fatalities with an estimate of accident costs.
- Comparison of Systems—Consider:
  1. Same light passenger rail service without the freight operations; and
  2. Typical commuter rail operation with typical train control systems operating over the same route combined with the same freight service.

Achieving Safety Equivalence

Equivalent safety is not expressly defined in 49 CFR 211, the legal basis for wavier petitions and approved deviations from the Code of Federal Regulations (see Task 9, subsection "The Waiver Process"). Federal law requires:

> . . . the petition should explain how a level of safety at least equal to that afforded by the FRA rule will be provided by the alternative measures the petitioner proposes . . . requires a quantitative risk analysis of the risk of collision . . . (49 CFR 211, Appendix A, Section II, Part 2, Paragraph C).

In other parts of 49 CFR 211, the concept of equivalent safety is often cited. The lack of explicit definition leaves this familiar and oft-quoted term open to interpretation both by regulators and petitioners. The prospective operator should endeavor to satisfy federal regulators on a practical level by addressing several concerns as part of its waiver petition.

- How is equivalent safety measured or evaluated in this project?
- What is the appropriate and acceptable method for comparing the safety of a fully compliant operation to the proposed shared-track project?
- Is the validity of the comparison limited or qualified in any way?

Comparing measures of safety equivalence with standards for other modes of transportation merits incorporation in any analysis. This multi-modal risk analysis should consider the null alternative (doing nothing), increased auto use, travel by bus, etc., that might result if a shared-track system is not built. Such an approach has been used for proposed Mag-Lev systems and air travel to determine overall risk, rather than mode specific risk.

Equal Risks, Equivalent Safety

Equivalent safety is best understood in terms of equal risks. Risk levels assumed for a federally compliant system must remain unchanged for any operating alternatives proposed for the project.

Risk is defined as likelihood multiplied by consequence. Likelihood is the probability of a hazardous condition arising. Consequence is the severity of the hazard. Likelihood itself is a complex product of probability of a train encountering a hazardous event, number of trains and train miles operated in a given time, and number of passengers on each train. Together likelihood and consequence measure the total exposure of life and property to potential hazards. Table 4 provides a simple illustration of the three major constituents of total risk assessment.

Table 4. Illustration of three parts of total risk.

	Likelihood		
	Probability	**Period**	**Consequences**
Definition	Chance of a hazard event affecting each unit of transportation service.	Units of transportation services operated in a given time period.	The average amount of damage done given that a hazard event occurs.
Aviation Example	Chance of a plane crash on a given flight.	Number of flights operated per day.	Average number of lives lost given a plane crash.
Shared-Track Example	Chance of an intrusion accident affecting a light rail vehicle and a freight train.	Number of light rail vehicle trips operated per day; number of freight trains operated per day.	Average loss of life and property given that an intrusion event occurs.
Source of Data	History of hazard events provides a probability per unit of service. Assumptions are made where there is insufficient data.	Operating plan and ridership projection defines the units of transportation services to be provided each day.	Accident history provides quantification of severity of each type of accident.

Thus, equivalent safety can be expressed by the mathematical relationship that includes the chance of a hazard event, the measure of consequence, and the predetermined time period. While the mathematics is straightforward, the availability of real world accident and incident data may be limited. To demonstrate safety equivalence, a variety of operating and accident scenarios must be modeled and tested. Assumptions of consequences may not be based on historical data, and thus might be overly conservative or optimistic.

The benefit of a risk assessment methodology is that a repeatable procedure and reproducible data is provided, ensuring objective scenario comparisons. However, the methodology also has some critical shortcomings: (1) lack of actual data for a specific scenario; (2) assumptions regarding consequences; and (3) limitations on the scenarios envisioned. A risk analysis template showing the process is contained in Part IV after the business case template.

Underpinning the Case for Shared-Track

The fulfillment of safety and regulatory objectives is focused on the features and characteristics of technology used to control the operation and provide the service. Most other institutional concerns are addressed via legal agreements, financial arrangements, memoranda of understanding or other official and formal commitments. But safety is a front line issue, where the rubber meets the road. Here, shared-track projects are most vulnerable to rejection, delay, modification or the addition of costly features and technology mandated by regulators. A risk analysis is a component of the safety case. And the safety case is essential to support the business case.

It should be recognized that the choices in technology would impact the risk assessment, which in turn affects the costs and operations cited in the business case, the freight operation, FRA Waiver Petition content, and SSO approval. There are trade-offs to consider and decisions should not be made in isolation. The approach to assessing the merits uses the tools described in Chapter 4 "Shared-Track: A Handbook of Examples and Applications" to determine the choice.

- Business model—outlines participants and relationships.
- Business case—defines the fiduciary contributions cost/benefits of alternatives.
- Safety case—analyzes the relative safety of the alternatives, defines roles of FRA and SSO, and the influence of the risk assessment.

One shortcoming of the risk analysis is that the theory and results are not fully understood or appreciated by sanctioning authorities. The probabilistic aspect does not satisfactorily address a nightmare scenario event. There is simply less comfort in calculating a one-in-a-billion chance of an accident event every 10 years. Regulators can more easily understand that if an event occurs, then passengers are protected.

CHAPTER 3

Enabling Shared-Track: Technology, Command, and Control

Introduction

The technology essential to enable shared track operations encompasses Command and Control systems, signal and train control, communications, and vehicle technology. The choices are influenced by economic and regulatory considerations. Technology options impact the business and safety cases.

This section reviews the variety of train control systems, communications systems, operational Rules and Procedures, and vehicles that are particularly suitable or adaptable to the shared-track environment. The emphasis is on those features or characteristics that will compensate for vehicle structural deficiencies by minimizing the risk of a collision or mitigating the effects in such an integrated system. Above all, this combination of features and capabilities will have to fulfill the FRA safety mandates.

Achievement of those objectives does not imply that all systems and vehicles should be FRA-compliant. Rather, they must satisfy Federal guidelines and conform to jurisdictions and principles established in the 1999 joint FRA/FTA policy statement, which were subsequently codified in current regulations, 49 CFR Parts 209 Appendix A and 211 Appendix A. Under these requirements, the FRA must be satisfied that all technical and operational aspects of the proposed shared-track system are sufficiently safe prior to authorizing revenue service.

A survey of operational and proposed systems, summarized in Chapter 4 (performed for the Task 5 Report), strongly suggests that a fail-safe train separation system and intrusion detection in high risk areas are critical, and a necessary prerequisite to concurrent shared-track operations. The importance of autonomous collision prevention is amplified when the vehicles involved have disparate structural capabilities, speeds, or weights.

The Role of Command and Control Systems in Shared-Track

The growth of shared-track applications in the United States is dependent upon the evolution of fail-safe Command and Control systems that provide no ambiguity, overlaps or gaps in authority, misunderstanding or disagreements among users. It is important that the research establishes minimum requirements of Command and Control systems for shared-track operations and recommends potential enhancements to assure the safety of all users.

Command and Control can be seen as a triangular relationship of elements that, when properly integrated, improves safety and supports operational requirements and passenger and freight service objectives. The elements are:

1. Train control systems;
2. Communications technology; and
3. Rules and procedures.

Effective integration means that Rules and Procedures are woven into the train control system, in conjunction with a communications network, to assert effective C&C over all train movements while protecting employees and the public. Together they provide redundant fail-safe features to prevent collisions and protect against technical failures or human errors.

Each individual facet contributes in a complementary manner with the other two. If one component of the triangle malfunctions, the remaining two elements must compensate for the deficiency. During such eventualities, performance can be permitted to suffer, but safety cannot be compromised, particularly in a shared-track environment. Rules and procedures take on greater importance under such circumstances.

Train Control Technology

Signal and train control technologies are defined as those technologies directly involved in ensuring the safe movement of trains and preventing collisions. This segment reviews current and emerging train control technologies that can provide fail-safe backup to override inevitable human errors and therefore assist in preventing collisions between trains on the same tracks, and between trains and other encroachments into the clearance envelope of an adjacent train. The applicability and practicality of train control technologies for a shared-track setting are assessed and evaluated.

Evolution of train control systems has been propelled by many factors. Accident experience and a desire to avoid financial losses, injuries or fatalities, ultimately have driven technological innovation and influences principles of design. More recently, regulations have assumed a greater role in forcing technology development and deployment. Finally, any system must be proven to serve its intended purpose and satisfy functional requirements. Practically speaking, multiple stakeholders must be satisfied with the design, manufacture, installation, and testing of a train control system. While such issues are generic to any train control systems design, their implementation in a shared-track environment merits special attention. In FRA and railroad parlance, they are considered vital systems.

1) Train Control System Functions

Train control systems are designed to prevent three major types of collisions: (1) head-on collisions between trains traveling in opposite directions on the same track; (2) flanking collisions for trains moving or standing on a siding when approaching or departing a main line track; and (3) rear-end collisions between trains following one another.

However, train separation alone does not mitigate all hazards. Besides train-train collisions, a shared-track system poses some unique risks. Intrusion collisions, where freight equipment intrudes on the active passenger track due to a roll-out, derailment, or shifted-load, are not necessarily detected by the train control system. Secondary collisions between freight and passenger equipment (i.e., caused by an intrusion event) may not be prevented by the train control system, so the best course is to prevent the primary (root cause) event. Where track is shared between compliant and light passenger rail cars, the FRA has required fail-safe train separation as a *sine qua non* for its approval. Figure 1 outlines technological approaches to train control that regulators would find acceptable without excessive scrutiny or burdensome strictures.

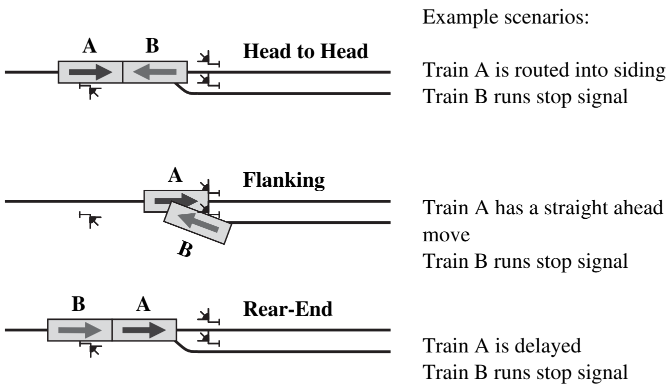

Figure 1. Train accident scenarios.

Train control technologies for railroad and transit operations are mature, but continue to evolve with the introduction of improved technology and components that offer additional capabilities. Train control systems are first and foremost installed to ensure safety. They provide three basic protective functions:

1. Train detection—indicates presence and location of trains;
2. Train separation—maintains safe following distances between trains; and
3. Route interlocking—prevents unsafe moves on/off branches or conflicting routes through crossovers and turnouts (that might cause collision or derailment).

Conventional signal systems are required by federal regulations where passenger train speeds exceed 60 mph, although shared-track would merit a signal system at any speed. Above 80 mph, federal regulations generally require active protection against three situations regardless of operator performance: (1) entrance to occupied block; (2) overspeed with respect to signal aspect; and (3) operator error.

The most significant limitation for shared-track applications of conventional fixed block is that multi-aspect signal technology, typically sufficient for passenger operations (below 80 MPH), is not adequate for shared-track operations, due to its lack of active protection. Wayside signals relay information with the expectation that the operator will respond properly. Override capabilities are not provided to catch and correct operator error. Consequently such conventional signal systems are not likely to be deemed acceptable for a shared-track environment with light passenger rail cars, regardless of speed.

2) Train Control System Design Parameters

The design of signal systems must be based on assumptions and parameters that include maximum speed, train acceleration and deceleration rates, train length, route gradient, curves, and civil speed limits. Other factors, such as number of tracks and features like reverse running, also are considered. Designers usually apply various safety factors (for example, diminished braking performance and additional stop distance margins) to system criteria to allow for potential failures or malfunctions of the vehicle. As shared-track operations are planned, the signal system must accommodate both short light rail cars and longer freight trains, with widely different stopping distances.

Adjustments to basic designs are made to take into account system service objectives, protection features, overspeed conditions, wheelslip/slide conditions, brake system failures or deficiencies, gradient, curvature, visibility, civil speed limits, rail volumes and variety of traffic, and other relevant factors. All designs must consider failure scenarios involving train control technology, rail vehicle functions, and human factors.

Most freight branch lines are dark (unsignaled), and therefore lack basic train protection capabilities. With low traffic levels operating at low speeds, train control mechanisms are simple and inexpensive to maintain. If any passenger service is contemplated on such a route, additional features need to be incorporated to provide better train protection, more operational safety, and flexibility. Certain features are mandated by regulation, whereas others simply improve the service or line-haul capacity. Although a passive system (dependent on the human operator) may be acceptable, an active system (that compensates for human error or component failure) is preferred. The addition of a train control system can be viewed as a no cost fringe benefit from the freight operator's perspective.

Whatever the design requirements or features incorporated in a basic train control system, there are fundamental regulatory requirements for any train control system design:

- Prevent entry into an occupied block;
- Stop distance to signals must be based on full-service brake rate;
- Provide broken rail protection; and
- Invoke automatic train stop systems based on maximum authorized line speed.

Each impacts the train control system design for shared-track operations.

3) Train Control Technology—Conventional Systems

Conventional or traditional train control technology is based on fixed blocks, multiple aspect, power frequency or direct-current (DC) track circuits. The fundamental element of a basic train control system is the block. The block is a section of track with defined limits. Its occupancy is governed by a signal. Figure 2 shows a simple example.

Each vertical tic mark indicates a separate block. Block lengths are established during signal design. Each block is an electrically separate track circuit, and individual lengths vary. Train movement is controlled by signals that require an appropriate response by the train operator.

Train control technology now in service in the United States is mature, reliable, well understood and based on simple, time-tested principles. In fact, this advanced stage of development obstructs the introduction of new technology or its adaptation to nonconventional applications.

4) Train Control—Emerging Technology—PTC and CBTC

Positive Train Control (PTC) and Communications Based Train Control (CBTC)were developed to expand the train control and information services provided by the signaling system. PTC refers to a North American family of train control technologies that provides functionalities over and above the most advanced continuous cab signal systems. PTC and CBTC are being developed for high-density or high-speed lines such as urban heavy rail rapid transit lines and mixed passenger/freight main line applications. However, they are not necessary for fail-safe train separation required for concurrent operation of conventional railway rolling stock and light passenger rail cars on shared track.

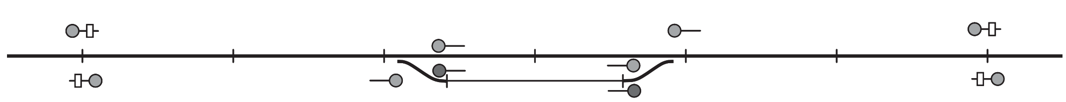

Figure 2. Signal block layout.

5) Train Control Technology—The Supply Side

The process of creating a practical train control system is lengthy and expensive. Designs must be prepared, products manufactured, components assembled and installed in the field, and the system tested. Since the dominant issues include products and installation, the supply side is often the most significant of all to stakeholders.

The signal supply industry falls into three major categories:

- Large, full-service suppliers;
- Niche or specialty product vendors; and
- Procurement consultants.

System suppliers and consultants assume primary responsibility for transforming operating requirements, standards, regulations, and design parameters into a functioning train control system. The supplier is responsible for the most important phases of implementation: manufacture of hardware, assembly of components, and system testing. Once installed, signal systems tend to have a long life cycle, and can serve reliably for more than 30 years with periodic maintenance and repairs. A long-term business relationship is the norm between the operator and the vendor, as specialized or proprietary parts often are necessary for repair and maintenance. This association is compounded by the vested expertise effect: when agency staff becomes accustomed to a particular product line, familiarity and experience often result in a sole-vendor relationship.

6) Proving the Train Control System

Basic Testing Requirements

New signal system installations must be proved in a succession of steps. The system is first cut-in by joining hard wire connections from rails to vital equipment in bungalows. Functionality is verified through a series of local and component tests. The tests are then gradually extended and combined to include adjacent interlockings. Once signal engineers are satisfied that the system is safe, test trains are run to confirm performance. There is nothing particularly novel about this sequence. The FRA establishes test requirements for signal system components and functions.

- 49 CFR Part 234.247 to 234.273 specifies Inspections and Tests for Grade Crossing Equipment.
- 49 CFR Part 236 specifies Inspections and Tests for various categories of equipment including Systems, Interlockings, Traffic Control Systems, and Automatic Train Stop and Cab Signals.

While these requirements are geared towards regular maintenance and inspections, they are also the starting point for a new installation. Often a railroad will create a more detailed inspection and test plan tailored to its own installation.

System and Integration Testing—Vendor Role

Vendors also must test and prove other aspects of new train control systems, to verify performance and functionality. Such tests are witnessed or monitored by the operator, to authenticate the test performance and results. In a shared-track operation, such testing will be required with conventional rolling stock and the light passenger rail car. By this point all assemblies, components and equipment would have passed factory tests. Once in place on the railroad, there is typically a six-step field and wayside test and inspection program: (1) installation testing; (2) static testing; (3) integration testing; (4) dynamic testing; (5) design or field changes; and (6) retest.

Proving the system also may include other activities such as:

- Test plans, procedures, and reports—normally defined in procurement documents;
- Maintenance—inspections and periodic testing—addressed in 49 CFR Part 234 and 236 tests; and
- Verification and validation—typically required for software based systems.

7) Practical Considerations for Shared-Track

Because of its impact on safety, train performance, and operator behavior, the selection of a train control system may be the most significant choice for a transit agency considering shared-track. Transit-like (2–5 minutes) headway is not envisioned on shared-track lines. Most likely, an occasional freight move is required along the corridor during an off-peak period when the transit vehicles are running at 20–30 minute intervals. In some cases, the last few passenger trains of the day would overlap with a freight train switching on-line industries.

Train control can be the dominant influence on the regulatory review process and directly affect the viability of the project. The choice of technology is influenced by many considerations. Some of the most important are:

- Current train control technology is mature and offers little room for improvement. Marginal improvements are achieved at significant cost. Absent a strong business case, there is little incentive to change or upgrade the technology.
- Design, manufacture, and installation of train control systems are expensive and require a long lead time. Once in place, train control systems are not readily adaptable to changes in technology or operating patterns without incurring substantial costs and time-consuming field modifications.
- Railroads and regulators can be very conservative in adopting new technologies, particularly where safety is affected. The FRA staff carefully scrutinizes any divergence from requirements of 49 CFR Parts 234 or 236. While deviation from regulations is sometimes incorporated, each must be justified to the FRA case by case.
- The system must be suitable for both freight and passenger equipment. It also must fulfill owner specified requirements and support the service plan envisioned.

8) Issues Unique to Train Control for Shared-Track

When choosing a train control system, the prospective operator is advised to develop a design that meets FRA regulations and acknowledges the need to submit a waiver petition to the FRA. The system designers and operators should engage the Federal authorities as early as possible to engineer an acceptable train control system. Any request for relief from Federal requirements must be justified. The following technical choices may encourage a favorable regulatory review and acceptance by the freight operator.

1. A train control system that provides fail-safe train separation is essential for concurrent operations.
2. The train control system should favor the transit operation and accommodate only an occasional freight movement among off-peak passenger service.
3. The design should consider the needs of the freight operator in addition to standard passenger rail service requirements. To enlist cooperation of the freight operator, the benefit of a new train control system should be quantified.
4. Designers should consider vehicle shunting characteristics for both conventional and light rolling stock, for track circuits, and grade crossing warning systems.

5. System designers should incorporate a complementary approach to the human interface of the train control system, including: (a) a full function control-center; and (b) appropriate operating Rules and Procedures.
6. The system must accommodate a transition between line-of-sight street running (if the system has a street running portion) and cab signaled territory. Light passenger rail cars must not enter shared territory without functioning cab signals without a safe operating protocol; conventional equipment must be prevented from entering street running sections by accident.

The objective is to use signal technology to prevent collision hazards by enforcing movement authority. No new technology is necessary, but the train control system must provide the minimum required feature set defined here, including the fail-safe train separation requirement and an emphasis on local hazard mitigation technology using auxiliary safety critical systems. All components are readily available in off-the-shelf configurations from multiple full service and specialty vendors. However, application of current technology to novel situations may be required.

Auxiliary Safety Critical Systems

Safety concerns for track sharing are compounded due to structural disparity between conventional equipment and light passenger rail cars. Four issues are especially prominent shared-track concerns.

1. Intrusion Detection. Advance warning of encroachments on the light rail train clearance envelope. Two types exist, continuous and point detection. One such device is illustrated in Figure 3:
2. Hazard Detection. Prevention or warning of failures in freight equipment or other hazardous conditions that could result in derailment, such as rock slides, hot axle boxes, or dragging equipment. Detection devices may be necessary where freight is operating nearby, preferably close to limits of shared-track zones.
3. Roll-out Prevention. Prevention of freight equipment roll-outs from sidings or at crossings, onto the main line used by a light rail train. Typically derails and electric locks are used for this protection.
4. Broken Rail Detection. Detection of rail failures, potentially averting derailments. This function is typically provided by a track circuit.

Placement of these systems should consider volume and speed of the freight traffic, train length, type of cargo, terrain, gradient, track centers and visibility. If feasible, fixed barriers and

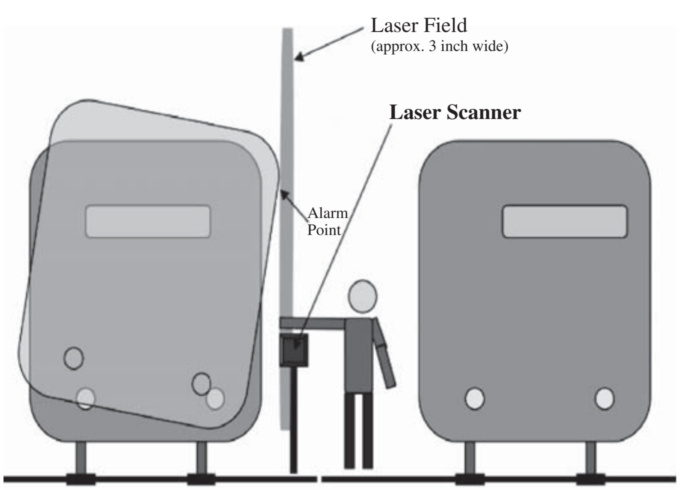

Figure 3. Intrusion detection technology.

other methods of limiting potential damage from a derailment should be considered. Detectors generally don't prevent problems, but provide early warning of hazardous conditions, and can be more easily installed. When a detector is triggered, an interface with the train control system normally causes nearby signals to display a STOP aspect and also broadcast a radio alert to operators and the control center. Generally the operating rules stipulate that all traffic must halt until a restart movement command is received from the control center. The control center would investigate the cause of the alarm and confirm a safe condition exists before authorizing traffic to resume.

Interoperability of Freight Trains in Shared Territory

A key issue for shared-track operations is the compatibility of freight equipment with the train control system. The locomotives used on branch lines can be a dedicated fleet, and fitted with the vehicle-borne cab signal apparatus. They will operate normally in a cotemporaneous manner, with the train control system ensuring safe spatial separation between trains. The controls on board a locomotive would be programmed differently to factor in freight braking rates and operating speeds. Freight train lengths may exceed the length of light passenger rail trains. A longer freight train could occupy two or more track blocks. The train control system should automatically accommodate the longer train.

The most difficult condition is the operation of a nonequipped "foreign" (i.e., from a railroad outside the shared-track corridor) locomotive on the shared-territory. Where unequipped freight equipment operates, special operating Rules and Procedures will assure operating safety.

- Temporal separation methods can be used to backstop the occasional situations where nonequipped conventional equipment must detour over the shared territory.
- If conventional trains only travel for a short distance on shared-track, turnouts can be set and locked to give the nonequipped freight train exclusive possession while they make the movement. The train control system will still prevent intrusions by passenger trains.

Application of speed control systems to freight trains is potentially problematic. Enforced braking of freight trains has two principal drawbacks.

1. The braking performance of a freight train is more variable and unpredictable, depending on the mix of loaded and empty cars, the car types in the train, and the condition of the brakes.
2. Too high a braking rate can result in high longitudinal forces in the train, potentially leading to damage and derailment.

However, with a properly designed enforcement system, freight locomotives could apply a low braking rate that does not pose a derailment risk. This is feasible and may be justified for a captive fleet of locomotives where freight trains travel for a substantial distance on the shared-track.

Planners are advised to review typical freight cargo, train lengths, operating speeds, active tracks, car counts, and other traffic characteristics along with track alignment and geometry. This can aid in identifying potential hazards or warning system locations.

9) Fail-Safe Train Separation

If a true cotemporaneous operation is planned, a higher level of safety assurance is required. The train control system must prevent a human error or component failure from jeopardizing operational safety. A minimum off-the-shelf shared-track train control system should feature intermittent or continuous cab signaling. The recommended system uses appropriate combinations of traditional signaling technology. The system should incorporate automatic train stop capability and overspeed protection.

- Automatic train stop capability: vehicle-mounted components that communicate with the signal system to force a train stop when there is insufficient separation from the train or obstruction ahead. The primary additional device is a receiver to read and process information carried by track circuits, beacons, or electro-magnets. The carborne receiver is specific to the chosen train control system.
- Overspeed protection: limit train speed to below posted speed limits to prevent excessive speeds on curves or through switches and to provide adequate stopping distance.

In general, these methods of providing fail-safe train separation supply additional functionality using elements physically integral to the rest of the basic train control system (track circuits, line wires, and bungalows and wayside signals) and adding appropriate components.

Essentially, the train control system monitors train speeds where speed reduction is necessary. The location to begin braking is selected on the basis of entry speed, deceleration rate, and distance to go before encountering a stop signal or a collision hazard.

a) *Applications of Automatic Train Stop Systems (ATS) (Intermittent)*
   Basic railroad-style ATS systems are unlikely to provide an adequate level of collision safety, especially on single-track lines. The high number of train meets at passing sidings, and the chance of an "acknowledge and forget" event constitutes unacceptable risk. Transit-style ATS, with an enforced stop on passing a signal at danger combined with modest top speeds and high braking rates is an option for less demanding applications. Transit ATS could be applied where freight traffic is very low or where passenger vehicles are to be prevented from encroaching on a short section of track "locked out" temporarily for a freight movement, as on NJ Transit's Newark City Subway.

   Enhanced ATS appears to be the most attractive for concurrent shared-track operations. The risk of "acknowledge and forget" incidents is much reduced by the additional warnings and enforcement to limit speed approaching a danger signal, and by enforced braking on passing the danger signal.
b) *Applications of Cab Signal Systems (Continuous)*
   Traditional power frequency fixed block systems with cab signaling and enforcement, like that installed on the Northeast Corridor and on New York area commuter rail systems, is mature and also would be suitable. Designed for high density, high speed operation with mixed locomotive-hauled and multiple-unit trains, they will likely exceed safety requirements for ordinary shared track operations.
c) *Audio Frequency Coded Track Circuits: The State of the Art*
   Continuous cab signal technology (in "b" above) requires high capital and maintenance costs. Recent technological advances have reduced somewhat the life-cycle costs of coded-track circuit based systems. Compared to a traditional cab signal system, the audio-frequency track circuit system has many advantages.
   - Lower capital and maintenance costs
     - Testing and maintenance burden is minimized
     - Fewer relays are used, thus bungalows and relay cases are smaller
     - Fewer impedance bonds
     - Fewer conductors means fewer terminations and less wire tagging, simpler installation
     - Very few insulated joints, reduces installation and track maintenance costs
   - Easier to bid and award because of nature of technology and larger pool of vendors
   - Track circuit lengths are easier to tailor to a route
     - Longer in line-haul segments
     - Shorter near stations and crossings, for better operational control

The audio frequency track-circuits provide both train detection and transmission signal aspects. The vehicle borne equipment reads the code and interacts with the train control system to alert the operator and/or reduce train speed as necessary. There is ample domestic light rail experience, and the system can be designed to comply with federal regulations. The cost is likely lower than power frequency cab signal systems, but thus far has not been applied in the U.S. mainline railroad environment. Table 5 provides an overview of the capability of train control systems in hierarchical order, lists primary components, and notes the extent of safety hazard protection each affords. Appendix 4 provides relative cost comparisons of various train control systems for planning purposes.

Command and Control: Communications

1) Communications—Information Processing

Railroad communication systems allow operating personnel to capture operational and other essential status information; transmit it to various locations, devices or persons that require this information; enable the systems to process or users to view the various conditions; and issue commands to control, alter or otherwise acknowledge the status. The constituent pieces that effect this capture and transmission of information and serve both verbal and data content include:

- Command & control information—voice, data (i.e., the information content to be monitored or transmitted);
- Carrier technology—medium of transmission via wire, wireless radio, fiber optic, land line or cell phone;
- Carrier frequency—VHF, UHF, SHF, spread spectrum (i.e., the format of the data transmitted);
- Communication system components—hard wired or portable radio, landline or cell phone, CRT display, mimic board, data transmitters/receivers, compatibly linked via interface devices to the transmission and frequency carriers.

2) Regulatory and Practical Requirements

For shared-track operations, an entirely new communications system will be required for the passenger service, and must, by regulation, incorporate direct interconnection with the freight carrier. On a shared-track system, the transit control center should be the exclusive hub for all freight and transit communications related to safety and train movement. The system component design and functionality must be based on a combination of published standards and regulations.

- Onboard equipment has to comply with the *APTA Manual of Standards and Recommended Practices, for Rail Passenger Equipment, Volume VI, Standard for Passenger Railroad Emergency Communications* and American Railway Engineering and Maintenance of Way Association (AREMA) *Communications & Signal Manual of Recommended Practices Volume V,* 2006. This contains railroad frequency and channel information for radio transmission systems.
- FCC requirements. Operator needs to apply for license for base stations (antenna height, broadcast range, and frequency license for transmission) for all wireless communications networks.
- FRA requirements. Operator must comply with relevant FRA regulations for railroad communication. The FRA regulations and policies for shared-track operations appear in the Code of Federal Regulations (CFR), in 49 CFR Parts 209 and 211. Other Federal Regulations including 49 CFR Parts 217, 218, and 220 also influence the control of rail operations. Requirements

Table 5. Overviews of capacity of train control systems.

TRAIN CONTROL TECHNOLOGY	TRAIN DETECTION	MOVEMENT AUTHORITY	ACTIVE or PASSIVE PROTECTION	SYSTEM COMPONENTS		FEATURES & LIMITATIONS
CONVENTIONAL TECHNOLOGY				WAYSIDE EQUIPMENT	VEHICLE EQUIPMENT	
DARK	Visual	Provided by operating rules; dispatcher radio communications; and visibility	Passive	None	None	Relies solely on operator performance, rules and procedures. No redundancy.
LINE OF SIGHT	Visual	Provided by operating rules; dispatcher radio communications; and visibility. May be augmented with non-vital train to wayside communications	Passive	None	None	Relies solely on operator performance, rules and procedures. No redundancy. Typically used in street running segment of light rail systems
TIMETABLE	Visual	No signals, train movements are clock based and driven	Passive	None	None	Train must adhere to schedule, no flexibility for operational changes and delays
MULTIPLE ASPECT/FIXED BLOCK	Track Circuit	Block to block movement as permitted by wayside signal aspects	Passive	Wayside signals, bungalows and relay cases, lineside wiring. Impedance bonds	None	Fixed block lengths. Depends upon signal visibility. Relies on operator performance
TRAIN CONTROL SYSTEM ENHANCEMENTS						
CAB SIGNALING	Track Circuit	Block to block movement when permitted by cab signal. Speed changes possible based on cab signals. Signal indication supplemented by wayside signal aspects. Speed violation enforced by penalty brake application.	Active	Wayside signals, bungalows and relay cases, lineside wiring, speed code relays, impedance bonds	Car borne induction coil, signal display unit in cab; electrically; and mechanically interconnected with vehicle propulsion system.	Fixed block lengths. Cab signals reduce dependence on signal visibility. Operation reverts to wayside signals if cab signal fails. Protects against some types of operator error, but typically not effective at very low (<20 MPH) speeds.
AUTOMATIC TRAIN STOP (ATS)	Track Circuit	Block to block movement permitted by wayside signal aspects. Passing a stop signal enforced by penalty brake application	Active	Wayside signals, bungalows and relay cases, lineside wiring, impedance bonds, magnetic train stops	Car borne induction coil, electrically; and mechanically interconnected with vehicle propulsion system.	Fixed block lengths. Protects against operator stop signal violation.
AUTOMATIC TRAIN PROTECTION (ATP)	Track Circuit	Movement permitted by cab signal display, speed changes also permitted, overspeed enforced by speed reduction. Wayside signals are supplemental.	Active	Wayside signals, bungalows and relay cases, lineside wiring, frequency code generators. Can be audio-frequency (AF) or power frequency (PF) or DC track circuits	Car borne induction coil, speed display unit in cab; electrically; and mechanically interconnected with vehicle propulsion system.	Fixed block lengths. Cab signals reduce dependence on signal visibility. Operation reverts to wayside signals if cab signal fails. Protects against operator error and maintains safe train separation
AUTOMATIC TRAIN OPERATION (ATO)	Track Circuit	Automated control of train movements as directed by train control system. Stopping, acceleration, overspeed is enforced. Operator can override.	Active	Wayside signals, bungalows and relay cases, lineside wiring	Car borne induction coil, visual display unit in cab; electrically; and mechanically interconnected with vehicle propulsion system.	Increased technical and operational complexity. Operation reverts to wayside signals if system fails. Protects against operator error and maintains safe train separation. Possible deterioration in operator skills. Loss of flexibility under certain conditions.
*CTC and NX (Non-Vital) **	*NA*	*Central Logic Controls Signals and authorizes train movements*	*NA*	*NA*	*NA*	*Overlay built on top of vital logic of train control system*
ADVANCED & EMERGING TECHNOLOGIES						
Wayside/Track Based System	Inductive loop	Movement Authority and speed commands provided from central computer	Active	Inductive loop lineside wiring, speed sensors, wayside signals at interlockings	Car borne induction coil, visual display unit in cab; electrically; and mechanically interconnected with vehicle propulsion system, speed sensor	Offers PTC. Costs of installation and testing and time for regulatory approval exceeds conventional technology. Capabilities excessive for application. Significant impact on freight operator.
Radio Based System	Radio Beacon & Transponder	Movement Authority and speed commands provided from central computer	Active	Discrete transponders, wayside radios	Car borne induction coil and speed sensor, computer, route data base, visual display unit in cab; electrically and mechanically interconnected with vehicle propulsion system. Radio transmitter.	Offers PTC. Costs of installation and testing and time for regulatory approval exceeds conventional technology. Capabilities excessive for application. Significant impact on freight operator.
GPS & Radio Based System	GPS and Radio Transponder	Movement Authority and speed commands provided from central computer	Active	Discrete transponders, wayside radios	Car borne induction coil and speed sensor, computer, route data base, visual display unit in cab; electrically and mechanically interconnected with vehicle propulsion system. Radio transmitter.	Offers PTC. Costs of installation and testing and time for regulatory approval exceeds conventional technology. Capabilities excessive for application. Significant impact on freight operator.

* CTC and NX are "non-vital" capabilities integrated into the logic of the train control system via an electronic interface, and directed and monitored from the Control Center.

and constraints noted within these regulations should be evaluated for their applicability to shared use. All railroad communications are subject to FRA Part 220, which mandates radio requirements, wireless communications procedures, and what to do in the event of communications failure.

> . . . any train that transports passengers shall be equipped with a working radio in the occupied controlling locomotive and with redundant working wireless communications capability. . . .

- Safe and effective Command and Control requires that the communications network and transmission must limit access for safety and security purposes.

Technology allows for a controlled flow of information between two or more key participants outwards to multiple subscribers through a central hub or between central hubs such as control centers of freight and passenger railroads.

3) Purpose of a Communications System

One of the most important uses of communication is to back up or provide an alternate or supplemental means of train control in the event of failure or service disruptions. Whatever the technology, verbal communication remains the foundation of safe and efficient movement of trains. In the context of this report, verbal communications refers to communication either between a control center and/or supervisory personnel and the train operator or other staff. These requirements extend to work equipment on the right-of-way (ROW), MOW crews, or lone workers under specified circumstances.

The focus here is on non-vital systems and methods for information transmission (data or verbal), the content of that information, and the resulting action. The human interface for sending, receiving or responding to that information merits consideration in the practical outcome of the transmission.

4) Functional Design of a Communications System

In conventional railroad parlance, communications is considered non-vital but nevertheless essential. The communications system is supplemental to the train control system, augments it, and provides redundancy. This non-vital information is monitored and captured. Communications data flows through four steps.

A. Capture Information: Monitor, report status, conditions or events, digitally or verbally. The system operator may wish to capture certain types of data and will provide sensors or readouts such as:
   - Vehicle identification, location (direction and speed), condition;
   - Signal status (display and health);
   - Grade crossing warning system status;
   - HAZMAT (hazardous materials shipment) information;
   - Track clearance intrusion; and
   - Hazardous event detectors (dragging equipment detector, hot box).

B. Transmission via the Communications Backbone: Conveying information verbally or digitally from the capture device to the display device, using the communications backbone, either wired (including fiber optic and copper), or wireless.

C. Display Information: Receive information and present or report it in an actionable format. Vehicles, control centers, and other monitoring devices and systems are typically equipped with status information displays and alarm/alerting systems. The status display simply provides current information about a given device, or function.

D. User Interface: A user initiates a control action or responds to the captured information via an interface device (e.g., a control panel). Most displays involve a graphic user interface (GUI) and include alarms (continuous or one time). GUI can be a touch screen, keyboard, or mouse. Typically all information displayed and responses are recorded on a data base for retrieval, should it be necessary. Generally two independent data storage and retrieval systems are provided for redundancy, as are multiple monitors.

5) Communications Systems for Shared-Track

A single communications center as a hub for Command and Control is essential for the shared-track operation. Given the fundamentals of the railroad communications system, what guidelines should influence the choices for a shared-track operation?

The operator should weigh the factors that affect technical selections, such as capital costs, maintenance costs, personnel skills, proprietary systems, expandability for growth, and adaptability to technical progress, as well as reliability, redundancy, practical user friendliness, band width, and frequencies.

Some benefits or capabilities are considerably more appealing to passenger operations, and safety issues loom larger where passengers are involved. Clearly any shared-track operations will require a working radio on trains and work equipment, for designated personnel, and a redundant capability. Communications with passengers and with a Control Center are not new to rail transit systems. Coordinating transit operations with a freight carrier and developing and using joint communications protocols will be new. A unique design or advanced technology is not required for shared-track. Conventional systems properly applied are sufficient.

Command and Control Systems: Rules and Procedures

1) Purpose

Rules and Procedures (R&P) were created to manage the operation of railroads and transit systems. They are published in a rulebook and other ancillary documents, and issued to designated employees. Most follow a standard format and topical coverage, although they are tailored to the individual line or system. Passenger and freight R&P are different. Whatever the choice of train control, communications technologies, and capabilities, integration with R&P completes the framework of C&C.

First and foremost R&P are about safety. The significance of human factors in accidents is not lost on the railroad and transit sectors. Thus, R&P remain fundamental to all passenger and freight operations. They:

- Provide needed redundancy in the event of equipment failures;
- Complement and compensate for the limitations of technology; and
- Provide a prioritized set of operating protocols critical to assuring the safety of shared-track operations, but are not entirely dependent upon train control technology.

2) Regulatory Mandates

The crucial importance of operating R&P in shared-track operations is recognized by the FRA in 49 CFR Part 211, which details the FRA policy with respect to shared-track. Directly applicable to Command and Control systems, the FRA specifically requires the freight and passenger operations to be capable of communicating directly and adhering to common operating rules where track is shared. Other relevant regulations include 49 CFR Part 214 Railroad Workplace

Safety, Part 217 Railroad Operating Rules, Part 218 Railroad Operating Practices, Part 225 Railroad Accident and Incident Reporting.

3) Rules and Procedures—Practical Considerations

Both freight and passenger operator must be under the authority of the same control center, preferably managed by the passenger operator. The control center must be able to communicate with train crews, MOW crews, supervisors, and maintenance of equipment (MOE) personnel and vice versa. In the case of shared-track operations, freight crews and other personnel must be able to communicate with the passenger control center and be trained and conversant in their R&P.

In a shared-track environment, the day-to-day operation encompasses the four likely scenarios over a typical service day or during special operations.

A. Shared-track operation of light passenger rail cars movements commingled on the same track where freight movements occur;
B. Parallel movements involving light passenger rail cars on one track and a freight train on an adjacent track;
C. Exclusive use by either the light passenger rail cars or the freight equipment;
D. Transitional periods when passenger service is starting or ending, in conjunction with freight period ending or starting.

Different rules and procedures for freight and passenger operations when combined for freight and passenger traffic in a commingled operation must accommodate those four scenarios as well as some unique to each mode:

- Freight operations. Train control system, communication protocols, speed, train length, cargo, drill operations, train inspections, shifted loads, fouling of main tracks, close clearances, and accident/incident response; and
- Passenger operations. Train control system, communication protocols, pre-departure safety inspections, schedule, speed, changing ends, terminal activities, passenger conduct and relations, station stopping, movements at grade crossings, hazardous condition alerts and accident/incident response.

In most cases rule books are issued to employees, who receive training, and then are responsible to learn the rules, keep up-to-date with changes, and have the books on or near their person at all times while working. To contribute to safety, R&P also serve these purposes.

- Governance: Specify the duties of operating and maintenance employees and direct their actions in any situation that may arise while they are operating trains or controlling or affected by train movements.
- Regulatory conformance: Fulfill regulatory requirements.
- Acknowledge limitations: Recognize the limitations of technology and human capabilities and behavior, and compensate for these shortcomings.
- Supplement train control systems: They are designed to address circumstances not accommodated in the train control system and failures of technology, and to provide safe work arounds for most eventualities.

4) The Rulebook

The ideal system of R&P will provide movement authority for all foreseeable situations. Railroad-based rules and procedures are preferred as the nucleus, for a rulebook that provides:

- Sufficient and appropriate content for the nature of the operation;
- Adequate management resources to staff, train, and monitor application and enforcement of R&P;

- Proficiency testing, fitness for duty and fatigue management practices;
- Supplemental and revised documents to reflect system or operational changes;
- Physical characteristics map and guide of the route for each employee;
- Communications protocols for all employees of the passenger and freight system. A reliable communications system that links the control center to light passenger rail cars, freight equipment, MOW crews and work equipment, MOE crews and supervisors, and monitors/commands the train control system.
- Guidelines and instructions for incident and accident response and management

While each system's rulebook may be organized differently, they all cover similar themes in a way appropriate to their system and culture. It is important that the freight operator be involved in the process of drafting the rulebook. While not all topics will be of concern to the freight carrier (e.g., light rail transit street running), there must be concurrence on topics of mutual interest.

5) Rules and Procedures for Shared-Track

Operating R&P defines how the signal system directs train movements and interactions between traincrews, the control center, and trains. Rules describe signal aspects, their meaning, and standard procedures both in normal operation, and when failure occurs. This is a key aspect of train control and must complement the characteristics of the operation and technology. Shared-track operation complicates the development of rules because operating procedures for freight trains will necessarily differ from those for light passenger rail cars. Designers of a shared-track operation should address some or all of the issues bulleted below.

- A prospective operator for shared-track operations should be cognizant of the mandates of FRA/FTA policy and regulations.
- The agency operator must blend cultures and practices developed to serve freight movements, passenger operations, and a street running light rail transit (LRT) operation.
- Implement joint training and testing programs, common rulebooks, user based special instructions and procedures, and physical characteristics training, including periodic revisions and currency updates. Institute proficiency testing.
- Delineate ownership and responsibilities of each entity using the corridor, creating a need for communication between the parties at both a senior management level and the front line level for day-to-day operations.
- Understand that Command and Control practices that may be necessary or appropriate for a passenger operation may not be valued, or may be perceived as impediments to their operations, by the freight carrier.
- Establish a control center that can set signals and switches, monitor and authorize train movements, and is capable of two way communications with train crews of both the passenger and freight equipment, and all MOW and MOE crews who access the shared ROW.
- Confirm the transfer of operational authority for a former active freight line to a new passenger operating authority, along with the assumption of responsibility for Command and Control of both freight and passenger traffic.

Transportation staff responsible for drafting rules and procedures should recognize that:

1. Since each shared-track operation and its associated communications network will be unique, the approach to Command and Control will have to be specifically tailored for the system. Commencement of any proposed shared-track operation will generate the need for new rules augmented and integrated with appropriate technology. A good foundation for new rules is the freight operators Book of Rules.
2. Shared-track creates the possibility for multiple operating environments within the same corridor, including mainline railroad running, street running, mixing with automotive traffic,

pedestrians, traffic signals, line-of-sight operation and other situations. This may be more challenging for a vehicle operator than an exclusive commuter rail operation, and must be addressed in training and the rulebook.

A table of contents for a typical rulebook is shown in Appendix 5 "Sample Operating Rulebook Table of Contents."

Technology: Rail Vehicles for Shared-Track Applications

Introduction

This section describes vehicles and characteristics that can support progress towards the goal of commingled operations. New vehicle designs exhibit improvements in safety and crashworthiness. Energy absorbing design is quickly becoming a standard feature on new light-weight passenger rail vehicles, especially those designed for higher speed operation. While these rail cars do not meet all of the structural and other requirements of 49 CFR Part 238 (commonly referred to as FRA compliance), they can effectively dissipate much of the collision energy that would be generated if the vehicle were to impact a similar vehicle or a car, truck or other object fouling the ROW. Full structural compliance with 49 CFR Part 238 would significantly increase the weight and restrict potential applications of these vehicles. Added weight also affects operating costs, thereby influencing the economic viability of such equipment.

Background

Freight operations have seen many changes since the 1960s. Freight locomotives and freight cars have grown in size and weight. Freight trains have increased in length. Passenger cars that do not meet federal crashworthiness standards are no longer operated in mixed traffic with today's freight trains unless specifically grandfathered or otherwise exempted. Before the 1990s, FRA had very few regulations applicable to passenger equipment. The only requirements for passenger vehicles were for self-propelled equipment (termed MU locomotives), which required a buff strength of 800,000 lbs for trains over 600,000 lbs in weight, plus various anti-override requirements. The Association of American Railroads (AAR) promulgated equivalent standards for unpowered passenger cars.

In the early 1990s, federal concerns about rail passenger safety increased, and passenger safety standards for conventional rail service were upgraded. Interest in and questions concerning the application of European high speed trains in the United States, a more activist attitude to safety regulation, the development of new structural safety technologies (especially crushable, energy absorbing structures), and Amtrak's push to acquire high speed trains for the Northeast Corridor contributed to the change in regulation. After much research and industry discussion, the initial version of Passenger Car Safety Standards (49 CFR Part 238) was finalized and published in 1999. There have been and continue to be periodic revisions to them.

New standards required 800,000 lbs buff strength, with no exceptions. Shared-track advocates played no part in the development of the standards; the focus was primarily on intercity and commuter rail equipment. At the time, temporary waivers were granted. Several robust rolling stock designs at the margin of compliance, such as the Budd RDC, were grandfathered. Just as Part 238 was being finalized, shared-track proposals were being developed, notably for the NJ Transit River LINE. Thus the FRA was put in the position of either granting significant exceptions to its new standards, or rigidly applying the standards and outlawing preexisting, concurrent shared-track operations in San Diego. One result of these converging events was the 1999 FRA/FTA joint policy statement (now codified in 49 CFR Parts 209 and 211). That policy established a temporal separation requirement for light rail equipment that operates in a shared-track environment because it lacks the required buff strength. The FRA did contemplate the possibility of commingled operation under some form of fail-safe train separation and an affirmative risk analysis. However, no potential operator has fully undertaken the heavy burden of trying to meet this requirement.

Recent studies have acknowledged that temporal separation would be the guiding principle for shared-track because any other service would require some form of waiver from certain FRA regulations, given that existing regulations do not allow latitude to dispense with FRA compliance. Nevertheless, the state-of-the-art in these vehicles provides a variety of improvements that may make it easier to prove equivalent safety to the FRA, or at least near-compliance, especially when the vehicle safety features are augmented with other wayside systems and train control technology that contribute to overall safety.

Review of Suitable Candidate Rail Vehicles

While many vehicles and propulsion systems can serve this potential market, it is most likely that a selected vehicle will be equipped with a diesel engine prime mover whose propulsion system is either electric or hydraulic. Diesel as the choice of primary power source is fundamentally driven by system cost issues, since diesel eliminates the expense of electrification and also offers greater route and service flexibility. And a conventional roadway or marine diesel engine that fulfills current EPA regulations can be used. Moreover, a diesel prime mover avoids potential electrical clearance limitations to freight traffic and associated signal system complexities.

Many common terms of reference [such as diesel multiple units (DMU), light rail vehicles (LRV), electrical multiple units (EMU)] can be confusing or unclear to both experts and nonspecialists. For report purposes the term "light passenger rail cars" is suggested as a generic reference to all vehicles in service on, or considered for, shared-track operations that do not comply with FRA structural requirements (49 CFR Part 238). Where a specific reference (DMU, LRV, or EMU) is employed, it is used to focus the discussion on a particular subset of the universe of noncompliant vehicles under consideration. Appendix 7 is a "mini-catalogue" of typical light passenger rail vehicles, although some are more suited to shared-track than others.

1) Light Rail Vehicles

LRVs suitable for the shared-track environment have evolved from vehicles typically used as streetcars. Such LRVs are currently in operation in a number of U.S. cities, such as San Francisco, Boston, and Philadelphia. LRVs constructed for shared-track do, however, differ from LRVs designed for operation in urbanized areas, in a number of ways.

The shared-track LRVs tend to be longer, wider, and heavier than the vehicles designed strictly for operations in urbanized areas, and they operate at higher speeds. However, one of the recent main differences between standard street running LRVs and those intended for shared-track is the variety of propulsion methods, physical dimensions, and capability to enable these vehicles to operate on two or more different rail lines, including a downtown or street running portion.

2) Diesel Multiple Units and Electrical Multiple Units

DMUs and EMUs have been used traditionally to operate as commuter and intercity trains on lines with low ridership or those that require a high frequency of service. Those vehicles are constructed much like standard railway coaches with the addition of a propulsion system and an operator's cab. A new generation of lighter DMUs and EMUs (jointly referred to as light passenger rail cars) has been designed with the shared-track market in mind. They resemble current

LRV designs and feature multiple articulated carbody sections, and partial or full low floor design. While some of these new vehicles were designed mainly for railroad operation, several smaller models have been conceived to allow city street operation. Like the LRV, the light passenger rail car offers several different modes of propulsion.

Features Preferred for Shared-Track Operations

Certain key systems and capabilities exert an overriding influence on vehicle performance and suitability for shared-track duty. Other subsystems such as heating, ventilations, air conditioning (HVAC), doors, lighting and interiors, are common to nearly all rail cars and have little influence on shared-track.

1) FRA Compliance

The main focus of the requirements for vehicle crashworthiness specified in 49 CFR Part 238 is to protect the integrity of the vehicle structure in the event of a collision with another rail vehicle. While these requirements make FRA-compliant car bodies more resistant to collision forces, the vehicles are also relatively heavy, and the design flexibility to adapt the vehicle for differing service applications and operating environments is more limited. This is exemplified by the range in weight per seat of North American DMU products. Research showed that FRA-compliant DMUs are 63% heavier on a per seat basis than noncompliant ones, and approximately 25% of the vehicle weight is structure. Part 238 also addresses equipment and interior attachments, electrical safety, fuel storage, emergency lighting, and other matters.

Other requirements are set out in 49 CFR Part 221 (Rear End Marking Devices), 49 CFR Part 223 (Safety Glazing Standards) and 49 CFR Part 229 (Locomotive Safety Standards). They establish lighting conspicuity and other vehicle requirements. Since deviations will be scrutinized by the FRA, they should be limited to significant components or structural elements where feasibility, cost, or performance is negatively impacted. Noncompliance will have to be explained, and justified from a safety perspective.

2) Crash Energy Management (CEM)

While an FRA-compliant rigid car body can withstand a high impact force, if it has no means to absorb and dissipate collision energy, the impact on the occupants will be higher. Crash energy absorbing devices can provide a measure of protection to the train and most importantly to the passengers because the equipment is designed to control the rate, location, and extent of gross car body crush and thereby lower the deceleration forces experienced by the train occupants during a collision. This CEM approach has been exhibited recently by FRA demonstrations at Pueblo, CO, and also by the Safetrain project in Europe. The benefits of CEM can be envisioned by comparing falling on an ice rink to the experience of falling on grass.

Energy absorbing devices serve better than a FRA-compliant rigid structure to cushion the passengers inside the train from bearing the full impact force of a collision. This phenomenon has been noted in a number of National Transportation Safety Board (NTSB) Railroad Accident Reports.

Another method of protecting commuters is to provide a large volume unoccupied by riders as a sacrificial zone in the rail car, or multiple strategically placed voids to absorb crash energy. A disadvantage of this approach is that it impacts car capacity.

The majority of carbuilders now incorporate some sort of crash energy management features (as shown in Figure 4) on their multiple unit (MU), and LRV vehicles, aimed at mitigating hazards to train crew and passengers in the event of a collision. These devices fall into three primary categories. Each device is designed to absorb incrementally higher impact force loads,

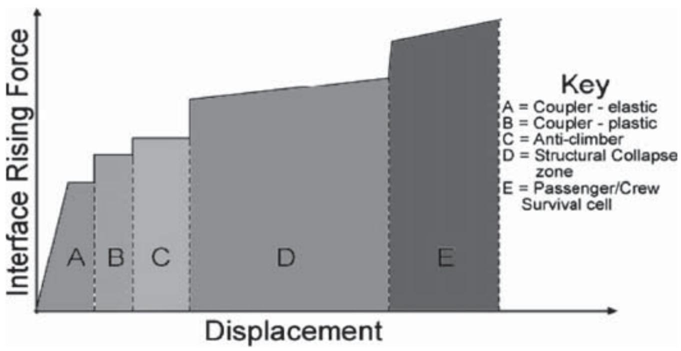

***Figure 4. Crash energy management** (typical controlled collapse under increased load).*

ranging from low energy impacts for the hydraulic devices, through moderate, to high impact forces, which will be borne by the vehicle structure.

- Hydraulic devices. Operate using hydraulic fluid as a means of absorbing impact force and are already in widespread use in the United States on many LRV and rapid transit vehicles. Low speed impact forces (at speeds up to approximately 5 mph) can be absorbed (Zone A).
- Energy absorbing elements. Typically consist of volumes filled with honeycomb type material that absorbs impact energy by deforming during impact at moderate speeds (usually 15–20 mph). Since many of today's vehicles are built with streamlined end caps, the volume present between the end cab structure and the front end of the car nose allows for considerable impact energy absorption and provides a small crush zone. In the event of deformation, the damaged elements will require replacement, but they are sacrificial components and afford more protection to occupants and vital components of the vehicle (Zones B & C).
- Deformable car structure. A design feature of European vehicles, these have end frames designed to collapse in a controlled manner and absorb any force left over after the hydraulic and crushable devices have been exhausted. The collapsible frame members typically come into play only during higher speed collisions (above 15–20 mph), and are designed to protect the driver's cab and passenger compartment in the event of a collision. Such an impact will of course result in more extensive damage and generate the need for substantial repairs, but the objective is to offer a higher level of protection to the passengers and crew, and to limit the propagation of the collision effects beyond the crush zone (Zones D & E).

3) Propulsion System

DMU vehicles are powered by a diesel engine and come in three basic propulsion configurations: diesel-hydraulic, diesel-mechanical and diesel-electric, sometimes also referred to as a DEMU vehicle. Diesel-hydraulic vehicles use a hydraulic transfer case to power the train axles directly from the propulsion engine and diesel-mechanical use a mechanical transfer case, although currently the hydraulic transmission is the preferred of the two. Examples of these types of vehicles include the Colorado Railcar DMU and the Siemens Desiro DMU. Diesel-electric systems, however, first use a diesel driven generator to produce electrical power and then use this electrical power to run electrical motors to power the vehicle (similar to a conventional locomotive). The Stadler GTW, Bombardier AGC, and Voyager all use Diesel-Electric propulsion.

Diesel-hydraulic propulsion equipment generally costs less, requires less space, and is easier to maintain than diesel-electric. A diesel-powered car with an electric or hydraulic propulsion system will be the most probable system. This vehicle class is likely to accelerate far more quickly than a conventional locomotive hauled commuter rail train, a distinct benefit where track capacity is constrained.

4) Superior Car Braking Performance

As mentioned above, and depending on material, construction techniques, and other structural requirements, light passenger rail cars (defined as non-FRA-compliant DMUs and EMUs) tend to be considerably lighter than rolling stock that complies with FRA buff strength requirements. Most are equipped with three types of braking systems; friction (either disc or tread or both), dynamic braking (this also can provide regenerative capabilities), and track brakes. Brakes can be actuated by air, hydraulic fluid, spring, or magnetic energy.

Because light passenger rail car vehicles weigh less, their stopping performance using only disc brakes can be considerably better than that of an FRA-compliant design. But many modern light passenger rail cars also are equipped with additional track braking systems that provide increased stopping force in emergency situations and are much more resistant to reduced rail adhesion. The deceleration performance of track brakes can exceed 5 MPHPS and can stop a rail car going 30 MPH in approximately 130 feet (e.g., the Stadler GTW 2/6 vehicle). Track brakes are normally activated at relatively low speeds. However, because they are so effective the deceleration rate can be hazardous to passengers, and use should be limited to emergencies or on cars moving at very low speeds.

Other operational benefits for shared use accrue from improved braking:

A) Redundancy. A relatively high deceleration rate can be maintained in the event of failure of a single brake or system, compared with a conventional commuter rail vehicle. Furthermore the track brakes are a robust and extremely reliable fail-safe design that provides significantly increased braking force.
B) Improved signal design. Traditional signal system design parameters incorporate safety factors for loss of braking efficiency. The dependably high deceleration rate and overall system reliability found on these LRV vehicles may offer engineers more design latitude to design a train control system more suitable for passenger service, when compared to traditional rail vehicles.

5) Other Considerations

A number of other vehicle-related factors need to be addressed in a shared operation.

- Coupler height disparity between FRA-compliant equipment and typical light passenger rail cars. Because of the relative difference in heights of buffing components at the end of each type of vehicle, the potential for vehicle override is increased, thus defeating the buffing mechanisms. This disparity argues strongly for fail-safe train control. Some light passenger rail cars can move their couplers to a safer position to protect pedestrians, but this is not possible with typical railroad couplers.
- Rail/wheel profile, which affects durability, noise, tendency to derail, and maintenance costs. The AAR wheel profile is standard for all rolling stock operated on the nation's general system of rail transportation. It is vital that any light rail vehicle introduced into a shared track operation conform to the AAR wheel profile.
- Shunting enhancement devices produce a magnetic field beneath the car that effectively acts as a shunt between the two rails to produce a block occupancy signal independent of any track or wheel conditions associated with standard rail shunting.
- Grade crossing collisions are a major concern for rail operations where grade crossings are present. Consequently warning system technology and mitigation techniques properly receive emphasis regardless of the type of rolling stock traversing the rail corridor. Reduced buff strength of light passenger rail cars may affect their survivability in a crash with a large highway vehicle (truck or bus). However, their high deceleration rate offers a greater possibility of avoiding the collision in the first place or reducing impact speeds; and the energy absorbing features will mitigate collision impact with a large vehicle. Their length and higher acceleration

reduces time spent blocking a highway crossing, which reduces driver impatience. To reiterate, the incidence and risk of a grade crossing collision is independent of shared-track operations, and is a hazard for all rail movements at a grade crossing.

- **EPA emissions compliance** is met by most new diesel propulsion units configured to conform to the latest EPA emission requirements.

Vehicle Cost Drivers

In any system, vehicles are a significant capital cost element and a major operating and maintenance expense throughout their life cycle. Research indicates that the car body is the most expensive element (average 28%), and the propulsion system is next (average 22%) in the magnitude of vehicle costs. Regulators tend to prefer more structural mass. The incremental cost of adding more material may not be all that significant based on the proportions above, but adding more weight to the car body negatively impacts propulsion system design and performance, requiring added braking capability and more robust trucks and suspension elements, in addition to increasing operating costs. A table showing vehicle cost drivers by percentage of total cost is in Appendix 6.

A vehicle procurement should budget additional funds of approximately 20% of the vehicle hard cost for associated soft costs (for example warranty, field support, training, tools, spare parts). Spare parts and special tools combine for 7% of overall vehicle procurement cost. Standardization of vehicles, components, and manufacture and assembly methods provides an opportunity to effect a noticeable savings and puts downward pressure on these soft costs, as well. Appendix 5 provides tables of the relative average cost contribution of various components, systems and soft costs.

Train controls average only 3% of the total cost of the vehicle (the bulk of train control costs resides in infrastructure elements), so for a relatively small expense, adding mass to the vehicle structure may be avoidable. Train control features may be more compatible with the regulatory goal of fail-safe train separation.

Not surprisingly, a second significant factor that affects cost is quantity. The unit procurement cost goes down as quantities go up. A recent survey for the Toronto Transit Commission (TTC) lists unit prices of rail passenger vehicles (subway type cars) and compares them to the quantity purchased.

- Car orders between 100 to 150 vehicles ranged between $2.2 to $2.5 million per unit
- Car orders exceeding 200 vehicles ranged between $1.7 and $2.2 million per unit

The same study listed benchmark prices of $2.3 million for new electric multiple unit type vehicles and $2.5 million for new diesel multiple unit vehicles. In contrast, recent acquisitions of shared-track vehicles have cost approximately $4.0 million per vehicle for very small orders.

The data reflect acquisitions by different agencies, and varying technical requirements. The lack of a standard light passenger rail car contributes to higher costs. If each system specifies a different car or selects unique systems and components, controlling costs incurred by a single agency becomes more difficult. The result is that an individual agency bears the front-end and startup costs, rather than spreading them out over a larger number of vehicles. Joint procurement and piggy-backing orders can address this issue.

Vehicles for Shared-Track Applications

Full compliance with FRA requirements for passenger equipment is unlikely. However, to offset their structural limitations, vehicles for shared-track generally have improved braking rates and energy absorption devices and operate at lower speeds than traditional FRA-compliant passenger equipment. These features provide a higher degree of safety for their operations. Their performance and design characteristics provide an advantage at grade crossings (the number one location for accidents on commuter rail lines), not only to avoid many such collisions, but also to reduce hazards that result from collisions. Such factors should be considered in addition to train control systems and operating procedures when approval for shared-track operations is requested.

In many cases, one of the DMU types will be the most appropriate vehicle choice, as low floor diesel powered vehicles are more easily adaptable to route changes, extensions, and pilot programs than LRVs that require a wayside power source (e.g., OHC).

Ultimately, the vehicle ought to be considered one part of an integrated system of safety that relies on crashworthiness, train control, communications, training, and R&P. The rail car component of this system should not be burdened unduly to mitigate all hazards.

1) Selecting the Optimal Vehicle

Selecting a heavy or light EMU/DMU or LRV (light passenger rail cars) vehicle is primarily based on operating speed and propulsion system assumptions. Additional influences on vehicle selection and design include:

- Operating environment (railroad, on-street, grade separated or reserved ROW);
- Clearances (primarily width and height); car static and dynamic envelope;
- Platform interfaces;
- Weight restrictions;
- Future flexibility for service changes; and
- Wheel tread and flange profile.

A suitable vehicle will likely operate across multiple environments in normal service. Where multiple types of right-of-way are used, operating restrictions, weight, turning radii, and clearances on any part of the line influence the technical specifications of rail vehicles.

2) Regulatory Approach

Currently FRA's policy considers commingled operations adequate when accompanied by a positive train separation system. The FRA may consider modifying regulations for such applications. For example, future regulations might offset structural strength requirements with collision energy management design. Regulations could be altered further to describe certain key operating and vehicle design characteristics more suitable for shared-track (e.g., specify freight speeds, minimum track centers, lateral clearances, train control system, energy absorbing features, deceleration rates), effectively creating a new tier of vehicles. Defining certain minimum performance characteristics and features would simplify the FRA's process of evaluating each vehicle and waiver petition.

3) Standardization

If a standard light passenger rail car model could use modular components and systems to allow limited unique system modifications (e.g., to the capacity of an HVAC system) and alternate suppliers, such a model effectively could reduce capital and maintenance costs for all operating agencies.

An economic benefit of standardized vehicle designs is the resulting cost savings. While each rail car is different, this distribution of proportional costs is useful for planning or budgeting purposes. The data also emphasize three other benefits of standardized designs, car bodies, and systems.

1. Regulatory review process is eased because the FRA does not have to initiate a fresh review for each new light passenger rail car waiver petition. Standardization also results in more accumulated service history with a specific vehicle model. Although the latter is a noneconomic benefit, it may enhance the appeal of the concept.

2. There is a commonality of maintenance practices, training, documentation, and tooling across multiple users similar to the aviation industry.
3. Standardization contributes to lower vendor prices by creating a larger market, a more constant level of production, and potential for competition.

Recommended Vehicle Research

The FRA considers the structural capabilities of light passenger rail cars to be the primary deficiency with respect to shared-track operations. Additional research and analysis may alleviate some of their concerns by providing more technical data to support regulatory evaluations and improve project vehicle design decisions. High value topics that merit further investigation include:

1. Typical braking systems used on light passenger rail car equipment are not incorporated into rolling stock otherwise manufactured for use in the nation's general rail transportation system. Accordingly, including a detailed explanation of the performance and reliability of track brakes or hydraulically actuated brakes in a waiver petition would enable the FRA to make a more informed decision. These data should include various comparisons of test results with multiple brake systems fully functional and tests with one or more of the systems cut out or malfunctioning.

   Test results then can be compared to similar data for conventional freight and commuter rail equipment to justify a signal design more appropriate for a shared-track operation. The data could also support a waiver petition for relief from provisions of 49 CFR Part 236 and contribute to the safety case.
2. Support/encourage computer simulation of structural failures caused by various accident and impact scenarios. Even better would be results of a real-world test between a light passenger rail car and a freight car or locomotive. Presently this has been performed for conventional freight and commuter rail equipment and is contributing to improved CEM designs for passenger rail cars.

   There is a need for a similar exercise using light passenger rail cars to verify or improve CEM designs. Such a research program would quantify effects of low and high-speed impacts on the car body and interior, and identify the secondary collision effects on passengers. Computer analysis and test results would help validate a risk assessment and support a safety case.

Applying Technology to Shared-Track Operations—A Brief Guide

Transportation planners and specialists should be familiar with train control systems and appreciate their impacts on safety, operations (both freight and passenger), and capital and operating costs. These systems are a significant contributor to a favorable outcome of an FRA Waiver Petition process and thus affect project viability. Local officials and transit agencies that consider a shared-track project are advised to give the selection of a train control system top priority.

1. Command and Control (C&C) encompasses the train control system, communications network, and R&P. C&C provides and enforces movement authority for all rail traffic and is intended to emphasize safety via collision avoidance rather than depending upon vehicle crashworthiness. The system capabilities, relative costs, and performance features help to drive the choices of technology. These selections have a pervasive impact on:
   - Risk assessment and by extension the waiver petition;
   - Costs—capital, operations, and maintenance; and
   - Operational capabilities and limitations of both the freight and passenger services.

2. A range of technology from conventional through advanced systems can be considered, and risk reduction is available from both traditional and leading edge technology. Appendix 4 provides relative cost comparisons of various train control systems for planning purposes.
3. Effective and reliable communication between freight carriers and passenger operators is relatively easily provided using conventional technology, without incurring excessive or disproportionate costs.
4. Despite the C&C safety features, the FRA also will scrutinize the vehicle data for crashworthiness capabilities and other regulatory features. Near compliance to the extent possible should include:
   - Structural elements and features that manage crash energy and afford some protection for passengers in the secondary collision (passengers impacting elements of the car interior) that would follow an impact;
   - Lights and markers that look like a rail vehicle to highway vehicle operators at grade crossings;
   - Window glazing on passenger railcars (both forward ends of bidirectional railcars, side windows).

Control of movement authority is the key to safety and regulatory compliance. C&C and vehicle choices can enhance the safety case, which in turn is presented in the FRA waiver petition.

CHAPTER 4

Shared-Track: A Handbook of Examples and Applications

A transit agency making the choice to pursue a shared-track system will be able to provide service to a greater passenger base. As a starting point all shared-track projects require a willing freight partner. The tool-kit presented here is designed to create a map for the practitioner to navigate the steps to accomplish this goal more quickly and easily than might be otherwise possible:

1. Transit agencies that have already studied potential shared track operation provide a baseline of experience and lessons that can be used in the future for exploration of possible options. Some jurisdictions are exploring ways to allow a limited number of freight trains to operate during passenger service off-peak hours. These experiences are recounted here in Chapter 4.
2. The business case template section starts with a review of the costs and benefits of shared-track compared to other alternatives and lays out the analytical steps. What are the trade-offs between the shared-track alternative and other investments that could equally service mass-transit needs? For each of the alternatives, a detailed cost analysis is required. The worksheets provided here allow entry of data collected into eight broad categories of costs.
3. A template for risk analysis and its application to the safety case is described. Conclusions derived from the business and safety case templates are presented.
4. Another portion is devoted to shared-track transit systems in San Diego and Southern New Jersey as illustrations of what works, incremental progress, and an American approach to shared-track transit operations.
5. Specific guidelines that increase the likelihood of implementation success.

Shared-Track Operations—The North American Experience

The team was tasked to inventory North American agencies with planned or existing shared-track programs. No domestic entity runs a truly contemporaneous operation. Because of restrictions imposed by existing regulations, most of these are near shared-track operations. Nevertheless, results of their experience and lessons learned can be transferred to future projects. While their diverse operations and situations also offer a range of experience, a review of the results reveals common traits and challenges facing transit systems planning or operating service where light transit equipment shares track with conventional railroad trains. An extensive review of findings can be found in the report prepared for Task 5. Appendix 8 provides a status summary and operating characteristics of 20 systems: those currently operating (7 systems), in final design (1 system), environmental impact study (5 systems), feasibility study (2 systems), and those that chose to avoid commingled operation (5 systems).

1) Public Ownership and Control

The transit authority typically purchases the service line, makes infrastructure improvements necessary for higher speed/higher frequency passenger operation, and then provides freight access to the satisfaction of the former owner of the line. The transfer of ownership and control appears to offer tangible benefits to both the transit operators and the freight railroad. These common arrangements demonstrate the appeal of shared-track to shortline railroad operators. Of advantage to the railroads is that infrastructure costs and primary risk gets shifted to the transit operators.

A. Infrastructure investment. New rail transit operations usually require substantial upgrades to the former freight-only branch line to raise operating speeds, improve ride quality, increase capacity by adding second tracks and sidings, and building stations and transit car yards. Public investment in infrastructure is protected and facilitated if the underlying corridor is transferred to public ownership and control. All but two of the eight systems in current operation (or in final design) entail public ownership, control, and maintenance of the shared track infrastructure. Five of the 12 systems in various stages of planning have identified the need for public ownership or control of the shared track infrastructure (see Appendix 8, "Shared-Track System Status").

B. High density light passenger rail vehicle operations. All operational and most planned shared-track operations feature much higher densities of light rail transit trains than conventional railway train. The daily ratio of light passenger trains to conventional trains is at least thirty to one, as shown in Table 6. At these relative traffic densities, it seems obvious that the passenger service should own and control the shared line. This finding underscores the observation that the U.S. shared-track challenge (at this time) is not really about the operation of noncompliant railcars on the conventional railroad system, but instead should be considered as the operation of low-density freight operations on urban transit tracks. By contrast the most celebrated aspects of the Karlsruhe model demonstrate that on one line the vast majority of trains use conventional equipment.

2) Former Private Freight Railroad Owner Becomes a Privileged Tenant

When the shared-track system is in planning and development, the freight railroad owning the critical right-of-way is in a powerful position to negotiate. While the nature of the shared-

Table 6. Daily passenger to freight train count ratios.

System	Status	Passenger: Freight Ratio
San Diego	Operating	74:1
Salt Lake City	Operating	79:1
Trenton-Camden	Operating	23:1
Oceanside Escondido	Operating	32:1
Atlanta	EIS	75:1
Madison *	EIS	13:1*
Austin *	Engineering	2.4:1*

Note: Austin and Madison are considered exceptions. Both are planning to operate a commuter-rail style service. Madison is planning hourly headways in the off-peak; Austin is planning to run peak hour services only, due to substantial (and increasing) freight volumes on the publicly-owned line.

track operation generally requires the freight railroad to relinquish dispatching and maintenance control, the participation of freight rail owners gives freight interests a strong voice in determining when freight service will take precedence. Some freight service schedule adjustments may be necessary, but it is the transit authority that must attempt to accommodate the freight carrier's needs, or else risk having the process stalled. This possibility arises from the FRA requirement that conditional approval of any waiver petition requires the agreement of the prospective freight tenant.

In several instances the transit system design shifted to require compliant vehicles to satisfy the service needs of the freight railroad, while avoiding conflict with federal regulations. In most cases, the compromise to use compliant equipment degraded the attractiveness of the transit service to the public agency and its customers.

As a tenant of the transit system, the freight operator enjoys the use of a substantially upgraded facility while it is simultaneously relieved of the burden of maintaining and operating its former freight-only line.

3) Risks Are Managed by the Transit Agency

Risk management and insurance are part of the general administration of the shared-track operator. Transit insurance packages generally cover all operations or all rail operations. For the systems reviewed, there are no instances where separate liability insurance is provided for shared-track, nor are there any where the freight railroad is required to carry liability insurance for the passenger operation. However, private owners of freight lines are generally concerned about the liability implications of introducing transit passenger operations on their freight-only line. Therefore, the transit agency usually insures freight carriers against increased liability risks due to the presence of passengers. In fact, two agencies (San Diego and NJ Transit) are self-insured. It appears that if ownership, control, and maintenance of the shared-track line pass to the passenger operator, the freight carrier may be better shielded from liability for accidents and injuries along the line.

A. Agency liability is covered by existing agency insurance. In six out of eight currently operational or soon-to-be operational systems, the risk of accident and injury claims is managed through an agencywide contract covering all aspects of the agency's operations. San Diego MTS's insurance covers bus, trolley, and rail operations. San Diego NCTD's agreement covers the proposed noncompliant service, as well as existing commuter rail and express bus service. New Jersey Transit's (NJT) contract covers all aspects of NJT's operations. Both San Diego and NJ Transit systems are self-insured. Maryland MTA's policy covers both its light rail and subway operations.
B. Transit agency insures against the perceived increased risks for freight operation. Despite research that shows the risks are minimal, many freight operators require extra indemnity against transit accidents. On the River LINE, NJ Transit pays Conrail explicitly for an increase in Conrail's insurance fees due to the existence of a passenger operation on the Bordentown Secondary. On the San Diego Trolley, the agency names the freight operator as an insured party in their policy. On the San Diego NCTD, the agency is assigned most of the liability for mishaps, even when the freight operator is found to be negligent. The risk of the freight-passenger collisions is thus essentially insured through the agency's policy.

4) Pressure to Commingle Is Heaviest on Lines with Higher Freight Densities*—A Review of Different Solutions

Where the route has strategic value as both a freight and transit corridor, and/or where the freight train service density is more than one roundtrip per day, there is likely to be greater pressure to commingle transit and freight trains.

A. NJ Transit River LINE. Although 19,440 freight carloads move over the line per year (average of 78 carloads per day based on annual non-holiday weekdays), Conrail was concerned about the need to divert trains on to the line in the event of a blockage. NJT was planning to operate passenger service later into the night, with the last trains running until 1 AM, instead of the current 10 PM. The 16/8 hour split between passenger and freight operations satisfied neither NJT nor Conrail. NJT is preparing to request a waiver allowing freight and passenger trains to share a 3,000 ft. single-track segment providing access to Pavonia Yard and would make signaling improvements to provide the safety equivalent to the procedures permitted on the Newark City Subway's shared-track segment.
B. San Diego Trolley. Because of the length of the shared segment and increasing traffic, freight trains require more than the four hours of exclusive freight operations allotted to them. The 20-hour passenger period required by SDTI has contributed to the urgent need to obtain special waivers to allow limited nighttime joint operation.
C. NJ Transit Northern Branch. Here, the freight operational patterns placed the onus on public officials to develop a strategy for commingling. As a result, compliant DMU rail vehicles are being considered (as opposed to noncompliant electric light rail trains) to permit flexible freight operations. This proposed change in the vehicle mode will result in less passenger convenience, requiring an additional transfer at the North Bergen Station, instead of a one-seat ride on a through route via connection to the existing HBLR service.
D. NJ Transit Newark City Subway.* Freight density is not significant on this line. In this case the freight line that serves one customer about once a week was ideally located for a service extension, hence the desire to share track. The shared section of track was sufficiently short to permit the entire segment to be designated as one interlocking. Specialized signaling equipment fulfills the fail-safe train separation requirement while allowing freight trains to operate between light rail trains, under the supervision of the Transit Authority.
E. Austin, Texas Commuter Rail. Transit service may be suspended mid-day to allow freight services to operate. Overnight freight operations are not acceptable to the communities along the line. While viable, this approach limits operational flexibility, passenger convenience, and growth potential.

5) Public Transit Agencies Are Interested in Avoiding Shared-Track Arrangements

In some cases, especially where the freight line is not currently active, transit agencies have expressed a desire to disallow freight operations as part of a line sale agreement. Transit oriented developers tend to see a freight operation or the future possibility of a freight operation as an impediment to successful property redevelopment.

A. MARTA Belt Line. The lone customer (an urban sand and gravel plant) on the potential shared-track freight line is under pressure to relocate due to transit oriented development considerations.
B. BART State Route 4. Although the freight line is currently in disuse, the railroad continues to seek an easement for development of future freight services along that corridor. However, the transit agency has expressed a desire to avoid the possible future restoration of freight service, since such easement may ultimately affect the vehicle technology and development options available for the corridor.

6) Transit Operators Choosing to Avoid Commingling Sacrificed Service Quality and Efficiency

Designers of all systems choosing to avoid commingling initially considered the use of noncompliant equipment. Planners of three systems (Orlando, FL, northern NJ, and Oakland-

Antioch, CA) wanted to operate noncompliant vehicles to allow for interoperability with existing systems. Promoters in two cities (Raleigh-Durham, NC and Portland, OR) desired a trolley-style service that they claimed would provide better service to the downtown areas. Madison ruled out using noncompliant vehicles at the Draft EIS stage, but the business case for commingling is so compelling that the question has been reopened at the Final EIS stage. Austin is planning for noncompliant vehicles in anticipation of a future expansion option that involves street-running. The decisions made by the five agencies to proceed with compliant vehicles generally degraded the transit service quality and efficiency for their systems as initially designed and/or increased the cost of development.

The foremost reason for commingling (or sharing track) is interoperability in areas that could not otherwise justify, or do not have, space for separate alignments for two different vehicle types. A compliant vehicle capable of in-street operations that could negotiate the constrained geometry of a street-car network has yet to be designed. None of the U.S. systems surveyed replaced an existing conventional passenger rail service with a light rail vehicle to reduce costs or improve service. In the case of foreign shared-track operations, the focus has been on improving service quality by avoiding a transfer at the railroad/transit boundaries.

Business Case Template

The hypothetical business case presented identifies basic principles and traces a process for developing a transportation concept using light passenger rail cars in a concurrent operation with an existing freight operation. Using steps outlined here, planners can create a template to commence a project. The following example shows the application of the template and uses realistic values and quantities derived from databases or actual operations (a more detailed analysis is provided in the Task 10 Report, "Hypothetical Case Study").

Preparatory steps for a demonstration project were outlined in Chapter 2 (and detailed in the report for Task 11). With some emendations they serve as an introduction to a business case tool kit, and have the merit of being familiar ground to most transportation practitioners.

- The project is the locally preferred alternative under federal and state planning regulations.
- The sponsor agency has the technical competence and know-how to implement a shared-track project.
- The selected corridor will generate sufficient ridership and economic benefits to deliver the cost-effectiveness goals.
- The project delivery team has the required discipline to manage potential issues, especially regulatory and safety issues, and contain costs.
- The proposal has wide public support, particularly from riders, abutters, local government, and the freight operator.

These five points listed acknowledge the unique environment or localness within which each agency exists. Evolution of any project will reflect the special needs and requirements of each undertaking and will undoubtedly require variations in following the recommendations contained in this section. A second imperative is to understand the significance the FRA plays in its regulatory capacity since it will be the final judge of whether a particular shared-track operation is safe to operate. Therefore, one of the more significant determinations to be made is the risk and safety analysis.

Appendix 9: Shared-Track Configuration and Operational Alternatives, provides much of the following information in a tabular format that includes many of the qualitative considerations for each of the most likely alternatives.

Alternatives Analysis

While the focus of the research is shared use of track (i.e., concurrent operations by light passenger rail cars and freight equipment), the nonconcurrent alternatives must be analyzed. Therefore, a component of the business case is completion of an "Alternatives Analysis that Accompanies a Major Investment Study" (MIS) and as a justification for the choice of shared-track. The MIS will evaluate the costs and benefits of shared-track compared to other alternatives, in order to reflect trade-offs between the shared-track and other investment options that could equally serve mass-transit needs. At a planning level, four distinct types of alternatives can be compared.

- **Nonrail alternative:** Likely scenarios range from the status quo to nonrail investments including carpooling facilities, bus route rationalization, transit priority lanes, or bus rapid transit investments. The FTA often requires a null alternative in the application process for federal funding.
- **Separate System alternative** requires construction of dedicated track for non-compliant rail vehicles. The service uses a new right-of-way, shares a right-of-way (but not track) with conventional trains, or uses the median of a highway.
- **Compliant Vehicle alternative** would establish commuter rail service on a railroad using FRA-compliant rolling stock. Modernization of signal systems and infrastructure, and new passenger facilities are required. Compliant equipment can share track without restrictions. However, high platforms could cause clearance issues for freight equipment and potential ADA (Americans with Disabilities Act) compliance issues. Downtown street running also may be precluded.
- **Shared-track alternative** entails seeking special regulatory approval to allow light rail vehicles to share track with conventional railway equipment. The infrastructure requirement can be similar to the compliant alternative, but the resulting service would be more flexible. Light rail passenger vehicles can continue off the railway alignment onto city streets. Low floor light rail passenger vehicles also avoid conflicts between freight and passenger operations, whereas high floor cars (and platforms) pose a new clearance constraint for freight operations.

Costs for developing a transit service should be compared for the different operating regimes under consideration. The cost and investigation of those alternatives are outside the scope of this research, but planners should be acquainted with the analytical effort.

For each operating regime the required plant, equipment, and operating plan must be described. This business case study template guides the analysis and development of capital and operating cost estimates based on physical characteristics. Subsequently, a risk analysis is necessary to show that safety requirements can be achieved for each alternative.

Data collection for the cost analysis falls under a number of categories.

- Physical characteristics of the existing and proposed corridor.
- Planned service characteristics of the rail transit service.
- Operating plan and structures.
- Service comparison of different operations.
- Cost analysis for signal system alternatives.
- System capital cost assessment.
- Ridership impacts.
- Alternatives evaluation-ridership and cost estimates are used as output measures.
- Risk analyses & modeling; model inputs.

Each of these topics is described in some detail. Worksheet templates can be used to record the results.

Physical Characteristics

Data collection begins with a description of the physical characteristics of the existing and proposed new corridor. This includes length, grades, curves, grade crossings, bridges and tunnels, sidings, crossovers, terminals, stations, facilities and other salient features. Table 7 shows a sample checklist:

Freight Operations: Describe the time of day, number of pickups and deliveries, any special handling requirements, length of any sidings, crews, and number of cars.

Rail Transit Service: Describe the planned service characteristics, routing and stations in broad terms, and the responsible entity for directing the project.

Vehicle Design: Identify vehicle options on the basis of performance, capacity, and other desired features. The available choices at the outset are:

1. Push-Pull Commuter Rail Equipment (compliant locomotive and coaches);
2. MU Commuter Rail Equipment (compliant MU coaches either diesel or electric); and
3. Diesel or electric noncompliant light passenger rail cars.

Reasons to Consider Noncompliant Equipment

The underlying assumption for this research is that FRA compliant equipment is either impractical or unnecessary and only noncompliant equipment will suffice. The primary reason to consider noncompliant equipment is the improved flexibility it offers. Because of the vehicle's physical characteristics, more routing options are possible. The constraints in curvature radius, grades, clearance envelopes, limits of acceleration, and deceleration make a lighter rail vehicle a superior choice for various environments. The following analysis explores the relative pros and cons of a temporally separated, a concurrent shared-track, and a shared-corridor light rail operation.

Such an analysis should resolve whether or not a compliant vehicle is suitable for the application. Once it is determined that only noncompliant equipment will suffice, then the next step is an analysis of shared-track options.

A typical example of choice 3 is a self-propelled rail car (SPRC), a passenger rail car with a self-contained, on-board source of motive power, making reliance on a locomotive or electric power distribution system unnecessary. The light SPRC is more flexible than a locomotive hauled train or an electric light rail passenger vehicle because it provides an economic means to operate passenger rail service over a mix of railroad environments. As one illustration (Figure 5), an SPRC

Table 7. Worksheet 1—System parameters existing condition.

Route Miles	
FRA Track Class	Class I
Signal System	Dark (Unsignaled)
Connection to Freight Tracks	Identify by milepost and type of connection, e.g., crossing, siding
Major Structures	Identify type, length and milepost
Grade Crossings	Identify milepost and type of warning system
Speed Limits	10 mph for freight trains Passenger trains are not permitted
Freight Operations	Describe as "Freight train originates…" " Exchanges outbound for inbound cars at yard and returns to the point of origin…."
Freight Train	Describe equipment, number of cars, speeds, locomotive fleet, cargo types
Workforce	List engineers, conductors and crews called per weekday
Rule Book	Northeast Operating Rules Advisory Committee (NORAC) Rules or whatever rule book applies

Figure 5. NJ Transit DMU Street running in Camden, NJ.

can use a radial mainline railway for line-haul transport from the suburbs, and then continue or switch to local street-running tracks to serve the downtown destinations, and other routing options are possible.

Historically nearly all SPRCs have used on-board diesel engines for power, and have been capable of operation as a train with a single train or with multiple cars. SPRCs are commonly called DMUs.

Additional economic advantages of concurrent track sharing can be realized if:

- There is an identified need to integrate transit service in a shared-track corridor with an existing light rail system;
- Street running is necessary to access downtown districts and serve dispersed demands within a larger city; emergency stopping distances are more compatible with street running;
- There are community concerns about the noise, vibration, and visual impact of large commuter rail vehicles; and
- The selected rail car whether LRV and SPRC is able to perform express, line-speed line-haul functions on railroad tracks, and local multi-stop distribution functions on embedded street tracks with mixed vehicular traffic.

Service Characteristics to Justify the Choice of a Light Rail System

Concurrent shared-track with light rail and conventional railroad vehicles is typically considered a fall-back option after it has been determined that the service requirements cannot be satisfied with FRA compliant passenger vehicles or a separate light rail system. It may then become necessary to conduct a feasibility study. If such a study concludes that a light rail system is the only viable alternative to satisfy local transit needs, then a shared-track project may be justifiable. The research for such a study should address four elements.

1. The travel forecasts. The rail transit should reach downtown to serve its primary market.
2. The pattern of development in downtown necessitates a street running transit service with stops at dispersed demand generators. In downtown, transit service also should support redevelopment objectives by improving mobility within the core.
3. The possibility of constructing a commuter railroad is an option that should be explored although such an alternative may be fraught with difficulties, high costs, and considered infeasible.
   a. All current FRA-compliant equipment is 85' long and has a minimum turning radius of 12 degrees (approximately 145 m or 480 feet radius). Constructing a suitable alignment at grade would necessitate substantial encroachment to traffic or land uses adjacent or proximate to the right-of-way, and may represent an unacceptable level of interference and disturbance to the local environment.

b. The lower acceleration and braking rates of compliant DMUs are not conducive to the frequent stops required for an effective downtown service design. This equipment also is unsuited to an operation that may require traffic light stops.
c. The residents of downtown are concerned about the noise and vibration generated by a compliant commuter rail car operating in the street. A lighter rail car with a smaller diesel engine would generate substantially less noise (comparable to common motor vehicle or bus).
d. The option to construct a new grade-separated railroad to reach the downtown was not considered due to its high expense and inability to serve multiple stops within the city.

4. Two other alternatives are to consider terminating a commuter rail service at a main station and serving the dispersed demands of downtown via a transfer; or to provide two-seat-rides. Two typical scenarios for the latter are:
   a. Hourly commuter rail service with bus connection. This is an economical option with much potential, requiring one push-pull trainset and a fleet of buses;
   b. Quarter-hourly commuter rail service with light rail connection. An option entailing high capital and operating costs compared to a shared-track option. Separate vehicle fleets and facilities are required for the street running and railroad portions of the routes respectively. The transfer penalty of five minutes represents an increase of 20% to 45% in journey time. A ridership decrease may result. A sample analysis worksheet is shown in Table 8.

Overview of Shared-Track Options—Operating Plan

Prepare a summary review of typical and most likely alternative operating regimes that would share track or ROW with a freight operator. The four listed cover the broadest range of choices. Other permutations are possible, perhaps modifying or combining aspects of the four shown below. For each operating regime, a different service plan, infrastructure, physical plant, and train control system is required. This approach can be tailored to site-specific circumstances. Table 9 summarizes the important systemic differences between the operating plans and the associated infrastructure, physical plant and systems for the four options.

Structures Considerations

If there are major structures on the route, then these structures must be inspected and rated for passenger service. In some scenarios, the structures must be expanded, replaced, or new structures erected. Structures affected could be none, some, or all of the following:

- Overbridges and overpasses;
- Elevated sections or viaducts;
- Grade separations;
- Shared ROW and retaining walls with highways; and
- Bridges over rivers or bodies of water.

Typical structural changes should be identified and recorded on a worksheet similar to Table 10.

Table 8. Worksheet 2—Ridership impacts of forced transfer.

Suburban Originating Station	Time to Downtown (Minutes)	Increase in Travel Time	Inbound Boardings		Outbound Disembarkations		Total Ridership Losses
			Direct Service	Forced Transfer	Direct Service	Forced Transfer	
Total							

Table 9. Worksheet 3—Sample operating plan infrastructure requirements.

Option	1	2	3	4
Operating Regime	**Strict Temporal Separation**	**Shared-Corridor Spatial Separation**	**Concurrent Single Track Operation**	**Concurrent Double Track Operation**
Station Platforms				
Grade Crossings				
Turnouts		Passenger Freight		
Diamonds				
Signal System	CTC	ATS	Cab signal	Cab signal
Onboard Cab Signal Device:				
Passenger Trains	None	ATS	Cab signal	Cab signal
Freight Trains	None	None	Cab signal	Cab signal
Special Signal System Features	"Mode Change" Control Software	Intrusion Detection		Intrusion Detection
Derails				

Service Comparison

Depending on the operating regime chosen, different service capabilities are possible. Option 1 is a Strict Temporal Separation Operation; Option 2 is Spatial Separation; Option 3 is Concurrent Single Track; and Option 4 is Concurrent Double Track. The parameters affected are: passenger service headways, hours of service, and freight blackout windows. The initial service design and maximum theoretical values under different operating regimes are summarized in Table 11. The values shown can be considered typical default scenarios, and should be modified to suit a particular situation.

Each option should be analyzed on the basis of its proposed

- Infrastructure;
- Passenger operations;
- Passenger distribution; and
- Freight operations.

Appendix 9 summarizes features, characteristics, and capabilities of each of the four alternatives. Information contained in that table is representative of the factors that should be considered in the analysis.

Cost and Ridership Analyses

An important part of any project study is collection, comparison and analysis of data describing capital and operating costs for traditional transit development and for shared-track alternatives.

Table 10. Worksheet 4—Disposition of major structures.

Option	1	2	3	4
Operating Regime	**Strict Temporal Separation**	**Shared Corridor Spatial Separation**	**Concurrent Single Track**	**Concurrent Double Track**
Overbridge				
Overpass				
Viaduct				
Grade Separation				
Shared ROW, Wall				
Bridge over water				

Table 11. Worksheet 5—Typical operating regime and corresponding service scenarios.

Option	1	2	3	4
Operating Regime	**Strict Temporal Separation**	**Spatial Separation**	**Concurrent Single Track**	**Concurrent Double Track**
Passenger Service Headways				
Initial: Peak Off-peak	 15 30	 15 30	 15 30	 15 30
Best Possible: Peak Off-peak	 15 15	 15 15	 15 30	 5 15
Maximum: Peak Off-peak	Headways shorter than every "X" min requires new sidings Headways shorter than every "Y" min requires double-tracking			Off-peak headways of less than "Z" min require dedicated freight sidings
Passenger Hours of Service				
Initial: First Train Out Last Train In	 6:00 am 7:30 pm	 5:00 am 1:30 am	 5:00 am 1:30 am	 5:00 am 1:30 am
Maximum: First Train Out Last Train In	 5:00 am 7:45 pm	24 hour service	24 hour service	24 hour service
Freight Operating Windows				
Initial	7:30 pm – 5:59 am	24 hour	9:00 am – 3:59 pm 7:00 pm – 5:59 am	9:00 am – 3:59 pm 7:00 pm – 5:59 am

X, Y and Z will vary to suit the circumstances.

The study should explore cost savings and other benefits to the community afforded by concurrent shared-track choices as transit development options are evaluated.

A bottom-up approach to costing is suggested. The transit system infrastructure and investment options should be broken down into components. The unit cost of each component can be calculated based on construction contracts, engineers' rules-of-thumb, and aggregate costs of labor and materials. To compute the unit cost of service delivery, take direct labor plus overhead using industry-average labor and overhead costs, and apportionment from known operating costs of comparable systems. Total cost is derived by summing component costs, then adding a percentage for indirect costs and contingencies.

Electric light rail projects proposed for FTA New Starts are typically more expensive than the sample system considered here. Additional costs such as real estate acquisition, planning and permitting, and electric traction infrastructure are not considered in this desktop analysis. Nonetheless, the analysis underscores the magnitude of savings available to local transportation officials who consider a shared track alternative.

Cost Analysis for Signal System Alternatives

Rough cost comparisons can be made between generic families of signal systems when applied to the same operation. There are a variety of available sources to arrive at an approximate per-mile cost estimate for systems similar to a proposed shared-track operation. Each basic train control regime should be considered:

- **Centralized traffic control (CTC) with wayside signals:** A basic, traditional CTC railroad signal system with remote controlled power interlockings, cables, track circuits, control center console, insulated joints, impedance bonds, wayside automatic signals with 2.5 miles on average between interlockings, typical of configurations under temporal separation.

- **Automated train stop** (intermittent, inductive implementation): Consists of a basic CTC signal system plus a two-aspect ATS system implemented as described in Option 2, based on block signaling principles. Freight train movement authorities are enforced by signal interlocked derails.
- **Multi-aspect inductive intermittent speed supervision:** A CTC signal system overlaid with a three-or-four-aspect Automatic Speed Control (ASC) system. Continuous supervision of train speeds is not provided, but trains are positively protected against signal overruns. It is sufficient for Options 3 and 4 if a suitable vehicle-borne apparatus can be installed on freight locomotives.
- **Automated speed control with enforced digital cab signals** (continuous, coded or audio frequency track circuit implementation): This technology is standard for modern light rail implementation. The system provides for continuous speed supervision based on cab signal aspects and may provide train-to-wayside data communication capabilities. Wayside signals are not installed except at interlockings. It is sufficient for Options 3 and 4.
- **Communication-based train control with speed enforcement:** This is an emerging technology for which no production examples have been fully implemented. Wayside signals are not installed except as backup. Systems adapted for Options 3 and 4 would have the same enforcement and display capabilities as a coded track-circuit system and would provide continuous supervision of speeds.

A summary of average cost per track-mile for these systems is presented in Table 12. As shown in the table, commercial-off-the-shelf train control systems are perfectly suitable and more appropriate for shared-track rather than advanced state-of-the-art technology.

A cursory examination of signal costs reveals that the two ASC options appear to cost between 25% and 100% more than the unprotected CTC options. Considering signal costs alone, both multi-aspect intermittent speed control and digital coded track-circuits with ASC capability seem to provide the necessary functionality at similar costs. The intermittent systems provide a cheaper per-signal cost but have a higher per-cab cost, whereas the coded track circuits require more expensive wayside infrastructure but the cab-borne equipment can be simpler and cheaper. Appendix 4 provides additional "Relative Cost of Train Control Systems" information.

Intermittent systems (Row 3 in Table 12) are used on some rapid-transit cab signal territories: on New York City Transit, the NJ Transit River LINE, and some legacy commuter rail and railroad lines in the Midwest. Both systems are proven and expertise to design and maintain both types of systems can readily be found in the United States The choice between these two families

Table 12. Range of unit costs for families of signal technology.

	Signaling Technology	Average Total System Cost per Track Mile ($ Million)	Cost per Signal or Block	Cost per Passenger Cab
1	Centralized Traffic Control	$1.6	$7,500 for wayside color light signals	None
2	Two-Aspect Automated Train Stop	$1.8	$7,500 for waysides + $6,000 per trip stop	$60,000
3	Multi-Aspect Inductive Intermittent Speed Supervision	$2.1 to $3.2	$7,500 for waysides + $10,500 to $15,000 per signal for transponders	$80,000 to $120,000
4	Automated Speed Control enforced with Digital Cab Signals	$1.9 to $3.0	No waysides $10,000 to $30,000 per "signal"	$50,000
5	Communication-Based Train Control	$2.1 to $5.0	No waysides Not signal based	More than $100,000

of ASC systems must be done on a case-by-case basis, factoring in such variables as number of interlockings, vehicles to be equipped, track miles, and what other systems are in use regionally for interoperability reasons.

Research emphasizes that it is preferable and less costly to use commercial-off-the-shelf systems and components rather than advanced state-of-the-art technology. Highly advanced train control systems are not justified by the service application or benefits.

System Capital Cost Assessment

Railroad capital construction costs are generally estimated in categories. An example of a costing methodology that can be used breaks the costs into six main categories.

- Roadbed, track, and special trackwork;
- Structures;
- Stations;
- Signals and communications;
- Engineering design, project management, and contingency (soft costs); and
- Vehicle and support facilities.

Costs not explicitly accounted for in this costing methodology include: real estate acquisition costs, allowance for planning studies and permitting, and various ancillary costs such as concessions to pacify certain route abutters. More detail for each category is provided in the Task 10 Report.

Table 13 illustrates a summary cost format for each option. Soft costs are identified by shading. Detailed estimates for each work item appear in the Appendix to this report.

While the actual amounts generated in the research example may not be directly transferable to all situations, some proportions may be reasonably extrapolated to similar circumstances, particularly if the methodology is duplicated.

1. The costs of planning, permitting, real estate, and right-of-way purchase can have a significant effect on the program.
2. The cost of adding the signal system for concurrent single-track operation (Option 3) is about 8% more than for a signal system for temporal separation (Option 1). The infrastructure for shared track is significantly less than for a stand-alone light rail transit system. The signal system for a two-track concurrent operation (Option 4) is the most expensive of all

Table 13. Worksheet 6—Capital costs for initiating transit service.

Option	1	2	3	4
Operating Regime	Strict Temporal Separation	Spatial Separation	Concurrent Single Track	Concurrent Double Track
Roadbed, Track, and Special Trackwork				
Structures (Railway and Highway)				
Stations				
Signals and Communications				
Engineering Design and Project Management				
Contingency				
Vehicles and Support Facilities				
Total				

options. Cost savings in shared track accrue mainly from subgrade, track, structures, and design work. Modest savings are available from stations. Signal system costs can increase or decrease, depending on implementation. Strict temporal separation remains the least costly option. No savings accrue in vehicle and facility procurements. Double-track shared use (for flexibility or safety reasons) negates most of the savings due to the sophisticated signal system needed on both tracks.

System Operating Cost Assessment

Railroad service operating costs are generally estimated in three main categories—transportation, MOE, and trackage fees/MOW. A typical charge is 45 cents per car mile for track access, consistent with industry standard practice. The American Short Line and Regional Railroad Association (ASLRRA) and AAR can be a source of economic information about freight operations.

Unit costs for transit can be derived from a review of the FTA's 2003 (or latest edition) National Transit Database, including hourly wages and labor costs for equipment maintenance. The base case scenario includes a one-person operation for light rail passenger vehicles, and an operator and a conductor for the freight train (both common industry practices).

A. Estimating transportation cost
B. Estimating mechanical cost (MOE)
C. Estimating MOW Cost. For the labor costs included in this category, assume supervisors, track, bridge and station maintainers, and signal maintainers appropriate for the system plan. The headcount will vary by such items as number of tracks, physical plant, length, and facilities.

Planners are encouraged to check with existing shared-track systems or LRT systems to ascertain a reasonable "headcount" for staff.

Estimating transit agency administrative cost. These costs may be estimated at 15% of the Transportation, MOE and MOW costs for an agency. Similar costs for the freight operator are a higher percentage of 17%, based on ASLRRA guidelines.

Total estimated annual transit agency operating cost. Summarize the forecast annual agency operating expense for each of the options. The operating expenses estimated here notably omit negotiated costs for contracted services, including: emergency repair and recovery, insurance for the transit operation, cost to defray additional insurance premium for the freight operation, and capital rebuild or rehabilitation for major transit system components. Costs range from a low of $3.6 million to a high of $4.8 million annually.

Revenues depend on fare policy, which should be defined. The transit operator usually receives an annual trackage fee from the freight railroad, depending upon the terms of an agreement. The agency also may receive revenue through noncore activities such as station concession leases, advertising rights, parking, and transit oriented development. Table 14 illustrates the cost categories.

A table or spreadsheet structured like the worksheet should be prepared to reflect the planned project. It can identify the cost elements relative to each option and hours of service. Regardless of operating regime, 24-hour dispatching must be provided, and the short-term MOW and MOE expense is likely to remain approximately the same.

Planners should estimate the volume and nature of freight traffic. Heavy freight is known to increase the long-term costs of track maintenance. At traffic densities of less than 1.0 million gross tons (MGT) per year, the differences in long-term maintenance costs are negligible. Software based techniques are available to estimate more accurately the effects of freight traffic on MOW expenses. Note also that the FRA track Class (typically Class 4 for LRT systems) affects the MOW cost. A higher track Class equates to more expensive maintenance. Since shared-track by definition serves freight traffic, FRA track maintenance classifications and practices are required.

Table 14. Worksheet 7—Sample annual operating cost estimate.

Option	1	2	3	4
Operating Regime	Strict Temporal Separation	Spatial Separation	Concurrent Single Track	Concurrent Double Track
	Operating Cost ($ thousands)			
Rail Transportation				
Train Operators				
Dispatching				
Supervision				
Fuel				
Mechanical (MOE)				
Direct Labor				
Materials				
Maintenance of Way (MOW)				
Direct Labor				
Materials				
Administration				
Annual Operating Cost Total				

Estimated freight shortline revenues and operating expense. Table 15 allows for the comparison of a forecast of annual freight operating revenues and expense for four typical options and the status quo (i.e., null alternative—no changes, no system). Operating expenses also should include a contingency for any contracted services (e.g., emergency repair and recovery, capital rebuild, and rehabilitation).

The Operating Ratio on the last line of the worksheet was derived from the Task 10 Report. It may vary for a specific project, but the relationship between Options 1, 2, and 3 and 3 and 4 is realistic. Under the Status Quo, the freight entity may bear relatively high MOW and transportation expenses. MOW is entirely funded by freight and must support a track maintenance crew and any materials from freight revenues alone. Additionally, the freight operator also must support a part-time dispatcher, and the traincrew. Revenues are based on fees for each car delivered.

Table 15. Worksheet 8—Sample annual freight operating account projection.

Option	0	1	2	3	4
Operating Regime	Status Quo	Temporal Separation	Spatial Separation	Concurrent Single Track	Concurrent Double Track
	Operating Cost ($ thousands)				
Rail Transportation					
Train Operators					
Dispatching					
Supervision					
Fuel					
Car Hire					
Mechanical (MOE)					
Locomotives					
Freight Cars					
Maintenance of Way (MOW)					
Trackage Fees					
Overhead					
Annual Operating Cost Total					
Annual Revenue Estimation					
Operating Ratio	93%	94%	91%	70%	70%

Under Option 1, expenses are reduced due to higher speed train operations and transfer of dispatching and maintenance responsibilities to the passenger operation. However, the costs for supervision, locomotives, and some of the administration functions remain unchanged. The relative cost impact/benefit of each option on the freight carrier must be assessed. Results may show little or no change to the prior financial situation (Status Quo).

Under Option 2, costs and activities are similar to the Status Quo. Marginally lower MOW expenses result from transit-funded track rebuild. The freight operator remains responsible for dispatching and supervising its own railroad. Under Options 3 and 4, the freight entity could decrease costs without affecting traffic levels. MOW and dispatching functions are transferred to the transit operator, and a lower trackage fee takes its place. For the freight operator, the mechanical, fuel, car hire, and supervision expenses remain the same, while the traincrew expenses are reduced, due to higher track speeds. Cost savings and retention of previous traffic result in a markedly healthier freight carrier, lowering the operating ratio to approximately 70%.

Ridership Impacts

Many established methods exist for measuring transit ridership. One method estimates ridership by station and by time-of-day using established survey methods. For temporal separation, ridership should be adjusted to reflect reduced span of service. The results of a desktop exercise was performed in the research for Task 10 Hypothetical Case Study, Table 16 shows how the data might be presented and compared. The principles may be logically extrapolated to similar circumstances.

Temporal separation jettisons a percentage of total ridership by eliminating pre-peak, evening, and late night service. The research sample results showed that much of the loss occurs in the morning peak period and in the evening (the "Option 1 Losses" are shown in Table 16 as a representation of a likely outcome and were derived from the research calculation). Option 1 could not serve second shift workers returning home late at night and third shift workers going to work during the evening. This results in losses of corresponding return trips. About 20% of evening and late night trips are leisure trips. These riders may be diverted to other parts of the service day.

Alternatives Evaluation

Ridership and cost forecasts are integrated to provide three key performance measures to rank and evaluate the service options shown in Table 17. They may vary for different circumstances.

Capital cost per weekday inbound passenger. Unless the proposed system is an extension of an existing shared-track system, virtually all of the forecast riders using the proposed service would be new. The forecast capital cost to divert these travelers from the highway would range between $13,000 and $17,000 per rider. This is comparable to the projected performance of similar shared-track projects currently in the FTA New Starts Program. The Oceanside-Escondido, CA project has a capital cost per daily boarding of $18,501. The corridor acquisition cost is addressed elsewhere.

Operating cost per passenger trip. Planners should forecast the operating cost per passenger trip ranges. Typical values between $1.00 and $1.20 per boarding have been estimated in this

Table 16. Ridership impacts of temporal separation.

Time Period		Option 1			Options 2, 3, 4			Option 1 Losses
		In	Out	Total	In	Out	Total	
Pre-Peak	5am-6am	NA	NA					100%
Morning Peak	6am-9am							8%
Midday	9am-4pm							5%
Afternoon Peak	4pm-7pm							3%
Evening	7pm-10pm	NA	NA					100%
Late Night	10pm-1am	NA	NA					100%
	Total							**17%**

Table 17. Worksheet 9—Typical key evaluation measures.

	Option 1	Option 2	Option 3	Option 4
Operating Regime	Temporal Separation	Spatial Separation	Concurrent Single Track	Concurrent Double Track
Capital Cost ($ Millions)				
Annual Operating Cost ($ thousands)				
Daily Ridership				
Capital Cost per Weekday Boarding				
Operating Cost per Passenger Trip				
Farebox Recovery	65%	71%	71%	68%
Mobility : Cost Index	69	59	77	59

research. The difference is small between the alternatives. Shared-track operations of this nature achieve economy though savings in capital costs.

Farebox recovery ratio. The percentage of operating costs covered by passenger fare revenue will come to between 65% and 71% for the four service options considered in this research. This ratio is fare dependent. This range is close to the reported farebox recovery ratios for the San Diego Trolley at 87% in 1985 and 67% in 1997. It is substantially higher than most smaller commuter rail systems.

Business Case Findings

Findings of the business case template are shown here. The reader may wish to review the Task 10 Report "Hypothetical Case Study" for a comprehensive analysis of all factors cited.

1. The compliant vehicle alternative may not satisfy local transit needs.
2. The temporally separated option may generate less ridership, while saving a percentage in capital cost and annual operating costs.
3. The spatially separated option may increase capital costs by a significant percentage, but generate the same level of ridership as the concurrent track sharing option.
4. The shared double track option increases capital costs by a significant percentage and operating cost by a marginal percentage, but it also generates the same level of ridership. The benefit of double track includes reduced risk and improved flexibility. The decision is site specific, but the analysis demonstrates that double tracking at the outset seems to defeat the purpose of a low cost shared-track service.

While affirmative indications of the business case are necessary, these are not solely sufficient justification to forge ahead. Most institutional concerns cited in the business case are addressed via legal agreements, financial arrangements, memoranda of understanding or other official and formal commitments. Risk analysis remains an outstanding and a major hurdle in the process. Risk analysis is a component of the safety case. And the safety case is essential to support the business case.

Risk Analyses Template

Introduction

A simplified risk analysis is provided to estimate the relative risk of casualties to train occupants in train accidents for each of the four alternative options defined. The purpose of the analysis was to determine whether concurrent shared-track and shared corridor operations, as defined for Options 2, 3, and 4, will deliver a safety performance equivalent to or better than for Option 1, with full temporal separation. Option 1 is comparable to several existing shared-track operations in the United States, notably those on the San Diego Trolley and the River LINE in southern New Jersey, and is used in this analysis as a base case that defines the standard of acceptability for safety performance.

The risk analysis methodology shown is an adaptation of that used and fully described in a recently completed (but not yet published) report to the FRA, "ITS Technologies for Integrated Rail Corridors." The analysis is intended to convince a transit authority considering a concurrent shared-track operation with light rail passenger cars and low density conventional freight that a safety performance acceptable to FRA can be achieved, and that such projects are worth further development. A much more exacting analysis would be required for submittal to regulatory authorities in support of a waiver application and would have to include a more detailed analytical back-up for model input parameters and a precise breakdown of accident scenarios.

Risk analysis has been applied to the four shared track options as described in detail in the Task 10 report. All four options combine a basic passenger service with 15 minute intervals during peak hours and 30 minute intervals in off-peak hours with two freight round trips a day and en route switching at two locations along the shared track.

The key differences among the options that affect safety performance are given in Table 18:

The following sections describe elements of the risk modeling methodology, the inputs to the model and the results obtained.

Risk Analysis and Modeling Methodology

The risk analysis methodology used in this analysis is a comparative quantitative risk analysis: the conclusions from the analysis are based on a comparison between the analysis cases rather than the absolute results. Many inputs are common to all the analysis cases, and even where the inputs vary between analysis cases, common sources and approaches have been used to estimate input values. This means there can be higher confidence in the relative comparisons than in the absolute quantitative results. The basic steps and building blocks of all risk analyses are explained here and shown in Figure 6.

Identify hazards. The first item in any risk analysis is to identify the hazards that will be the subject of analysis. In this case, the analysis is concerned with train accidents that can cause harm to passenger train occupants. While train operations on the shared corridor can result in harm

Table 18. Key safety features of the four options.

Option	Description	Freight Operation	Signal System	Other Safety-Related Features
1	Full Temporal Separation	Night Operations Only	Conventional CTC	Split Point Derails at Freight-Only Connections
2	Concurrent Separate Parallel Single Track	Unrestricted Daytime on Separate Tracks	Automatic Train Stop at Stop Signals	Two Freight Diamonds Crossing Passenger Tracks with Split Point Derails and Full ATS Protection
3	Concurrent Shared Single Track	In Passenger Off-Peak Hours	Cab Signals with Speed Enforcement	Split Point Derails at Freight-Only Connections
4	Concurrent Shared Double Track	In Passenger Off-Peak Hours	Cab Signals with Speed Enforcement	Split Point Derails at Freight-Only Connections

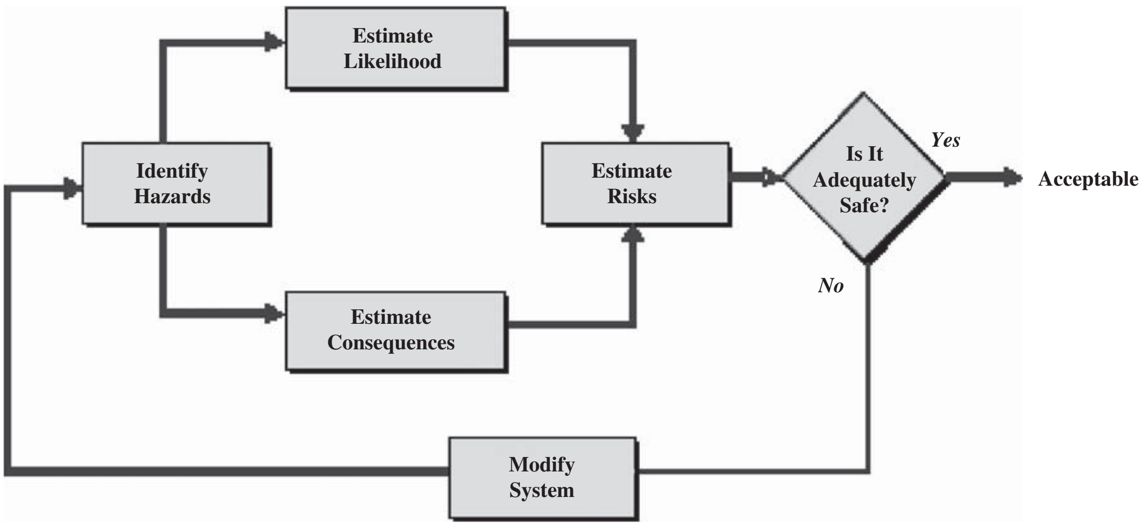

Figure 6. Basic risk analysis process.

to other parties, for example highway users at grade crossings or trespassers, the risks to these parties is minimally affected by the different forms of track sharing and have not been included in the analysis. There are two categories of specific hazards or accident scenarios described in this analysis:

I. Shared Track Operations—variable by option, time of day and analytical focus:
   1. Train-to-train collisions, whether between two passenger trains or between a passenger and freight train.
   2. Intrusion collisions, where freight equipment intrudes on the active passenger track, either because of a freight derailment on an adjacent track, a shifted load or a roll-out event at a connecting switch.
   3. Collisions at diamond crossings where freight movements cross active passenger tracks. Movements across a diamond are a feature of Option 2.

II. All Railroad Operations—common to all rail operations:
   1. Passenger train derailments, regardless of cause;
   2. Collisions with obstructions on the track other than with on-rail equipment or at a rail/highway grade crossing;
   3. Collisions with highway vehicles at rail/highway grade crossing.

This permits isolating risks induced by Category I events from overall risks to train occupants (passenger and crew) from train accidents.

Characterize hazards or scenarios. The primary inputs to a risk calculation are scenario characteristics, specifically the likelihood of the accident, usually quantified as accidents per million train-miles (or per million crossing passes in the case of grade crossings), and accident consequences, usually quantified as the number of casualties and financial losses associated with one accident. Measures used to quantify consequences must be aligned with measures used to quantify and evaluate risk. Accident likelihood and consequences are typically estimated from historic accident data, engineering analysis (for example collision crush and dynamics analysis) and simulations of rail operations. Specific methods used for this analysis are discussed in the model inputs section.

Estimate risks. Risk is the product of multiplying frequency, consequences and a level of activity on the system being analyzed, for example train-miles operated over 10 years. It is important to select units of measurement for risk that properly represent the kinds of harm that underlie the motive for the risk analysis. In this case the primary concern is the chance of injuries and fatalities among train occupants as a result of train accidents. Thus accident consequences have been estimated in terms of injuries and fatalities per accident; and risk totals are the estimated total injuries and fatalities in FRA-reportable accidents over 10 years of operations of the shared corridor. The longer period of 10 years was chosen because of the limited number of train miles operated each year. With total accident frequency for passenger train operations being about one accident per million train miles and annual train miles on this service being about 200,000, then accident and casualty numbers for each accident scenario will be small and hard to understand, but more meaningful to the reader over 10 years.

Risk calculations themselves are carried out in a spreadsheet. The basic calculation is to multiply frequency, consequences per accident, and train-miles to obtain an estimate of injuries and fatalities for each accident scenario. Because accident frequency and consequences are affected by traffic density, whether or not freight trains are active on or near the shared-track and no matter the number of train occupants, this calculation is repeated for each of the following categories of passenger train trips:

- Peak period trips in the peak direction (i.e., heavily loaded trains);
- Peak period trips in the reverse direction;
- Trips in the midday period between peak periods;
- Early morning and evening trips (which have lower ridership than midday trips);
- Freight-exposed midday trips; and
- Freight-exposed early morning and evening trips.

Freight-exposed means that the trip precedes, follows or passes an active freight train, either en route or actively switching a customer on the shared route. The model can provide for the higher frequency and consequences from collisions involving freight trains.

The end product of this calculation is an estimate of risk measured by estimated injuries and fatalities over 10 year's operation of the defined service. Because total ridership in Option 1 is a few percent lower than in the other Options, a direct comparison between estimated fatalities could be slightly misleading, and the more meaningful comparison is between casualties per billion passenger miles. Both measures are calculated in the model.

Assess safety adequacy. The final step in the risk analysis is to assess safety adequacy. As indicated earlier, the safety comparison is with Option 1, which represents a currently acceptable operation similar to those on the River LINE and the San Diego Trolley. If risk as measured by injuries and fatalities or injury and fatality rates for the other Options is equal to or less than for Option 1, then the equivalent safety requirement has been satisfied. Practically, however, it is unlikely that FRA and other regulatory authorities would be comfortable with a system that only marginally meets the criterion. Given the uncertainty of input parameters, there will be a significant probability that a marginal system would not meet the criteria. Therefore we look for substantially reduced risk for Options 2, 3, and 4 as compared with Option 1, to be sure that the system will be acceptable.

Model inputs. The most important activity and often the most time-consuming is defining all the inputs to the model. Inputs for accident frequencies, consequences, and any risk reduction factors applied to frequencies or consequences for safety improvements must be valid or the analysis results will not be meaningful. The following paragraphs summarize the inputs used in this analysis. Many of the inputs were obtained from the previously referenced FRA study, in which a very similar analysis was performed. All values and quantities cited herein are based on the Task 10 Report. The methodology is transferable when modified to fit project circumstances. Those factors and considerations can be extrapolated to other projects.

Table 19. Summary of basic route and service parameters.

Parameter	Units	Value
Days of Operation	Days	250
Shared Route Length	Miles	8.3
Number of Grade Crossings	Number	8
Grade Crossings per Mile	Number	0.96
Peak Service Interval	Minutes	15
Off-Peak Service Interval	Minutes	30

Route, traffic and ridership data. Basic route information was taken from the descriptions earlier in this chapter. The specific inputs to the model are given in Table 19.

Note that the analysis is performed for nonholiday weekdays only. It is assumed that freight trains only will operate on these days, and risks to train occupants at weekends are not affected. However when a more advanced signal system is installed to reduce and offset the risks from freight operations, this also will reduce risks of collisions between passenger trains during any weekend and holiday operations.

The numbers of passenger train trips/day are summarized in Table 20. Option 1 lacks early morning and evening trips, which are added in Options 2, 3, and 4.

In Options 2, 3, and 4 some midday and evening trips are freight-exposed, in that they precede, follow or pass an active freight train, including switching an en route industry track. Freight activity and the corresponding number of freight-exposed trips in Options 2, 3 and 4 are summarized in Table 21. In full temporal separation (Option 1), no passenger trips are exposed to risk from freight operations.

The higher number of freight-exposed trips in Option 2 is due to the lower freight operating speed and the extra time needed to make the moves over diamonds. In this option the freight exposure is to intrusion accidents and the diamond crossing movements.

Average train occupancy, needed in the calculation of injuries and fatalities, is displayed in Table 22 for each operating period.

Accident frequency and consequences for train-train collisions were estimated from FRA accident data for commuter rail collisions. Intrusion collision incidents are based on FRA data for existing mixed passenger and freight operations. Data for all other accident scenarios, including grade crossing collisions, derailment and obstruction also were derived from FRA studies.

Results and Risk Analysis Findings

Table 23 shows estimated numbers of accidents for each accident scenario. Tables 24 and 25 provide the injury rate and fatality rate per million passenger miles respectively. Details of the accident scenarios are in the Task 10 Report.

Results show a slight increase in the number of collision accidents in Option 2 compared with Option 1 (due mainly to more trips), and a substantial reduction in collision accidents for Options 3 and 4, in spite of the increased train miles and the increase in intrusion collision risks that arise from concurrent passenger and freight operations. The change is primarily due to the

Table 20. Passenger trips by time of day.

Traffic Parameter	Option 1	Option 2, 3 and 4
Peak Service, Peak Direction	23	23
Peak Service Reverse Direction	23	23
Midday	28	28
Early Morning and Evening	0	24

Table 21. Exposure of passenger trips to freight activity.

Parameter	Option 2	Option 3	Option 4
Operating Regime	**Parallel operations**	**Shared single track**	**Shared double track**
Midday Freight Activity	**One round trip, no industry switching**	**One round trip, switches one industry track**	**Same as Option 3**
Evening Freight Activity	**One round trip, switched both industry tracks**	**One round trip, switches one industry track**	**Same as Option 3**
Midday Freight-Exposed Trips	**12**	**8**	**8**
Evening Freight-Exposed Trips	**10**	**8**	**8**

Table 22. Occupancy of passenger train by operating period.

	Total Occupants (Standees in Brackets)	
Operating Period	**Option 1**	**Option 2, 3, and 4**
Peak Period Peak Direction	153 (18)	151 (11)
Peak Period Reverse Direction	19	19
Midday	75 (2)	79 (3)
Early Morning and Evening	0	29

Table 23. Estimated FRA-reportable train accidents over 10 years for each option.

	Option 1	**Option 2**	**Option 3**	**Option 4**
Accident Scenario	**Full Temporal Separation (Base Case)**	**Concurrent Separate Single Tracks**	**Concurrent Shared Single Track**	**Concurrent Shared Double Track**
Train-Train Collisions	0.181	0.171	0.079	0.039
Intrusion Collisions	0.009	0.021	0.021	0.024
Diamond Collisions	0	0.023	0	0.014
All Train Collisions	**0.190**	**0.215**	**0.099**	**0.077**
Derailments	0.092	0.122	0.122	0.122
Obstructions	0.198	0.262	0.262	0.262
Grade Crossings	1.032	1.366	1.366	1.366
Total Accidents	**1.51**	**1.94**	**1.85**	**1.81**
Train-Miles (millions)	1.54	2.03	2.03	2.03
Accident Rate per million train miles	**0.98**	**0.96**	**0.91**	**0.89**

Table 24. Estimated rates of passenger injuries for each option.

	Option 1	**Option 2**	**Option 3**	**Option 4**
Accident Scenario	**Full Temporal Separation (Base Case)**	**Concurrent Separate Single Tracks**	**Concurrent Shared Single Track**	**Concurrent Shared Double Track**
Train-Train Collisions	2.989	2.458	1.203	0.595
Intrusion Collisions	0.075	0.134	0.134	0.152
Diamond Collisions	0	0.007	0	0.004
All Train Collisions	3.064	2.60	1.34	0.75
Derailments	0.226	0.255	0.255	0.255
Obstructions	0.097	0.110	0.110	0.110
Grade Crossings	0	1.141	1.141	1.141
Total Accidents	4.40	4.09	2.84	2.23
Passenger miles (millions)	125.7	141.5	141.5	141.5
Injury Rate per million passenger miles	**35.02**	**28.96**	**20.09**	**15.70**

Table 25. Estimated rates of passenger fatalities for each option.

	Option 1	Option 2	Option 3	Option 4
Accident Scenario	Full Temporal Separation (Base Case)	Concurrent Separate Single Tracks	Concurrent Shared Single Track	Concurrent Shared Double Track
Train-Train Collisions	0.0448	0.037	0.0229	0.0113
Intrusion Collisions	0.0023	0.004	0.004	0.0040
Diamond Collisions	0	0.0002	0	0.0001
All Train Collisions	**0.047**	**0.041**	**0.027**	**0.015**
Derailments	0.0075	0.0085	0.0085	0.0085
Obstructions	0.0032	0.0037	0.0037	0.0037
Grade Crossings	0.0340	0.0380	0.0380	0.0380
Total Accidents	0.092	0.091	0.077	0.066
Passenger miles (millions)	125.7	141.5	141.5	141.5
Fatality Rate per million passenger miles	**0.73**	**0.64**	**0.55**	**0.46**

application of the ATS or ATC systems, which reduce the chance of train-to-train collisions for the entire passenger operation.

The other point to note is that grade crossing collisions with highway vehicles dominate the accident counts, and are unchanged by either the train control system or the presence of concurrent freight operations.

The numbers of injuries and fatalities change in tandem with changes in train control system and passenger and freight operations, and can be discussed together. The principal observations are:

- Train collisions are responsible for about 70% of injuries and fatalities in the base case, Option 1, but this reduces to only 35% in Option 4 due to the benefits from higher capability train control systems fully offsetting the added risks from freight train operations.
- As casualties from collisions are reduced, those from grade crossing collisions become dominant, emphasizing the importance of addressing crossing hazards.
- The best comparison between Option 1 and other Options is the injury and fatality rates given in the last line of each table. Using rates is the appropriate way of allowing for the effect of additional ridership exposed to accident risks in Options 2, 3, and 4. These rates show a steady decrease from Option 1 levels compared to Options 2, 3, and 4. Since Options 1 and 2 represent operations that are currently accepted by FRA, then it is clear that the safety performance achieved by Options 3 and 4 would be entirely acceptable.

Risk parameters used in the analysis properly represent the likely real-world performance of the system. However, it will be necessary to do more to convince regulatory authorities that this is so. Most importantly, a detailed analysis of the crash performance of typical light passenger rail vehicles in collisions with freight equipment must be performed, since this is the best way to understand the practical consequences of risk.

Safety Case Findings

The hypothetical case study determined that the following criteria have been met for the concurrent single track operation (Option 3). The process that was summarized previously offers these results:

- Proposed operation exceeds safety requirements typical of the transit industry; and
- Proposed operation has a lower estimated risk than stand alone light rail system (Option 2) in terms of rate of injuries and fatalities per passenger mile.

Results of the Sample Case Study

In this example, congruent results of the business and safety cases are integral to concluding that a shared-track project is feasible for the defined circumstances. Positive indications are:

- In terms of capital cost, proposed shared track operation is more economical than a separate and parallel (stand-alone) light rail system sharing a corridor with the freight branch.
- Although the temporally separated operation (Option 1) requires lower capital investment than the proposed operation, it does not fulfill the service needs of either the freight railroad or the transit customers, and suppresses the expansion of business for both track users.

The Business and Safety Cases—What Works in the Real World

The approach that has succeeded is evidenced in projects that commenced service in accordance with the temporal separation policy. The evolution of rigid temporal separation to near shared-track is reflected in real-world examples. Each of the systems cited below was begun to serve a particular transit need. Each started out simple and added complexity in response to a need. This need was apparent to both the transit and freight operator and resulted in improved capacity and flexibility for both modes. Services modifications are achievable. System safety features are based on traditional railroad technology and verifiable and use practices easily understood by the FRA. Operating rules and procedures adopted by the transit system closely resemble those of the freight railroads. In both cases the transit agency calculated a reasonable cost benefit ratio that justified the improvement. The incremental changes to these systems were merited by the business case and were deemed acceptable by the safety case. Some were in service long before the 1999 Joint FRA/FTA Policy. Others began after 1999. Progress made by current operating systems offers both guidance and confidence to prospective operators.

The experience of operating these hybrid systems, in conformity with a policy that previously was non-existent, required educating both operators and regulators. Regulators were and are knowledgeable about standard railroad technology, but at the inception of shared use, unfamiliar with noncompliant transit vehicles, their performance capabilities, and light rail operations. Additionally in 1999, the FRA introduced new and significantly revised regulation putting great emphasis on structural integrity and passenger safety, which influenced their perception of shared-track.

San Diego Trolley

1981–1989: Commingled operation. San Diego Trolley's track-sharing practice is both the earliest and the most advanced example of a shared-track rail corridor operating in North America. On both the Orange and Blue Lines in San Diego, freight trains operate almost every weeknight under FRA waivers. The San Diego Trolley, Inc. (SDTI) track sharing operation commenced in 1981, when trolley operations began on the Blue Line to the international border on half-hourly headways. Initially, the operation was fully commingled, with freight trains operating in the slots between light rail trains. This historic practice was extended to the Orange Line when trolley service began on that line in 1989. Neither of these commingled operations resulted in mishaps or injuries. The shared-track segment consists of 13.5 miles on the Blue Line, and 17.0 miles on the Orange Line.

1990s: Commingling terminated reversion to temporal separation. As transit service demand in the corridor increased during the mid-1990s, and headways were reduced from 30-minutes to 15-minutes, freight operations were moved to the early morning hours. Commingled operations continued on the fringes of the transit service day, when light rail trains ran less frequently. Some time after the opening of the Orange Line, the FRA disallowed the freight operations while light rail vehicles were on-line, resulting in effective temporal separation. The commingled operations on the fringes of the service day were outlawed.

2001: Restricted parallel single track operation. FRA later relented somewhat and allowed movements on separate tracks under highly restricted conditions. In 2001, the FRA granted a waiver to SDTI to permit its continued operations under a petition for "grandfathering" the previous practices. However, several aspects were restricted. This operating scenario was termed "limited night-time joint operation." It was not permitted for westbound movements on the Blue Line due to a potential single-track conflict.

2004: Scripted Temporal Separation. In 2004, a further waiver was granted to allow limited night-time joint operations for westbound movements on the Blue Line. Under the federally approved Standard Operating Procedure (SOP), one freight train is allowed to operate on one track while one trolley is allowed to operate on the other during the fringe period. The westbound freight train must come to a complete stop at a predefined meeting place on the double-track mainline before the SDTI dispatcher can release an eastbound trolley from the yard with signal indication. The trolley must pass the standing freight train at no more than 20 mph.

SOP reflects considerable caution regarding the possibility of overlapping authorities being granted by the train dispatcher, the possibility of trains exceeding movement authorities, and the possibility that freight train lading will intrude into the path of the passenger train. Under SOP, the two tracks are treated like two, almost independent, single track railways. During this carefully scripted mode of operation, the light and conventional rail vehicles remain spatially and temporally separated.

NJ Transit Newark City Subway

2001: Temporal separation. One Diamond Crossing with a freight carrier; 19 hour passenger window; 5 hour freight window five nights per week; impacts late night passenger movements.

2004: Short interval temporal separation (one mode at a time separation). Added vital signal protection with automatic train stop and interlocking at diamond, and central control of movement.

NJ Transit River LINE

1999: Temporal separation. Two Diamond Crossings with 24 hour access, then approximately 30 miles of mainline track; 16 hours passenger window; 8 hour freight window; transit vehicle equipped with automatic train stops (ATS), freight movement controlled by derail.

2007: Extended temporal separation. Added another 2.5 miles of shared track by using entrance/exit control over three interlockings. Applied ATS and derails to permit use by one mode at a time.

Achievable Incremental Steps

The incremental approach now has a credible foundation. Furthermore as regulators and policy makers gain more experience with sharing track, these examples can be replicated in other settings. The increments can be separate or combined:

Scripted temporal separation: carefully defined procedures and scheduled movements;

Short interval temporal separation: the period of temporal separation is not precisely defined by law, but it is implied. This technique positively restricts the train movements (i.e., separates them) for limited but shorter periods. These shorter operating windows are shifted from freight to passenger to freight more frequently within 24 hours, rather than only once;

Extended temporal separation: applies vital train control technology to increasing portions of the route, thus enforcing fail-safe train separation over more track.

Practical Shortcuts For Shared-Track

One goal of this research is to identify means to safely permit a limited cotemporaneous operation via a combination of technology and procedures. To be acceptable, a concurrent operation of light rail passenger cars and freight cannot increase risks or hazards to the operation, employees, passengers or the public, above those experienced in an operation served by compliant passenger and freight equipment.

The team's research indicates that shared-track methods may reduce the capital costs to develop a rail transit system by 40% to 66%. Concurrent shared-track light rail operations provide a mechanism to offer a higher frequency of service than commuter rail, while keeping the capital costs affordable and enhancing urban freight rail service. Valuable and cost-effective projects of opportunity are available in some of the larger urban and suburban areas in the United States.

The underlying principle is that all measures and technology applied to shared-track operations should enhance safety, and be verifiable and achievable. The following guidelines are practical and defensible, and condense the results of this research. The list below can be construed as a checklist for project implementation success.

1. The main reason to consider noncompliant equipment is the improved flexibility it offers. Constraints in curvature radius, grades, clearance envelopes, limits of acceleration, and deceleration make a lighter rail vehicle a superior choice for a regional service that traverses both urban and suburban environments.
2. A willing freight partner is essential.
3. Pursue near compliance wherever possible. The system has to look, feel and sound like a railroad to the FRA, while applying transit technology and most important, assume that an FRA waiver will be necessary.
4. Control of movement authority is the key to safety and regulatory compliance. Consider that the choice of a train control system can contribute to a positive review of the Waiver Petition, improve the freight operation, and provide a faster, safer passenger operation.
5. A fail-safe train separation system with the capacity to override the train operator is necessary to prevent a potentially catastrophic collision and essential for concurrent operations. Cab signals can provide speed enforcement and reduce risk.
6. Where possible, incorporate CEM features on rail cars to reduce risk of potential injuries and fatalities.
7. Temporal separation, while adequate, limits both parties and can be unacceptable for freight customers and restrict special services for transit. It also is more difficult to schedule MOW windows on a temporally-separated system.
8. A strong oversight function and negotiation skill is essential.
9. Analyze nature of freight traffic and the physical configuration of track, modify track separation and/or elevations to protect against derailment accidents where possible.
10. Local governments should deal with the railroads as peers in negotiations and in business transactions. However, state or local authorities may have the right of first refusal if abandonment is proposed by the freight owner.
11. As the project evolves, a transit agency should contemplate and pursue incremental progress and take small steps that maintain a successful track record, building FRA confidence in the operation. All planned improvements should benefit both the freight and passenger operator.

CHAPTER 5

Shared Use: Progress and Evolution

Given the preceding information, what means are available to advance this concept to true shared use of track? A few operations are on the verge of crossing the threshold, but that first step has yet to be taken.

- What actions are most likely to impel the process?
- Will a demonstration project help?
- Will the advantages outweigh the disadvantages?
- What are the barriers to progress?

Up until now, this concept has been equated with a "leap into the unknown" for all stakeholders, especially policy makers, planners, and regulators. Yet achievements to date are indicative of the benefits and future opportunities.

Demonstration Project

A viable business case for shared-track can be made and results from the risk analysis model indicate that equivalent safety criteria can be met. Widespread consensus exists in the transit professional community on the next steps for the shared use of track by conventional railroad trains and light passenger rail cars. With the background research on signaling, communications, operating methods, and vehicle technologies presented in Chapter 2 (detailed in the reports for Tasks 1 through 4), and business model and national business case information presented in Chapters 2 and 4 (detailed in the reports for Tasks 7 through 10), a clear picture for the way forward has emerged. Determination of project feasibility parallels that of making the viable business case.

In particular, the planning process requires four main steps, described in Chapter 2 (detailed in the Task 9 report): (1) Identify Service Requirements; (2) Define Alternatives; (3) Choose Shared-Track Operating Regime; and (4) Complete Economic Analysis. This process (or a standard alternative analysis process) should be followed to determine project feasibility and to understand demonstration project opportunities and constraints. In the case of an existing system, this process is less arduous, because it has already established a track record of safety as evidence for regulators.

At the present time, a demonstration project for shared-track operations may take one of two possible forms:

1. A currently operational, temporally separated shared-track line has identified a business need that requires concurrent operations; or
2. A currently operational light rail system has demonstrated a need to extend or expand its system using an adjacent freight railroad branch line.

Collision Safety of the Demonstration Project

Project sponsors will have the burden of proof to satisfy the FRA that equivalent safety would be achieved by the chosen technology and operating methods. The project team has identified three key issues related to federal regulatory acceptance for a concurrent shared-track demonstration project.

1. Understanding the severity of consequences of collisions between a light passenger rail car and conventional freight equipment through structural analysis. The result of collision may not be catastrophic.
2. Understanding differences in the rail-highway grade crossing risks posed by comparatively lighter rail vehicles. The grade crossing collision risks should be appropriately managed with due consideration to the speed of light rail cars, braking capabilities, and the type of traffic crossing over the railroad.
3. Demonstrating a consolidated equivalent level of safety in all aspects of the proposed operations. A risk analysis (safety case) specific to the line, demonstrating that the combination of train control system and other mitigation measures makes the system at least as safe as a stand alone light rail line or a conventional commuter rail line.

These issues are valid concerns to be addressed in a waiver petition for demonstration or pilot operation of concurrent shared-track. However, the transit system should not be held to a higher standard than other modes, and the null alternative—risks if nothing is done—needs to be considered.

Collisions Between Light Passenger Rail Cars and Conventional Equipment

The severity of collisions is the leading safety concern with concurrent shared-track operations. Many options are available to reduce the frequency of train-train and intrusion collisions, but the risk cannot be entirely eliminated. Much less information about the severity of consequences is available. Because the practice is relatively new and because measures to reduce the likelihood of collisions have been very effective, no meaningful historical accident information exists. If current and planned preventive measures are successful it will remain that way. Only very simple analyses of hypothetical collisions have been performed.

For the limited concurrent shared-track operations, such as the River LINE and San Diego Trolley, the FRA was provided with a qualitative risk assessment (performed by the transit agency) to provide safety assurance and took no exception to proposed train control systems and operating procedures for ensuring a fail-safe train separation. For more extensive concurrent operations, a more detailed analysis may be required. This analysis might include:

- Formal three-dimensional structural crush and collision dynamics analyses of representative collision scenarios; and
- A quantitative risk analysis that takes into account the results of the collision analysis and the expected performance of proposed train control systems.

Application of Risk Analyses Methodology to the Demonstration Project

The deficiencies of risk analyses are particularly apparent for concurrent shared-track projects. There is little actual accident or incident data. All operations to date entail some form of temporal separation, and are not truly concurrent. Ironically, due to the excellent safety record of many rail transit systems, there is a dearth of transferable data for risk modeling purposes. An example of this lack of information can be seen in Europe where tram trains and other forms of commingled shared-track arrangements are more prevalent; accident experience with these types of operation are very meager.

The risk model should reflect parameters considered appropriate to the shared-track environment. The analyses also should incorporate the impacts of actions that the prospective operator of the shared-track demonstration can take to reduce risk. These parameters are summarized here.

Recognized Risk Factors

- Accident rate variability with volume and type of rail traffic.
- Frequency, nature and proximity of freight traffic.
- Single or double tracks, yard operations.
- Operating speeds of the light passenger rail equipment.
- Consider secondary collisions (effects on standees is a particular concern).
- Reduced fire hazard from less fuel and improved protection for the fuel tank on typical DMU equipment.
- The number of cars in the consist.
- Collision effects on the articulated joint.
- Collision effects on power module or propulsion components.
- Number of grade crossings, volume and nature of highway traffic.

Potential Risk Reduction Measures

- Upgrade the track maintenance class to reduce the likelihood of a derailment.
- Lower the operating speeds of freight.
- Time of day track restrictions.
- Add intrusion detection and other hazard detection devices.
- Failsafe train separation.
- Protection from freight siding roll-outs.
- Automatic train protection.
- Grade crossing warning system technology.
- Extremely high braking rates and redundancy of brake system on DMUs and LRVs.
- Well developed operating rules and procedures with training and enforcement program.
- Provision of CEM design including frangible and crush-zone elements in vehicle, in addition to interior features that offer more impact attenuation for passengers.

Ultimately, equivalent safety drives mitigation of risk. Risk reduction alternatives may involve federal compliance with negative cost or operational impacts, or adoption of systems that alleviate specific hazards and reduce risk to levels consistent with those attained via regulatory compliance. To achieve a practical demonstration project of concurrent shared-track operations under the federal waiver paradigm:

1. Equivalent safety needs a precise and widely accepted definition that has an objective meaning to policymakers and technical staff; and
2. Risk mitigation measures should be quantifiable in the context of a shared-track environment. These “adjustment” factors should be acceptable to a consensus of technical experts.

Currently, risk assessment has been applied directly and exclusively to the rail mode, rather than comparing the results to other travel modes that would be used in absence of a shared-track system. Certainly planners and transportation specialists would like to know if relative risk increases or decreases, as a result of their plans.

Further tests and demonstrations to gather technical information are critical for validation of risk assumptions, and provide experience in selecting systems, equipment, and operating practices that contribute to a safe, concurrent shared-track environment.

Data Collection Plan

A demonstration project aims to achieve two goals: to explain the proposed technology to government officials and the public at large and to collect data about the technology that will inform the direction of technological research and development, and investment decision making. Any demonstration project should include a data collection plan and consider collecting an extensive set of cost and operating data.

Key to the success of the demonstration project and for shared-track proponents in general is statistics confirming that risks to passengers in shared-track installations are no higher than a comparable conventional commuter rail system. In addition to the standard federal and state requirements on incident reporting, the demonstration project should collect statistics about incidents on shared-track lines with the goal of making a general safety case for this method of operations in the future. Control center databases and vehicle event recorders can provide some of the raw data. Among the key events to record are:

- Train control technology failures, including failsafe events and any events that do not fail safe or where some other active intervention is required to prevent an incident.
- Incidents prevented (i.e., accidents averted) by the signal system.
- Other near-misses where an incident was prevented by mechanisms other than the train control system (and whether the incidents might have failed-safe had the other mechanism not functioned).
- Standard statistics on passenger injuries, fatalities, and property damage if any accident should occur. Post-accident analysis of vehicles and systems should be carried out to identify any lessons learned.
- Grade crossing incidents, particularly actual vehicle strikes that result in railcar damage and grade crossing incidents where the enhanced braking rate of light rail vehicles is successful in preventing a collision, or instrumental in limiting injuries or damage.
- Detailed operating statistics such as mileages and operating hours should be kept, such that accident rates could be normalized against any number of standard denominators.

Suggestions for Demonstration Projects

It is recommended that the shared-track transit systems currently operating in San Diego and Southern New Jersey be designated as demonstration systems for the development and promulgation of the American approach to shared-track transit operations. The transit systems in the two cities represent two different approaches to the safe management of concurrent shared-track operations on opposite coasts of the nation.

San Diego Trolley, Inc.

The older San Diego system has developed a tightly scripted manual track warrant based approach to allow freight trains at the end of their diurnal period to operate on tracks connected and adjacent to tracks used by light rail cars at the start of the passenger service day. The system does not feature any technologies that ensure fail-safe train separation. The 25-year-old system ran concurrent freight and passenger operations successfully on shared track for the first decade of its operation before such practices were outlawed by federal regulation. Present investments in technologies and specialized infrastructure to ensure fail-safe train separation on the lines are modest. The organizational culture of the line is dominated by transit perspectives, in that San Diego Trolley is designed and operated as a traditional U.S. light rail transit system. Procedures and technologies for monitoring and controlling train movements do not strictly conform to standard U.S. railway operating practices.

San Diego presents an opportunity to explore how existing shared-track systems can be upgraded with investments in technology and management systems to backstop the manual procedures presently used for very limited concurrent operations. This should lead to the implementation of management techniques and control systems that allow light rail and freight trains to use the shared tracks concurrently with a greater safety and frequency, thus improving service delivery for customers of both the freight and passenger railways.

San Diego could be used as a test case for the framework proposed in Chapter 4 (the Task 9 report). The service goals and objectives would be formalized based on freight and transit service requirements. The aim is clearly to upgrade the system for full concurrent operations if required by the freight traffic densities and schedules. Different train control technologies would be evaluated for the application, leading to installation and operation of a concurrent shared-track railway that fully meets the service requirements of both freight and passenger railway customers.

NJ Transit River LINE

New Jersey Transit's River LINE opened decades after the San Diego Light Rail system and was specifically designed with frequent concurrent shared-track operations. In contrast to San Diego, the system features conventional train control technologies to ensure fail-safe train separation and was initiated with a conventional railroad rulebook and organizational culture to facilitate shared-track operation. The system is beginning to use a novel combination of Automatic Train Stop (for passenger trains) and interlocking controlled split point derails (for freight trains) to ensure fail-safe train separation between freight and passenger trains at locations where freight trains must cross or occupy short portions of the shared-track railway during the course of the normal passenger service day. NJ Transit's unique combination of off-the-shelf transit and railway technologies to ensure that only one class of train can occupy the shared-track at any moment in time may prove to be the key breakthrough that allows concurrent shared-track transit lines to be routinely designed, built, and operated on many urban or suburban low-density freight lines.

The River LINE presents the opportunity to explore the incremental approach to improving the scope and technology of shared-track operations in a retro-fit fashion. It is a system of recent vintage designed with concurrent operations in mind but with only an incipient approach to controlling freight operations in the concurrent "fail-safe separation" mode of operation. Two years after the line opened, NJ Transit has committed to the NX signal logic (NX = entrance/exit) approach to locking out specific sections of shared-track to specific modes, recently adding approximately 2.5 miles territory to its NX zone. Other measures are being considered. The demonstration project should aim to understand the feasibility and scalability of the New Jersey approach over longer distances. NJ Transit and Conrail are interested in concurrent operations over longer lengths of the River LINE, particularly a 17-mile segment between Burlington and Trenton. Here the nature of the concurrent operation is more line-haul in nature rather than short crossing movements for which NX signal logic has been successfully applied. As a demonstration system, NJ Transit would be encouraged to refine and document its promising approach to ensuring safety, while making efficient use of limited urban transportation assets available for the transport of passengers and freight.

Barriers to Implementation

This research has highlighted some of the advantages and disadvantages of the shared-track concept, even where near shared-tracks are currently practiced. None of the disadvantages is insurmountable, if shared-track is the right fit. Often, they can be overcome through technical, financial, or legal resolution.

However, some more prominent barriers have subjective elements. These cases require alterations to the judgment of regulators or changes in the perspectives of policy makers. Since such perceptions can be based on the newness and limited experience with shared track and little exposure to DMU or LRV equipment, they need a stronger and more irrefutable objective argument to overcome some preconceptions. More research and cumulative performance experience may be essential to effect a change. These impediments are the primary reason that the concept has not been more readily embraced, as evidenced by the number of transit agencies that opted for conventional rail systems and other projects that were simply stopped.

- Liability: common to any passenger/freight operation (not unique to shared-track), but there is a lack of precedent and actuarial data for shared-track, so at the very least the unknown financial impacts may drive up the cost.
- Safety issues: disparate speeds and operating weight, structural incompatibility in multiple dimensions, frontal configuration, service characteristics.
- Waiver process: long, complex process; each is unique; may require external legal and technical support at extra cost; invites external parties to evaluate project.
- FRA Part 238 and 236 compliance (see waiver process): cost and legal implications.
- Regulatory unfamiliarity: officials are unfamiliar with light passenger rail equipment, its performance capabilities and operations. More exposure to this technology and standardized vehicle design would aid understanding.
- Risk analysis: application of risk analysis methodology and interpretation of results is somewhat esoteric; validated data to quantify risk is lacking; modeling risk events is a complex affair; some have a natural inclination to dismiss risk concerns while others display a tendency to overstate them; one school of thought places excessive faith in risk management while another has insufficient faith. The probabilistic aspect does not satisfactorily address a "nightmare scenario" event. There is simply less comfort in calculating a one-in-a-billion chance of an accident event every 10 years. Regulators can more easily understand that if an accident occurs, then passengers are protected.
- Lack of sufficient accident data: a perverse and ironic insufficiency of hard data compounded by lack of collision modeling via computer or field test results.
- Rigid temporal separation: is a "zero-sum" game. If the one mode gains the other loses.
- Potential for unknown outcomes: for planners, policy makers and all stakeholders, the planned or desired outcome of the effort is not assured. Costs, schedules, and technology choices are all subject to review and approval by the FRA, and may be amended at any stage in the process.
- Lack of strong voice: the novel and niche role of shared-track needs strong local or state advocacy to support and encourage it. The participation of project champions and likely beneficiaries (e.g., shortline operators) should be solicited.
- No corridor philosophy (similar to highway or air traffic): railroads are seen as exclusive corridors for conforming equipment, not as corridors or highways available to different vehicles sharing the same route.
- Local issues: particularly local speed restrictions for railroads enacted while plans are evolving can complicate or restrict the service plan; grade crossing impacts, associated horn-blowing noises, and ambient noise and operational impacts are also a concern.

Shared Track—The Potential Market

Track sharing between mainline trains and light passenger rail cars serves a niche market between commuter rail and a stand-alone light rail system. Viable operations in North America typically entail allowing a small number of branch line freight trains to operate over a line that is converted for medium-frequency light passenger rail use at limited speeds.

The community will benefit or be impacted by the advantages or disadvantages arising from shared-track, which are summarized here. There is no implied weighting of these factors, they are simply identified. A transit agency and various stakeholders should assign the relative value (positive or negative) to each.

Advantages

- Increase accessible passenger market; public transportation available in new, less served areas.
- Potential for route extensions, connections and passenger growth. Flexibility for test services.
- Walkability to and from stations.
- Downtown distribution.
- Lower cost than light rail.
- Quieter and with lower emissions than traditional commuter rail.
- Induced growth may be economically beneficial to locality.
- Shorter, faster trains.
- Viable in edge cities and suburban neighborhoods.
- Additional utilization of an existing railroad asset.
- Reduced social disruption construction relocation, and environmental disturbance by using existing facility.

Disadvantages

- Conflicts with growth in freight traffic. Temporal separation can be a zero-sum game, with winners and losers.
- Capacity limitations, not suitable for high density, high volume passenger movements.
- Stations require parking and improved highway access, and generate traffic.
- Noise generated by horn warnings when trains traverse grade crossings.
- Increase in noisy freight movements that will likely shift to night.
- A lightly used freight line must exist. The concept is applicable in selective circumstances.
- Existing freight corridor may not be optimally placed to generate ridership. Growth may be induced where inappropriate or constrained by other factors. Ridership may be induced rather than mode shifted.
- A cooperative freight partner is required.
- Extended and complex bureaucratic process; success not assured.
- Requires added systems and technology to protect passenger traffic from freight-based accidents.
- Route will likely include a large number of grade crossings. Realistic or not, concern is increased with noncompliant vehicles.
- Disparate speeds and weight, structural incompatibility of vehicles increases risk.
- Each incremental change requires approval from the FRA.

Market appeal can benefit from increased advocacy by state or local government entities and community movers and shakers as an economic stimulus and a practical approach to new system starts. Collaboration between a transit agency and a local shortline or branch line owner may be encouraged by explaining the potential infrastructure, economic, and operating advantages that would accrue.

Shared-Track Operation—An Evolving Concept

The future growth of shared-track operations is contingent upon shared-track being affordable and achievable without sacrificing safety. Technical advances and evolution of a more sophisticated business case is likely to enhance shared-track's appeal. The following recommendations for research and action will support progress for present operations and those being planned or considered:

1. Demonstration projects should encourage funding for development, evaluation, testing and documentation of methods to expand concurrent track sharing, and involve the SSO organization too. In both California and New Jersey, it would include a detailed evaluation of what

types of concurrent operations are necessary and desirable. The demonstration would provide for development and evaluation of approaches to facilitate those operations. The demonstration project would provide for design, deployment, testing, evaluation, and documenting, and recommend a preferred approach. Finally the project would report on the actual costs and derived benefits of extending concurrent shared-track operations.

2. The business case template and risk analysis technique illustrated in Chapter 4 should be adapted to a specific candidate line segment under consideration by a transit agency. The research for this report used hypothetical data for illustrative purposes. Expanding upon this research by applying the method to a real system could validate and calibrate the model, and quantify the benefits in a way that may be transferable to other prospective systems.
3. APTA currently sponsors a shared-track working group that serves to disseminate relevant experiences and information. A more active intervention and role by APTA in promoting this application of technology should be encouraged. One means of doing that is developing new FRA standards for shared-track under the auspices of APTA. The existence of any type of standard may assure that each project will not be treated as the first of its kind by the FRA. An approach similar to PRESS and RTOS programs could be adapted for Shared-Track. Creating standards and self-regulation may obviate some FRA concerns.
4. More structural research is needed, such as computer modeling and simulation of light passenger rail cars and freight vehicle collisions. Ideally a real-world test should be performed and results can be incorporated in new CEM designs and risk analysis models.
5. Investigate whether it is possible to use federal funding available for shortline/branchlines reconstruction or rehabilitation for a shared-track service, thus reducing costs to the transit agency.

Bibliography

Allen, W., M. Sussman, and D. Miller. “Regional and Short-Line Railroads in the United States.” *Transportation Quarterly,* Vol. 56, No. 4, 2002, pp. 77–113.

American Railway Engineering and Maintenance of Way Association Communications & Signal Manual of Recommended Practices, 2006.

Ames, L. and J. Walsh. “Short-line Railroads and Rail Transit Joint Development Planning Issues.” The 9th Joint APTA—TRB Light Rail Conference, St. Louis, Mo., 2006.

APTA Manual of Standards and Recommended Practices for Rail Transit Systems, Volume 4, Operating Practices, 2004.

APTA Manual of Standards and Recommended Practices for Rail Transit Systems, Volume 6, Signal and Communications Equipment Inspection and Maintenance, 2004.

APTA Manual of Standards and Recommended Practices, for Passenger Rail Equipment, Volume VI, Standard for Passenger Railroad Emergency Communications, 2006.

Armstrong, John H. *The Railroad-What It Is, What It Does.* Simmons Boardman Publishing Corporation, 1978.

Brigano, M. and Mc Cullough H. *The Search for Safety.* American Standard, Inc., 1981.

Christner, P. and P. Mauri. “Sharing of Track by Transit and Freight Railroads Access, Safety, and Insurance Issues.” Prepared for Walter Kulyk and Venkat Pindiprolu, Federal Transit Administration, U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, United States Department of Transportation, Cambridge, Mass., 2005.

Due, J., and S. Leever. “The Experience with New Small and Regional Railroads, 1993–1997.” *Transportation Journal,* Vol. 37, NO. 2, Winter 1997, pp. 5–23.

Due, J., S. Leever, and T. Noyes. “The Experience with New Small and Regional Railroads.” *Transportation Journal,* Vol. 42, No. 1, Fall 2002, p. 19.

Ensco, ICF, KKO, and R. A. Mayville. “Safety of Non-Compliant Passenger Rail Equipment.” Draft Report, Federal Railroad Administration, Office of Research and Development, 2005.

Federal Railroad Administration and Federal Transit Administration. “Statement of Agency Policy Concerning Jurisdiction Over the Safety of Railroad Passenger Operations and Waivers Related to Shared use of the Tracks of the General Railroad System by Light Rail and Conventional Equipment.” *Federal Register,* Vol. 65, No. 132, 2000, pp. 42525–42528.

Federal Railroad Administration. “Shared Use of the Tracks of the General Railroad System by Conventional Railroads and Light Rail Transit Systems-Notice and Final Rule.” *Federal Register,* Vol. 65, No. 132, 2000, pp. 42529–42553.

Federal Railroad Administration. Track Clearance. 1999. http://www.fra.dot.gov/us/content/1232. Accessed January 2006.

Federal Transit Administration and Federal Railroad Administration. “Shared-Track Operations in Karlsruhe, Germany.” Final Report, September 2000.

Geissenheimer, H. “New Vehicle Options for Lower-Cost Rail Mobility: Using Diesel or Dual-Powered Light Rail Cars as a Transfer of Technology.” In *Transportation Research Record 1571,* TRB, National Research Council, Washington, D.C., 1997, pp. 125–133.

General Code of Operating Rules (GCOR). GCOR Committee, 2005.

Homburger, W. “Practitioner’s Forum.” *Journal of Transportation Engineering,* Vol. 124, No. 5, 1998, pp. 402–403.

Johnson, J., D. McClure, K. Schneider, and D. Wood. “Short-line Railroad Managers Discuss Their Industry.” *Transportation,* Vol. 31, 2004, pp. 97–123.

Josserand, Peter. *Rights of Trains.* Simmons Boardman Publishing Corporation, 1957.

Liu, Rongfang (Rachel). *Survey of Transit/Rail Freight Interaction Final Report.* New Jersey Department of Transportation/Federal Highway Administration, New Jersey Institute of Technology, September 2004.

May, J. "Nordhausen Tram Trains Rule OK." *Tramways & Urban Transit,* November 2005. www.lrta.org. Accessed January 2006.

NORAC Operating Rules. Northeast Operating Rules Advisory Committee, 2003.

Phillips, Edmund J. *Railroad Operation and Railroad Signaling.* Simmons Boardman Publishing Corporation, 1942.

Phraner, D. *German Shared Track Experience Independent Supplemental Technical Study Tour Findings.* TCRP Project J06, Task 34, 2000B.

Phraner, D. Light Rail Sharing Track with Other Rail Modes: How Far Have We Come at the Millennium? Proceedings of *the 8th Joint Conference on Light Rail Transit,* Dallas, Texas, 2000A.

Phraner, D. *TCRP Research Results Digest* 47: *German Track Sharing Experience: Mixed Use of Rail Corridor.* TRB, National Research Council, Washington, D.C., 2002.

Phraner, D. *TCRP Research Results Digest 43: Supplementing and Updating TCRP Report 52: Joint Operation of Light Rail Transit or Diesel Multiple Unit Vehicles with Railroads Issue.* TRB, National Research Council, Washington, D.C., 2001.

Phraner, D., R. Roberts, P. Stangas, K. Korach, J. Shortreed, and G. Thompson. *TCRP Report 52: Joint Operation of Light Rail Transit or Diesel Multiple Unit Vehicles with Railroads.* TRB, National Research Council, Washington, D.C., 1999.

Pilgrim, R., L. Blaydes, and W. Burgel. Issues Associated with Light Rail Transit Use of Freight Railroad Right of Way. In *TRB Conference Proceedings 8,* Vol. 1, TRB, National Research Council, Washington, D.C., 1995, pp. 147–153.

Port Authority Trans-Hudson Corporation Book of Rules. Port Authority Trans-Hudson Corporation, 2000.

Rail System Rule Book. Chicago Transit Authority, 2002.

Rules and Regulations Governing Employees Engaged in the Operation of the MTA New York City Transit System. New York City Transit System, Office of Labor Relations, 2002.

San Diego Trolley Rules. San Diego Trolley, Inc., 2001.

Santa Clara Valley Rules. Santa Clara Valley Transportation Authority, 2001.

Schulte, C. F. "General System and Rail Transit Common Corridor Safety." *Rail Transit Conference,* Boston, Mass., 2001.

Sheys, K. M. and T. Spear. Safety Oversight of Shared Track Operations: an Update. Proceedings of *the 8th Joint Conference on Light Rail Transit,* Dallas, Texas, 2000.

SNJLRT Light Rail Operating Rules. NJ Transit's River LINE, 2004.

Tayabji, S., and D. Bilow. Concrete Slab Track State of the Practice. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1742,* TRB, National Research Council, Washington, D.C., 2001, pp. 87–95.

Tereschuck, P. Draft of Implementation Strategy. Joint LRT/Freight Operations. 2005.

Ullman, K. and A. Bing. Operations and Safety Considerations in High-Speed Passenger/Freight Train Corridors. In *Transportation Research Record 1489,* TRB, National Research Council, Washington, D.C., 1994, pp. 37–49.

van der Bijl, R. and A. Kuehn. Tramtrain: The 2nd Generation New Criteria for the Idea Tramtrain City. http://www.lightrail.nl/TramTrain/tramtrain.htm#ChecklistsCriteria. Accessed February 2006.

Vigrass, J. Joint Use of Track by Electric Railways and Railroads: Historic View. Proceeding of *the 7th Joint Conference on Light Rail Transit,* Vol. 1, TRB, National Research Council, Washington, D.C., 1995, pp. 154–163.

APPENDIX 1

Abbreviations

AA	Alternatives Analyses
CFR	Code of Federal Regulations
DEIS	Draft Environmental Impact Statement
DMU	Diesel Multiple Unit—a diesel powered (with either electric or mechanical transmission) multiple unit self-propelled rail car. Used generically to describe any internal combustion propulsion system
EBA	"Eisenbahn Bundesamt"—Germany's Federal Railway Authority, similar to the FRA.
EBO	"Eisenbahn—Bau—und Betriebsordnung" Metropolitan Railway Regulations (German Federal uniform urban railway regulations on construction and operation).
EMU	Electric Multiple Unit—a rail car that is an electrically propelled passenger vehicle designated as a motor, trailer or other sub-type to comprise a train consist
FE	Final Engineering
FEIS	Final Environmental Impact Statement
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
LRV	Light Rail Vehicle—vehicles typically used for electrically powered urban rail service
MIS	Major Investment Study
NEPA	The National Environmental Policy Act of 1969
PE	Preliminary Engineering
SPRC	Self-propelled Rail Car, a term that refers to all passenger rail cars containing their own propulsion system. Compliance with FRA structural requirements is not specified

APPENDIX 2

Glossary of Shared-Track Definitions

Abandonment

Abandonment and discontinuance of railroad service is allowed by federal law, which permits a carrier to end its obligation to provide common carrier service over a particular rail line. Abandonment procedures are set forth in 49 CFR 1152. The procedures for abandonment or discontinuance of a rail line are complex and they establish rigid time limits. Railroads therefore sometimes mothball a branch line without formally abandoning it.

Centralized Traffic Control (CTC)

A centralized traffic control system is a method of train dispatching that emphasizes the remote operations of the interlocking plants from a central control center. Typical features of a CTC installation includes: (1) remotely controlled, interlocked switches; (2) track occupancy indicator lights on mimic boards located in the control center; (3) traffic controls that enable specific track sections to be designated for a direction of traffic; (4) automatic wayside signals that behave in concert with the traffic control settings; and (5) full bidirectional operations on all tracks under rules similar to NORAC Rule 261.

Class I Railroad

The Surface Transportation Board defines a Class I railroad as a railroad carrier whose operating revenue exceeds $277.7 million (in 2004). Class I railroads generally operate freight trains on the general system of railroads. There are currently seven Class I railroads in the United States: CSX Transportation, Norfolk Southern Railway, BNSF Railway, Union Pacific Railroad, Kansas City Southern Railway, and the U.S. portions of Canadian National Railway and Canadian Pacific Railway.

Commingled Operations

Commingling between light transit and conventional vehicles implies that trains operating over a shared-track segment are separated from one another on purely track warrants, signal indications, automated train control systems, or other such like train signaling systems. FRA stipulations require a system that ensures "fail-safe train separation" between light transit and conventional railroad trains. On a commingled system, both light transit and conventional equipment are dispatched in the same manner, with no operational distinction made for the train or equipment type. It does not mean that light transit and conventional equipment is operated in the same train consist.

Crash Energy Management (CEM)

A method structural design that controls structural crush by analyzing the dynamic crush behavior of the vehicle, relating it to passenger safety incorporating features into the railcar structure to absorb and dissipate collision energy in a manageable and predictable fashion to minimize injury to passengers and crews. Also referred to as collision force management and controlled crush design.

Diesel Multiple Unit (DMU)

A diesel multiple unit is a passenger railcar that has a number of special features: (1) Onboard (typically underfloor) propulsion equipment that enables it to move under its own power without a locomotive; (2) Multiple unit capability, which allows two or more DMUs to be coupled together and simultaneously operated by a single operator as a train; and (3) Typically has driving cabs at both ends allowing the DMU to reverse direction without a loop or wye track facility. For the purpose of FRA Regulations, a DMU is classified as a locomotive.

FRA-Compliant

This refers to the requirements in CFR 49 Part 238 for 800,000 lb sill end compressive force resistance (buff strength) and other specified strength requirements, including anti-climbing, forward facing end structures, collision posts, corner posts, rollover strength, and side structures. See Non-FRA-Compliant.

FRA Waiver

For any entity to operate non-FRA-compliant equipment on track that is connected to the general system of railroads, exceptional permission must be sought from the FRA by petition. The FRA will publish a notice in the Federal Register, solicit public comments, and conduct analyses. At the end of the regulatory process, the FRA will publish a Letter of Decision. Typically, the letter of decision grants certain relief from specified parts of Title 49 of the CFR. FRA commonly will impose certain conditions or limit the scope of a specific element of a petitioner's request. This Letter is sometimes referred to as the FRA Waiver. The Waiver gives the entity legal authority to operate in the specified manner, subject to the conditions outlined in the Waiver.

Fringe Period

Fringe periods are the periods near the beginning and end of the transit and railroad service days, typically between 11 p.m. and 1 a.m., and between 4 a.m. and 6 a.m. This is sometimes termed the shoulder of the service day.

General System of Railroads

General railroad system of transportation means the network of track over which goods may be transported throughout the nation and passengers may travel between cities and within metropolitan and suburban areas, and portions of the network that lack a physical connection may still be part of the system by virtue of the nature of the operations.

Grandfathering

An operating practice is said to be grandfathered if it predates a legal requirement that outlaws the practice, but is allowed to continue on an exception basis.

Haulage Rights

A "guest" railroad has haulage rights over another if it has the legal authority to require the host railroad to transport the guest's traffic over the host's lines, using any means deemed appropriate by the host railroad.

Light Passenger Rail Cars

Light rail passenger vehicles, a generic term applied to all passenger vehicles that do not comply with 49 CFR Part 238 Subpart C Specific Requirements for Tier I Passenger Equipment. See Non-FRA-Compliant.

Limited Nighttime Joint Operation

The scripted temporal separation arrangement on the San Diego Trolley is termed "limited nighttime joint operation" in the original petition submitted by SDTI and in the corresponding FRA letter of decision.

Non-FRA-Compliant

This refers to rolling stock used on the general system of rail transportation that does not comply with the structural requirements of 49 CFR Part 238.

Northeast Operating Rules Advisory Committee (NORAC)

NORAC is a voluntary association of railroads that maintains a common set of operating rules for the Northeastern United States. The main members include: Amtrak, Conrail, NJ Transit, SEPTA, Providence & Worcester, New York Susquehanna & Western, and a number of smaller railroads. Other railroads that incorporate elements of NORAC Rules within their own rulebooks include Guilford Rail Systems, CSX Transportation, and Norfolk Southern.

Operations Control Center (OCC)

An operations control center supervises train operations over a railroad or light rail territory. Typically light rail controllers or conventional railroad dispatchers are stationed in the OCC. The OCC often has track occupancy indicators, radios, phones, and other tools designed to monitor operations and ensure the safe and orderly movement of traffic. A CTC installation is not necessary for an OCC, but an OCC is a prerequisite for a CTC installation.

Scripted Temporal Separation

Light transit operations are under scripted temporal separation if there is a script governing the transfer process, allowing more operationally complex modes of sharing the segments of the shared-track system. This script is approved by the FRA in a Waiver Petition, and may only be modified with the permission of the FRA. The script may entail joint operation of conventional and light rail equipment in opposite directions, in double track territory. See the San Diego Trolley case study in text.

Shared Corridor Operations

Use of a rail corridor by various types of equipment including freight and passenger. It is assumed to include FRA-compliant rolling stock, technology and practices and non-FRA-compliant rolling stock, technology and practices. Parallel operation of any or all types of equipment on adjacent tracks is implied but shared use of the same track is excluded (since that is defined by shared track). See Spatial Separation.

Shared-Track

In shared-track operations, light rail vehicles operate on the same tracks used by conventional trains. FRA has written policy governing this type of operation, in which fail-safe train separation between light transit and conventional railroad trains is required. The term “shared use” is occasionally used when “shared-track” is meant.

Shared-Track Operations

Use of a track on the general system of rail transportation by various types of equipment including freight and passenger, assumed to include FRA-compliant rolling stock, technology, and practices and as well as rolling stock that lacks the required buff strength, technology and practices. Commingled operation of any or all types of equipment on the same track is implied.

At this time, temporal separation is the only acceptable technique currently in use and approved by FRA for a number of specialized transit operations in the United States. Therefore, there are no true shared-track operations at present. The FRA/FTA Joint policy statement (“Proposed Joint Statement of Agency Policy Concerning Shared Use of the General Railroad System by Conventional Railroads and Light Rail Transit Systems,” 64 Federal Register; 28238; May 25, 1999) gives some guidance for the consideration of a positive train separation system as a possible alternative to temporal separation. This policy is now codified in 49 CFR Part 211.

Spatial Separation

Light transit agencies are considered spatially separated from the general system of railroads if the two operations do not share track. Diamond crossings are not considered spatially separated and special FRA regulations apply. See Shared Corridor Operations.

Split Point Derails

A split point derail is a specially designed railroad turnout that allows either a straight ahead movement or a derailing movement that directs the train into a runaway ramp. It is sometimes called a catch point. It offers better protection than a mechanical derail, which is a small metal wedge that sits on top of one rail.

Standard Operating Procedure (SOP)

Standard Operating Procedure is a document typically issued by a light rail operating agency that governs light rail employees in addition to the rulebook. It is typically used to cover special operating conditions. The equivalent document on a mainline railroad is generally a special instruction. It is termed a special order on some East Coast light rail systems. In the case of San Diego Trolley, the SOP forms a script that describes a number of operating scenarios. The SOP is a critically important element of each petition submitted to the FRA.

Temporal Separation

Light transit operations are considered temporally separated from the general system of railroads, if the two share track, but may only operate on the shared segment within predefined and fixed time windows. The track is shared by freight and light rail, and each mode is allocated a separate and individual operating period. Occupancy of the track is typically transferred between the light rail and the railroad operations once daily. See Shared-Track Operations.

Trackage Rights

A guest railroad has trackage rights over another's tracks (the host railroad) if it has the legal authority to operate trains over the host's property, while following the host's rules and under the supervision of the host's dispatcher.

Transfer Procedures

Transfer procedures refer to the mechanisms employed to ensure that vehicles entering the shared-track territory are safely regulated and controlled. For temporally separated operations in the United States, the shared track enters freight mode when all light rail operations have ceased, the shared-track is verified as vacant by the dispatcher, and a predefined transfer procedure is carried out to change operations to freight mode.

APPENDIX 3

TCRP A-27 Research Task Descriptions

Phase I (Tasks 1–6) Effort

Phase I focused on the present and evolving state of the art in the shared-use environment, specifically examining train control technology, operating rules and procedures, communications systems, vehicles, shared-use operations, and governance and business models of existing and planned systems.

The team took a comprehensive view of "Command and Control" as including the variety of train control and communication systems, operational rules and procedures that are particularly suitable or adaptable to the shared-track environment. The emphasis was on those features that compensate for vehicle structural deficiencies by minimizing the risk of a collision in such an integrated system. While the TCRP Research Statement separated tasks 1, 2, and 3, together they comprise a unified Command and Control system and were considered in that light.

Tasks 1 and 2: Current and Emerging Train Control Technologies

Results of Tasks 1 and 2 were combined into one larger report for two major reasons. These are that: the line between current and emerging technologies is blurred due to the rapidity and breadth of advances in signaling and train control technology; and technology and applications often involve blended and overlapping issues that are difficult to distinguish conceptually. Development and deployment of train control systems are of central importance because they are designed to assist in preventing collisions between trains and between trains and other vehicles or rolling stock encroaching on the clearance envelope. The team reviewed the train control technologies used in various systems across the country and internationally and evaluated each for its applicability in shared-use environments. A description and review of the recent enhancements to conventional signaling such as positive train control (PTC) and advanced communications-based train control (CBTC) systems, were included as examples of leading edge advances. Other activities documented the influence regulations in the selection and implementation of technology; for example, adoption of grade crossing warning systems; and systems designed to identify specific hazards such as derailed freight equipment or shifted loads. The team also contacted train control system suppliers and entities planning or implementing train control system improvements or enhancements, to identify prospective equipment and technology.

The consolidated Task 1 and 2 report reviews the available train control technologies to determine the suitability of each for application in shared-use operations. It provides the

results of research into emerging technologies, to determine their applicability to the shared-use environment. Task output provided:

- *A table of different signal technologies, suitability for shared-use operations, special or distinguishing capabilities or limitations, comparative costs, and application criteria and guidelines;*
- *A table of emerging technologies and their characteristics, anticipated costs, regulatory issues, and applicability in a shared-use environment;*
- *A technical memorandum describing possible new operating Rules and Procedures, and the potential benefits and disadvantages entailed in their adoption. The report goes on to summarize how these might be combined with emerging technologies to best effect for shared-use operations;*
- *A set of guidelines for proving new integrated systems.*

Task 3: Command and Control Systems

The FRA and FTA's shared-use policy emphasizes common operational objectives. Task 3 examined the traditional roles communication and Rules and Procedures have played to ensure a safer environment in the rail industry. The focus was on non-vital systems and methods for information transmission, the content of that information and the resulting action. The team identified communication systems and other technologies that may be applied to both freight and passenger equipment and operations. It went on to review how these systems and technologies are integrated with the train control system and what methods are used to provide detection, transmission of alarms and elicit responses.

Technology was not the primary focus of this task. Instead the emphasis was understanding how it is used and applied by operating personnel and its influence on decision making. The team probed the niche and content of Rules and Procedures to understand their limitations as well as the administrative resources essential to support and enforce them. In a further effort it gathered information on techniques that are not dependent on train control technology, and a variety of operating procedures that can be employed to prevent collisions and increase the overall safety of shared railway environments.

The resulting report for Task 3 recommends a minimum standard for Command and Control systems and describes essential communications technology and Rules and Procedures.

Task 4: Light Rail Passenger Vehicles for Shared-Use

The team reviewed the list of vehicles in the current inventory and updated that inventory where necessary (e.g., changes in availability or specifications). Databases of existing railcars were supplemented with additional research about self-powered railcars. Further investigation revealed classes of vehicles that are in the process of being developed and that could impact shared-use services with attributes such as enhanced braking or crashworthiness that will be beneficial to operation in a shared-use environment.

The Task 4 report identifies new or in-development railcars and vital features that may positively impact the safety of shared-use operations.

Task 5: Shared-Track Operations and Appendix

A survey of North American shared-use operations cited in regional long-range transportation plans was conducted for the project. Transit agencies were consulted to develop an inventory of proposed shared-use operations. For each of the planned operations, the principal characteristics of the business model were described.

- Ownership of rail ROW and equipment
- Dispatching authority for both freight and passenger operations
- Division of infrastructure maintenance responsibilities
- Staffing and training responsibility
- Division of repair and emergency recovery responsibilities
- Allocation of regulatory reporting responsibilities
- Cost allocation
- Safety planning
- Public and private sector roles, if applicable
- Resolution of liability and insurance questions.

The report output comprises a presentation of regional transportation plans and programs that incorporate shared-use operations into their concepts or strategy. The most valuable details of the inventory have recapitulated for their use in future applications of planned shared-use systems.

Task 6: Phase I Interim Report

The Phase I Interim Report is a narrative of the research completed and an analysis and summary of the results accomplished in Tasks 1 through 5. Incorporation of tables, lists, matrices and specific summary and graphical materials is intended to simplify the presentation of information in those Tasks.

Phase II (Tasks 7–13) Effort

Phase II examined financing, characteristics of freight railroads, parameters, and metrics for a business model. The resulting product is a case study and a summary of characteristics and practices of shared-use operations.

Task 7: Freight Railroad Characteristics

The team examined the characteristics of "real world" shared operations for Class 1, regional, and shortline freight operations. Task outcome was to provide a baseline for understanding the critical issues and concerns of the freight railroad.

- Ownership
- Approach to financing and other business issues
- Approach to ROW maintenance, dispatching, and transportation crewing
- Role of the Surface Transportation Board

The Task 7 report identifies and records the principal characteristics of each of the classes of railroad (Class 1, regional, and short-line) that may affect passenger service on a shared-use system; and created a matrix of railroad characteristics affecting shared-use operations.

Task 8: Business Model

The consultant team developed a business model and combined information about the experiences of North American shared-use operations discussed in the Task 5 report, with the characteristics identified in Task 7. The business model includes:

- Approach to liability, indemnity, and insurance
- Ownership, rights, responsibilities and priorities, the pros and cons of public versus private ownership, and the relative ease and cost of public versus private financing

- Dispatching authority for both freight and passenger operations, and the costs and benefits of dispatching authority residing with the passenger or freight operator
- Division of maintenance responsibilities
- Role of labor agreements and Federal labor laws
- Division of repair and emergency recovery responsibilities
- Assignment of regulatory reporting responsibilities
- Cost allocation

The Task 8 report presents an outline business model for shared-use operations.

Task 9: Business Case and Practical Guide

The team developed an outline business case that could be used by new project sponsors to determine if there is a viable business case to be made. Key issues in the business case include:

- The costs and benefits of the impact on overall safety in the corridor, i.e., consideration of the total cost of introducing shared-use transit or not;
- The costs of the alternatives to shared use;
- The ROW has value and restrictions on its use. For example, the passenger operator's running trains restricts the current owner's opportunity to operate revenue freight trains, or to develop the property may justify compensation;
- Risks associated with transporting large numbers of passengers in proximity to moving trains and potentially dangerous materials should be addressed;
- Increases in the cost of operation and maintenance of the ROW improvements as a result of increased traffic and hours of operation must be suitably allocated;
- The need for waivers from the FRA to permit the passenger operation to share the track or route. There are schedules, costs, and technical impacts associated with preparation and submission of a Waiver Petition to the FRA;
- The potential benefits to the owner from investments made to improve and provide a high-quality passenger operation that may also be advantageous to the freight railroad, through faster trip times as a result of better track quality or additional customers due to the improved service potential of the line.

The Task 9 report lists and calculates both direct and indirect costs and benefits and builds a business case that can be used by agencies in support of a planned shared-use system.

Task 10: Hypothetical Case Study

The team defined a representative shared-use operation that is a composite of the actual and planned rail systems identified in Task 5. The case study examines several variants on a primary system to explore the sensitivity of the business case and risk analysis results to variations in system characteristics such as plant, equipment, and operations.

Case Study Step 1: Define and Describe Representative Rail System

Typical variants that could be explored in the case study include:

- Null or no system;
- Strict Temporal Separation;
- Separate systems sharing the same corridor;
- Concurrent (commingled) operation, true shared-use on a single track;
- Concurrent (commingled) operation, true shared-use on a double track.

Case Study Step 2: Business Case Analysis

Representative capital and operating costs for infrastructure and equipment and operations were derived for the null system, as defined in Step 1, and its four variants to obtain a set of life-cycle costs.

Case Study Step 3: Risk Analyses

A simplified risk analysis demonstrated that likely safety requirements can be met. The specific activities in the risk analysis are:

- Define risk measures and criteria for equivalent safety;
- Estimate likelihood and severity parameters of each accident scenario for the case study and the variants;
- Exercise the FRA risk model for the base case and variants using the FRA model.

The case study produced in Task 10 examines the issues related to developing a viable shared-use system.

Tasks 11 and 12: Demonstration Program and Recommended Practices

These task reports were combined because the criteria for program assessment and best practices are not discrete or unique, but in fact overlap. The logical relationship between the two is illustrated by consolidating the information.

The primary product of these tasks elaborates a clear set of criteria for evaluating programs to determine eligibility for a demonstration program. Results of the previous tasks—particularly those in Tasks 1, 2, 3, 4, 9, and 10—are used to develop a set of characteristics and criteria that can define a shared-use system.

- Business case
- Operating model
- Technology
- Regulatory framework

The combined report for Tasks 11 and 12 recommends characteristics and criteria against which programs can be measured to determine eligibility for a demonstration program. It provides a "Best Practices" handbook for planning and establishing a shared-use operation, with specific guidelines, practical strategies, technical details, and factual information. The report also notes shared or competing interests and the multiple parties to planning and implementation of shared-use operations.

Task 13: Final Report—Part II

(13.) Prepare (1) a final report that documents the entire research effort and (2) a stand-alone, user-friendly guide that explains the business case; business model(s); and technologies, operating procedures, and other techniques that could support a shared-use operation using non-FRA-compliant public transit vehicles. The guide should include descriptions and sources of real-world examples of these applications. The guide should also identify the advantages and disadvantages and the issues and barriers of shared-use operation

APPENDIX 4

Relative Cost Comparison of Train Control Systems

RELATIVE COST COMPARISON of STANDARD TRAIN CONTROL SYSTEMS & FEATURES

TRAIN CONTROL TECHNOLOGY	Conventional Wayside Signals	Conventional Wayside Signals + ATS	Conventional Wayside Signals + Cab Signals	Audio Frequency (AF) System with Wayside Signals + ATP	Audio Frequency (AF) System with Wayside Signals + Digital Cab Signals (ATP)
	Increasing System Complexity →				
TRAIN CONTROL SYSTEM ELEMENTS	Multi-aspect signals Electric Switch machines Track circuits- Power frequency or DC Impedance Power Bonds Insulated Joints on Rail Cables Relays Wayside cases Power Supplies	Multi-aspect signals Electric Switch machines Track circuits- Power frequency or DC Impedance Power Bonds Insulated Joints on Rail Cables Relays Wayside cases Power Supplies *Electro- pneumatic train stops*	Multi-aspect signals Electric Switch machines *100 Hz Coded Track circuits* Impedance Power Bonds Insulated Joints on Rail Cables Relays Wayside cases Power Supplies *Cab 4/5 code display (Clear, Approach, Restrictive)*	Multi-aspect signals Electric Switch machines *AF Track circuits, same cab frequency* *Tuned Transmitters/ Receiver Bonds* *No Insulated Joints* Cables Relays Wayside cases Power Supplies *Cab Authorized Speed display - 0, 15, 25, 45, 55..)*	*Multi-aspect signals only at interlockings* Electric Switch machines *AF Track circuits, different tunable cab frequency* *No Bonds- Use loops within S shaped Hi current capacity cable* *No Insulated Joints* Cables *Processor Based controller* Wayside cases Power Supplies *Cab display - Speed Limit, Target speed, Distance to Go*
SYSTEM CONFIGURATION	10 miles, 10 station, 4 interlockings, fleet - 40 cabs (20 X 2) two ended, 124 track circuits	10 miles, 10 station, 4 interlockings, fleet - 40 cabs (20 X 2) two ended, 124 track circuits	10 miles, 10 station, 4 interlockings, fleet - 40 cabs (20 X 2) two ended, 124 track circuits	10 miles, 10 station, 4 interlockings, fleet - 40 cabs (20 X 2) two ended, 124 track circuits	10 miles, 10 station, 4 interlockings, fleet - 40 cabs (20 X 2) two ended, 124 track circuits
ESTIMATED COST + INCREMENTAL COST	10 million	10million+ 400k	10 million + 620k	10million-320k(IB) +620k(AF) - 120k(IJ)	10million-320k(IB) +1.24million(AF) -120k(IJ) - 1miilion (space, power etc) - 100k (Signals)
COST of CAR BORNE EQUIPMENT	NA	NA	$800,000	$1,200,000	$2,000,000
TOTAL COST	**$10,000,000**	**$10,400,000**	**$11,420,000**	**$11,380,000**	**$11,799,900**
COST / UNIT - MILE	**$1,000,000**	**$1,040,000**	**$1,142,000**	**$1,138,000**	**$1,179,990**

Legend

ATS =Automatic Train Stop
ATP =Automatic Train Protection, includes cab signaling
Red / or Italics =Additional elements and changes to train control system
IJ = Insulated Joint
IB = Impedance Bond

APPENDIX 5

Sample Operating Rulebook Table of Contents

While each system's rulebook may be organized differently they all cover similar themes in a way appropriate to their system and culture. The list below reflects the content typical of operating rulebooks and can serve as a good checklist for topical inclusion in a rulebook for Shared-Track Operations.

1. TITLE PAGE (showing date, issuing authorities, version)
2. TABLE OF CONTENTS
3. TERMINOLOGY, DEFINITIONS, AND AUTHORIZED ABBREVIATIONS
4. GENERAL RULES
5. REPORTING FOR DUTY
6. MISCELLANEOUS SIGNALS
7. TAMPERING
8. INSPECTION OF EQUIPMENT
9. MOVEMENT OF TRAINS
10. PROTECTION OF TRAINS
11. TRACK PERMITS and TRACK PERMIT CONTROL SYSTEM
12. GENERAL SIGNAL RULES
13. SIGNAL ASPECTS AND INDICATIONS
14. AUTOMATIC BLOCK SIGNAL SYSTEM
15. INTERLOCKINGS AND CONTROLLED POINTS
16. RADIOS AND TELEPHONES
17. MOVEMENT OF TRACK CARS, FOREMEN AND TRACK CAR DRIVERS
18. CONTROLLERS (CONTROL CENTER)
19. TRAIN OPERATORS
20. GENERAL LIGHT RAIL TRANSIT RULES
21. LIGHT RAIL TRANSIT STREET RUNNING
22. TRACK PERMIT FORM and ILLUSTRATION

Customer service and emergency/accident/incident responses are often treated in separate documents manuals.

APPENDIX 6

Vehicle Cost Drivers

Vehicle cost factors are summarized in the two tables below, the first, "Vehicle Systems & Component" table that lists the "hard" costs of rolling stock, by noting the relative cost contribution of materials, systems and components that comprise a typical rail car. The second table, "Peripheral Support Elements" similarly reviews the "soft" or indirect support costs of typical vehicle procurements.

Vehicle Systems & Components	High	Low	Average	Median
Car Body	37%	24%	28%	30%
Windows	2%	1%	1%	1%
Seats	1%	0.59%	1%	1%
Trucks & Suspension	12%	6%	8%	7%
Wheels & Axles	2%	1%	1%	1%
Couplers	4%	1%	3%	2%
Train and Car Controls	5%	2%	3%	3%
Power Collector	0.38%	0.30%	0.30%	0.29%
Auxiliary Electrical Equipment	7%	2%	5%	6%
Propulsion	27%	10%	22%	20%
Friction Braking	8%	6%	6%	6%
Doors	11%	4%	6%	7%
HVAC	9%	6%	6%	7%
Communications	3%	2%	2%	2%
Information Signs	2%	2%	2%	2%
Lighting	2%	1%	2%	2%

Peripheral Support Elements	High	Low	Average	Median
Car Assembly	10%	1%	6%	7%
Truck Assembly	1%	1%	1%	1%
Mock-ups	1%	0.03%	0.25%	0.20%
Contract Management	7%	1%	3%	2%
Design & Engineering	8%	1%	4%	3%
Testing	2%	1%	1%	1%
System Assurance	3%	1%	1%	1%
Warranty	1%	0.19%	0.67%	0.53%
Field Support	2%	0.24%	1.16%	1.17%
Manuals	2%	1%	2%	1%
Training	1%	1%	1%	1%
Special Tools, Test and Diagnostic Equipment	4%	2%	3%	3%
Spare Parts	5%	3%	4%	4%
Other	3%	0.03%	1.21%	0.57%
Duty & Taxes	3%	0.06%	1.27%	0.98%
Total Percentage of Overall Vehicle Procurement Cost	**27%**	**11%**	**19%**	**18%**

NOTE: The totals of the high and low columns do not add up to 100% because they aggregate the highs and lows. The average and median cost columns total 97 to 98% due to rounding errors

APPENDIX 7

Some Examples of Current Production LRV and MU Vehicle Types

Alstom Citadis:
Available as Single Supply LRV, Dual Mode LRV, LRV with Short Distance Autonomous Capability

Orleans, France version

Length:	98 ft-5 in
Width:	7ft-7in
Weight (empty):	82,600 lbs
Passenger Capacity:	176 (40 seated)
Maximum Speed:	43 mph

Alstom Coradia LINT
Available as Light DMU, Light EMU

DB, Germany version

Length:	137 ft
Width:	9ft
Weight (empty):	153,000 lbs
Passenger Capacity:	320 (120 seated)
Maximum Speed:	74 mph

Bombardier Flexity:
Available as Single Supply LRV, Dual Supply LRV

Minneapolis, MN version

Length:	94 ft
Width:	8ft-8in
Weight (empty):	105,000 lbs
Passenger Capacity:	246 (66 seated)
Maximum Speed:	55 mph

Bombardier AGC
Available as Heavy DMU, Dual mode DMU, Heavy EMU

SNCF, France version

Length:	188 ft-4 in
Width:	9ft-8in
Weight (empty):	266,500 lbs
Passenger Capacity:	420 (200 seated)
Maximum Speed:	99 mph

Colorado Railcar
Available as Heavy DMU (FRA Compliant)

Single deck version

Length:	85 ft
Width:	10ft
Weight (empty):	160,600 lbs
Passenger Capacity:	98 (seated)
Maximum Speed:	90 mph

Siemens Combino
Available as Dual Mode LRV, Single Supply LRV, Dual Supply LRV

Nordhausen, Germany dual mode version

Length:	65 ft-9 in
Width:	7ft-7in
Weight (empty):	55,000 lbs
Passenger Capacity:	99 (31 seated)
Maximum Speed:	43 mph

Siemens Avanto
Available as Single Supply LRV, Dual Supply LRV

San Diego, CA version

Length:	91 ft
Width:	8ft-8in
Weight (empty):	88,000 lbs
Passenger Capacity:	162 (68 seated)
Maximum Speed:	55 mph

Siemens Desiro
Available as Light DMU, Light EMU (FRA compliant version under design)

DB, Germany version

Length:	136 ft-10 in
Width:	9 ft-4 in
Weight (empty):	150,000 lbs
Passenger Capacity:	198 (75 seated)
Maximum Speed:	74 mph

Stadler Regioshuttle
Available as Light DMU

DB, Germany version

Length:	82 ft
Width:	9 ft-6 in
Weight (empty):	94,700 lbs
Passenger Capacity:	160 (75 seated)
Maximum Speed:	74 mph

Stadler GTW
Available as Light DMU, Light EMU

New Jersey Transit version

Length:	102 ft-6 in
Width:	10ft
Weight (empty):	120,700 lbs
Passenger Capacity:	164 (70 seated)
Maximum Speed:	60 mph

United Goninan Prospector
Available as Heavy DMU

Westrail (Australia) version

Length:	175 ft- 8 in
Width:	10 ft-6 in
Weight (empty):	295,600 lbs
Passenger Capacity:	188 (seated)
Maximum Speed:	124 mph

APPENDIX 8

Shared-Track System Status

Status	System	Existing or Planned Operating Configurations						
		First Year of Active or Planned Operation	Shared Track in Recent Past	Currently Sharing Track	Planning to Share Track with Non-Compliant Vehicles	Shared Track Miles	Temporal Separation	Limited Night-time Joint Operation
Operating	MTA Baltimore Light Rail, North Line, Baltimore, Md.	1988	●	○	○	10.9	○	○
	OCTranspo Capital Railway "Ottawa O-Train", Ont.	2003	●	○	○	5.0	○	○
	Utah Transit Authority, TRAX Sandy Line, Salt Lake City, Utah	2001	●	●	○	12.0	●	○
	NJ Transit, River LINE	2004	●	●	○	33.0	●	◗
	San Diego Trolley Inc., Blue & Orange Lines, San Diego, Calif.	1981	●	●	○	31.1	●	●
	NJ Transit, Newark City Subway, Newark NJ	1999	●	●	○	0.2	n/a	●*
Final Design	North County Oceanside-Escondido SPRINTER, Calif.	2006	○	○	●	22.0	◗	○
	Capital Metro, Northwest Austin "Commuter Rail", Austin Tex.	2008	○	○	●	33.0	◗	○
EIS	MARTA, Belt Line, Atlanta, Ga.	n/a	○	○	●	~8	◗	○
	Madison, Wis. Transport 2020 Study	n/a	○	○	●	~12	◗	○
	BART, I-80 "eBART" Feasibility Study	n/a	○	○	?	~10	◗	○
	BART, I-580 Corridor Transit Study	n/a	○	○	?	~14	◗	○
	Sonoma-Marin Area Rail Transit, Marin County, Calif.	n/a	○	○	?	?	?	?
Feasibility	Denton County Transportation Authority, Denton to Carrollton, Tex.	n/a	○	○	●	~14	◗	○
	Five Town Rural Transit, Inc., East End Shuttle, Suffolk County, NY	n/a	○	○	?	?	?	?
Chose to Avoid Commingling	Triangle Transit, Raleigh-Durham Regional Rail, N.C.	2008	○	○	○	0.0	○	○
	Tri-Met, Washington County Commuter Rail, Ore.	2008	○	○	○	0.0	○	○
	NJ Transit, Northern Branch Rail Project, North Bergen to Tenafly, N.J.	n/a	○	○	○	0.0	○	○
	FDOT, Central Florida Commuter Corridor Study, Fla.	2009	○	○	○	0.0	○	○
	BART, State Route 4 Transit Study	n/a	○	○	○	0.0	○	○

● Active ◗ Planned ○ Not active ? Not determined

Source: E&K Analysis based on FRA Data, FRA Dockets, and local plans.
* Newark City Subway has provisions for dynamic temporal separation. Light rail and freight trains do not operate on shared-track at the same time, but the track can be changed at any time between passenger and freight modes by having the freight train conductor request a mode change from the NJ Transit dispatcher.

APPENDIX 9

Shared-Track Configuration and Operational Alternatives

Option Operating Regime	1 Strict Temporal Separation	2 Spatial Separation	3 Concurrent Single Track	4 Concurrent Double Track
Train Control System Description:	Under temporal separation, automatic train stop isn't strictly necessary. Access can be restricted by an interlocked switch and derail, protected by electric locks and points indicators. A special software program is required on the CTC system console for the diurnal "transfer procedure" that enables the dispatcher to "unlock" the freight connection and locks the light rail yard at the prescribed time. Intrusion detection may or may not be necessary depending upon the freight activity and/or clearances.	With spatial separation, automated train stops are required for any diamonds. This option enables freight to operate at all times of the day. The automatic train stop (ATS) system on the LRVs protects crossings of freight trains over the switch diamonds. The ATS would be a two-aspect system that initiates the emergency brake should an LRV fail to stop. The train stop would be located at braking distance from the fouling point of the diamond crossing. Intrusion detection may or may not be necessary depending upon the freight activity and/or clearances.	For single concurrent shared-track, a cab signal system with automatic speed control would be required on both freight and passenger trains. The line would be signaled and maintained for maximum passenger and freight speeds of 60 mph and 30 mph respectively, requiring a three-aspect system that regulates speed and initiates braking prior to STOP signals. The system would supervise train speeds and enforce maximum speeds. It could be transponder based or coded-track circuit based. Intrusion detection may or may not be necessary depending upon the freight activity and/or clearances.	For concurrently shared double-track, the same Option 3 signal system would be required. Under this scenario, a freight train could pass an opposing light rail train at speed on adjacent tracks, increasing the risk of shifted-lading strikes. On a single-track system, close clearances between two tracks may be less common. Intrusion detection may or may not be necessary depending upon the freight activity and/or clearances.
Infrastructure	Note the physical configuration, track layout (single and double), grade crossings, structures, alignment, grades, route environment (e.g. downtown or suburban), sidings, crossovers, freight customer facilities, stations. Train Control System – e.g. Centralized Traffic Control (CTC) is provided, with train movements controlled by wayside block and interlocking signals. All freight connections to passenger tracks are interlocked with the signal system, and are protected by derails. At siding connections, the predominant danger is unattended freight cars rolling onto the main line – and not a moving freight train that has exceeded movement authority.	The requirements listed in Option 1 apply. However, in this scenario a dedicated track is provided for freight service. Fail-safe train separation (automatic train stop) is only provided at diamond crossings between freight and light-rail track. Depending upon local geometric constraints, the freight track may need to be reconstructed completely to make room for stations and other passenger facilities. The track roadbed may also need to be widened.	The requirements listed in Option 1 apply. The proposed concurrent shared-track system features 15 minute peak headways and half-hourly off-peak service. Light rail tracks may extend to the downtown district via the local street network. Simple island-platform stations provide passenger ingress and egress. A cab signal system protects against freight-light rail collisions. Estimate the end-to-end trip time and allow the "turn-time" to change ends at the terminal station to calculate hourly round-trip car cycles. Passing sidings may be required for flexibility.	The requirements listed in Option 1 apply. The transit system would operate every 15 minutes in the peak, and 30 minutes off-peak. The double-track allows increased train frequencies without new construction and provides better passenger on-time performance. The main motivations of double tracking are threefold: 1. More reliable passengerservice; 2. Greater flexibility in service planning for passengers and freight services; 3. Greater passenger safety.

Option **Operating Regime**	**1** **Strict Temporal Separation**	**2** **Spatial Separation**	**3** **Concurrent Single Track**	**4** **Concurrent Double Track**
Infrastructure	All signal and communication systems, track and structures are designed, constructed inspected and maintained to FRA standards. NORAC (see note 1) operating rules are used for all freight and passenger movements. Track is maintained to FRA Class III. Grade crossing warning systems should be upgraded to MUTCD standards and be equipped with flashers, bells, and gates. Low-volume or private crossings can be protected by flashers and bells if authorized by State (see note 2).		Freight trains will not operate during the passenger peak periods. During the off-peak period, freight trains will serve customers en-route, using the sidings to allow half-hourly passenger services to 'get by' as appropriate.	In essence, when one track segment is blocked out to serve a freight customer, the passenger service 'sees' an additional 'single track' section. These constraints impact passenger scheduling, but not as severely as it does with single track.
Passenger Operations & Timetable	Identify operations via track shared with the freight carrier and the distance traveled over shared-track. Note the time of passenger service operations, i.e. hours each weekday from start to finish. Describe the temporally separated shared-track, e.g., is it primarily single track with any passing sidings to provide for bi-directional passenger operations. Prepare a train schedule. Typically a service may operate at 15 minute headways during the daily peak service hours and 30 minute headways during the off-peak. This provides the total daily weekday trips in each direction, and peak hour trips. This will establish the number of trains in operation during peak and off-peak service.	The information requirements of Option 1 apply. Along side the freight track there is now a dedicated transit track. It is primarily single track with two passing sidings to provide for bi-directional passenger operations. The light rail passenger service differs from Option 1 by having extended service hours earlier in the morning and later into the night. The passenger service can operate 20 hours each weekday from 5am to 1am the next morning. Weekend services can span the same hours but may have longer headways. As an example, service can operate with 15 minute headways during the peak service hours and 30 minute headways during the off peak, except at late nights when the headway is hourly.	The information requirements of Option 1 apply. The light rail passenger service differs from Option 1 by having extended service hours earlier in the morning and later into the night. The passenger service can operate 20 hours each weekday from 5am to 1am the next morning if it wishes. Weekend services can span the same hours but may have longer headways. As an example, service can operate with 15 minute headways during the peak service hours and 30 minute headways during the off peak, except at late nights when the headway is hourly.	The information requirements of Option 1 apply. The light rail passenger service differs from Option 1 by having extended service hours earlier in the morning and later into the night. The passenger service can operate 20 hours each weekday from 5am to 1am the next morningif it wishes. Weekend services can span the same hours but may have longer headways. As an example, service can operate with 15 minute headways during the peak service hours and 30 minute headways during the off peak, except at late nights when the headway is hourly.
Passenger Distribution	Identify the heaviest ridership period in the shared-track area on any single train during the typical service day. Establish any train meets during the rush-hour. Estimate ridership during the midday off-peak period by time of day, segment and direction. Calculation of the passenger loading of trains is a key input to the risk assessment. Ridership varies substantially by time of day. Under this option the incremental risk of adding freight service is influenced by off-peak train occupancy, so knowing hour by hour train occupancy is necessary.	The information requirements for Option 1 apply. However, ridership for Option 2 captures additional early morning and late night riders. Overall passenger mobility is increased with ridership above temporal separation because of the extended hours. Therefore the ridership calculations will vary.	The information requirements for Option 1 apply. The assumption for rider distribution for Option 3 remains the same as Option 2, since the service headway and the span of service remains unchanged. Therefore the ridership calculations will vary.	The information requirements for Option 1 apply. Passenger distribution for Option 4 is the same as Option 2. Therefore the ridership calculations will vary. A full major investment analysis would determine whether the incremental benefit of double-track justifies the incremental cost of its construction.

Option Operating Regime	1 Strict Temporal Separation	2 Spatial Separation	3 Concurrent Single Track	4 Concurrent Double Track
Freight Operations	With the introduction of temporal separation, some changes to freight operations are necessary. Identify the volume and mix of traffic moved. Note the changes to times for pick-ups and deliveries, on/off duty times for crews, impacts on train movements, complications for customers. Certain customers may not have the flexibility to alter their receiving hours. Reconstruction or reconfiguration of customer sidings may also result.	Freight service on the reconstructed freight track remains unchanged. At any transit/freight track crossings or diamonds, the freight train conductor must contact the transit dispatcher to request permission to cross. Rebuilt track can be built to a higher class in order to raise speeds if desired. Increased speed can be an operating benefit from a transit investment. Under temporal-separation, service markedly deteriorated for some customers. With a separate system arrangement, few additional freight benefits are accrued (over the "null" condition). Both the good and bad aspects of the status quo are maintained.	With concurrent shared-track, greater latitude to design freight services is available. The freight local no longer has to work in the exclusive freight window. The on-duty time can be chosen to suit the business. Freight moves can be scheduled to minimize conflict with the passenger traffic. The improved line speeds allow the freight train to complete the interchange and return more quickly. The chance of "trapping" freight equipment may be minimized. The fully concurrent track sharing affords much more flexibility to the freight carrier. If the traffic pattern should change, then freight train starts can be adjusted. Freight trains can operate any time except during the passenger rush hours, although the locomotive must have fail-safe train protection equipment installed. The freight service under Option 3 is comparable to the base case. None of the services are markedly deteriorated, and some aspects improved for some customers. Furthermore, the transit investment in passing sidings allows more flexibility in operations, reduced time for run-arounds, and faster track speeds.	The freight service operation remains basically the same as Option 3. With shared double-track available, there is much more track for recovery from a disrupted schedule or unexpected events. The double-track affords maximum flexibility to the freight and transit operation to change their shared service plan to provide best service to their customers and constituencies. The freight service is comparable to the base case, but can operate faster, more reliably, and more flexibly.

1.) The NORAC rulebook is referenced because of broad application in Northeast region of U.S.; other standard freight rulebooks do exist and could be used where appropriate.
2.) Grade Crossing Warning Systems at grade crossings are NOT mandated by the FRA or Federal Government. State Law typically establishes the requirements for the type of system installed. The configuration, technology, traffic controls of grade crossings and warning systems are within state and local purview. However, once installed they have to function and be maintained in accordance with FRA 49 CFR Part 234 requirements. The absence or presence of grade crossing warning systems may affect the outcome of the FRA review of a Waiver Petition.

For each option it may be necessary to prepare tables, graphics and charts to aid understanding and illustrate the operating characteristics of each option. These would be prepared to support the Major Investment Study and could be adapted for presentation to the FRA in pursuit of a waiver petition.

- Graphic representation of track occupancy by time of day and route segment for freight and passenger movements
- Traditional schedule "stringlines"
- Passenger Train Schedules
- Passenger Loading per train, time of day, daily trips, standees
- Track schematics and diagrams for each option

Samples of formats and applications of these graphic presentations are included in Task 10 Hypothetical Case Study Report.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation