RMRA Alternatives Development Workshop

Market Analysis
Technology Options
Corridors

November 1, 2008

High Speed Rail Feasibility Study

TEMS, Inc. / Quandel Consultants, LLC

Alternatives Development Workshop

November 1, 2008

Workshop Process/Organization

High Speed Rail Market Analysis

High Speed Rail Technology/Operations

Proposed Route Options

Session #1 - 3 Breakout Groups

- I-70 Route Options
- I-25 Route Options (2)

Session #2 - Denver Metro Route Options

Selection of Reasonable Alternatives

- Combination Market, Operating and Engineering Options

Conclusions/ Other Business

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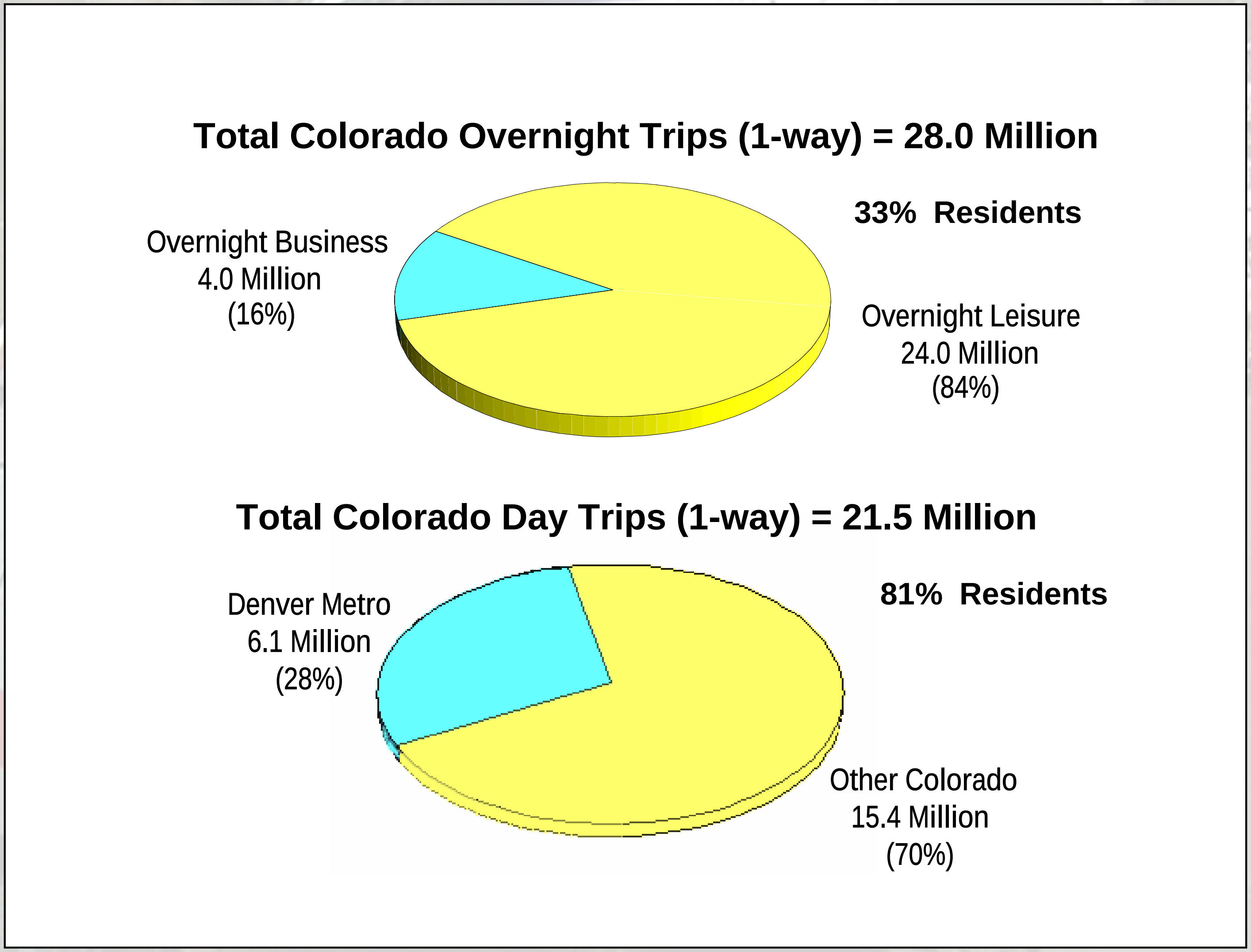
Overnight and Day Trips in Colorado 2007



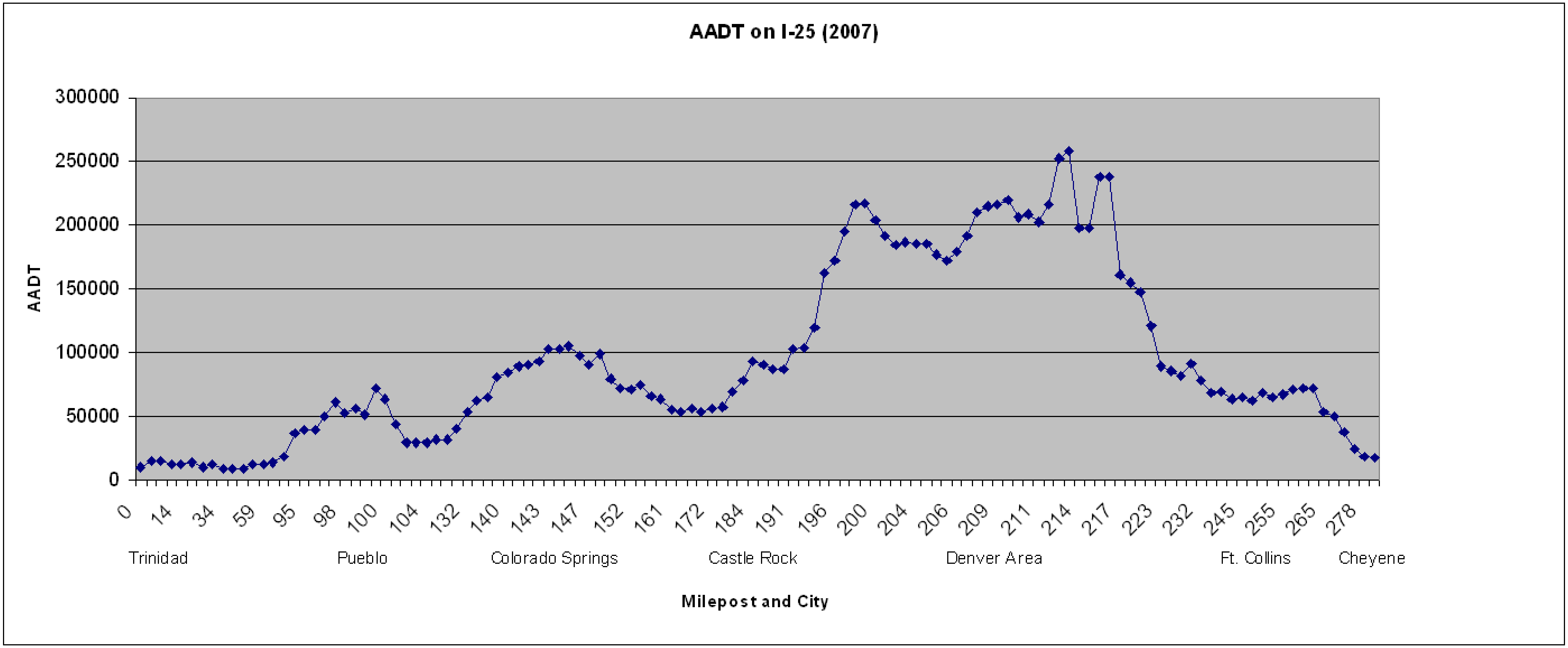
Source: Longwoods International Colorado Travel Year 2007

Colorado Skier Visits

	1998-99	1999-2000	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08
Destination Resorts										
Aspen Highlands	142,090	127,389	140,640	136,136	157,317	160,836	167,390	193,242	193,648	211,635
Aspen Mountain	334,536	331,121	319,343	310,381	315,130	298,830	304,495	324,465	328,002	337,774
Buttermilk	178,089	158,194	148,826	145,683	141,077	139,213	148,012	159,081	153,957	154,926
Crested Butte	462,478	414,642	367,263	336,483	342,416	333,011	375,936	411,729	366,765	416,009
Cuchara	21,678	32,154	DNO	DNO	DNO	DNO	DNO	DNO	DNO	DNO
Durango	304,735	235,000	321,600	250,500	263,712	268,486	278,767	211,003	251,794	278,994
Howelsen Hill	14,475	14,000	14,000	15,208	14,000	14,009	16,526	18,423	17,054	20,128
Silverton Mountain	DNO	DNO	DNO	DNO	2,382	3,600	3,683	3,900	5,589	6,000
Snowmass	777,140	707,600	740,241	676,505	669,701	724,752	747,293	768,007	770,407	771,455
Steamboat	1,013,254	1,024,832	1,003,317	1,001,003	1,001,020	1,002,821	971,770	1,046,650	1,071,786	1,022,193
Telluride	382,467	309,737	334,506	341,370	367,252	367,775	411,396	390,346	426,244	450,730
Wolf Creek	202,053	114,802	187,116	170,847	183,907	210,857	215,821	197,052	222,979	195,583
Total Destination	3,832,995	3,469,471	3,576,852	3,384,116	3,457,914	3,524,190	3,641,089	3,723,898	3,808,225	3,865,427
Front Range Destination										
Beaver Creek	614,549	586,004	676,528	657,956	718,353	768,542	815,350	875,455	889,812	917,863
Breckenridge	1,385,927	1,444,365	1,422,783	1,468,518	1,424,770	1,402,055	1,470,961	1,619,043	1,650,321	1,630,106
Copper Mountain	867,394	803,312	992,888	1,005,913	1,058,016	931,143	1,046,242	1,132,021	1,046,959	934,870
Keystone	1,253,192	1,192,198	1,230,100	1,069,111	1,038,942	944,433	1,021,069	1,093,939	1,170,710	1,129,608
Vail	1,334,939	1,371,702	1,645,902	1,536,024	1,610,961	1,555,513	1,568,192	1,676,119	1,608,204	1,569,788
Winter Park	980,408	902,827	978,539	975,256	998,772	955,615	990,837	1,077,001	1,007,582	1,000,221
Total Front Range Destination	6,436,409	6,300,408	6,946,740	6,712,778	6,849,814	6,557,301	6,912,651	7,473,578	7,373,588	7,182,456
Gems/Front Range Resorts										
Arapahoe Basin	267,406	220,945	240,406	151,678	317,401	275,428	328,892	326,428	360,247	430,897
Berthoud	20,101	16,870	20,160	DNO	DNO	DNO	DNO	DNO	DNO	DNO
Echo Mountain	DNO	DNO	DNO	DNO	DNO	DNO	DNO	3,238	18,758	23,073
Eldora	175,939	229,785	233,741	250,000	286,528	278,454	281,242	305,030	308,794	286,017
Loveland	230,333	225,896	209,757	199,781	244,621	203,916	240,961	245,610	263,163	280,683
Monarch	140,000	127,215	147,266	138,850	147,094	144,984	142,190	166,451	160,941	175,173
Powderhorn	55,613	71,941	70,118	76,456	79,624	82,948	81,893	79,103	70,714	83,014
Ski Cooper	62,145	60,171	66,225	68,893	64,499	58,408	57,389	64,751	56,669	61,394
SolVista	90,330	92,514	71,303	62,837	65,900	58,482	57,886	64,882	71,633	74,459
Sunlight	78,290	77,047	84,104	82,742	92,382	66,650	72,004	80,139	73,567	78,010
Total Gems/Front Range Destination	1,120,157	1,122,384	1,143,080	1,031,237	1,298,049	1,169,270	1,262,457	1,335,632	1,384,486	1,492,720
Total:	11,389,561	10,892,263	11,666,672	11,128,131	11,605,777	11,250,761	11,816,197	12,533,108	12,566,299	12,540,603
# Increase/Decrease	(590,158)	(497,298)	774,409	(538,541)	477,646	(355,016)	565,436	716,911	33,191	(25,696)
% Increase/Decrease	-4.93%	-4.37%	7.11%	-4.62%	4.29%	-3.06%	5.03%	6.07%	0.26%	-0.20%

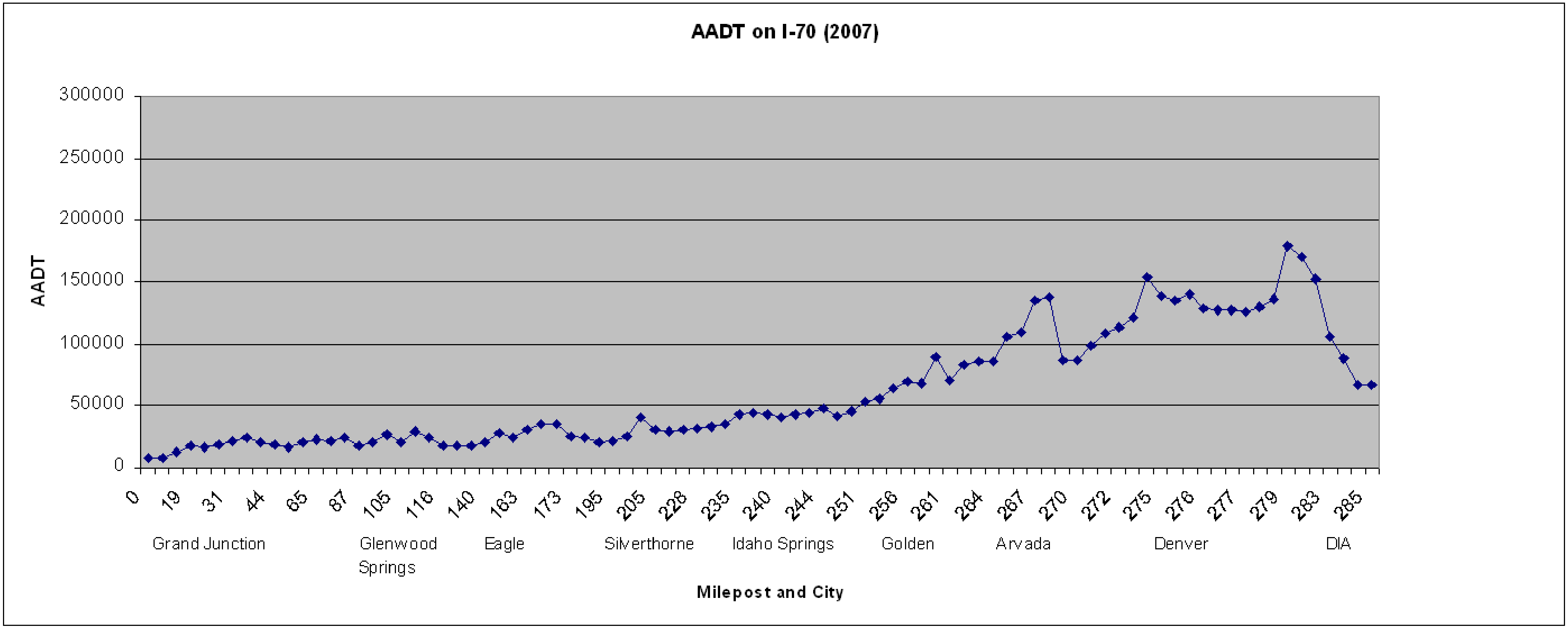
Source: Colorado Ski Country USA, http://media-coloradoski.com/cscfacts/skiervisits/

AADT on I-25



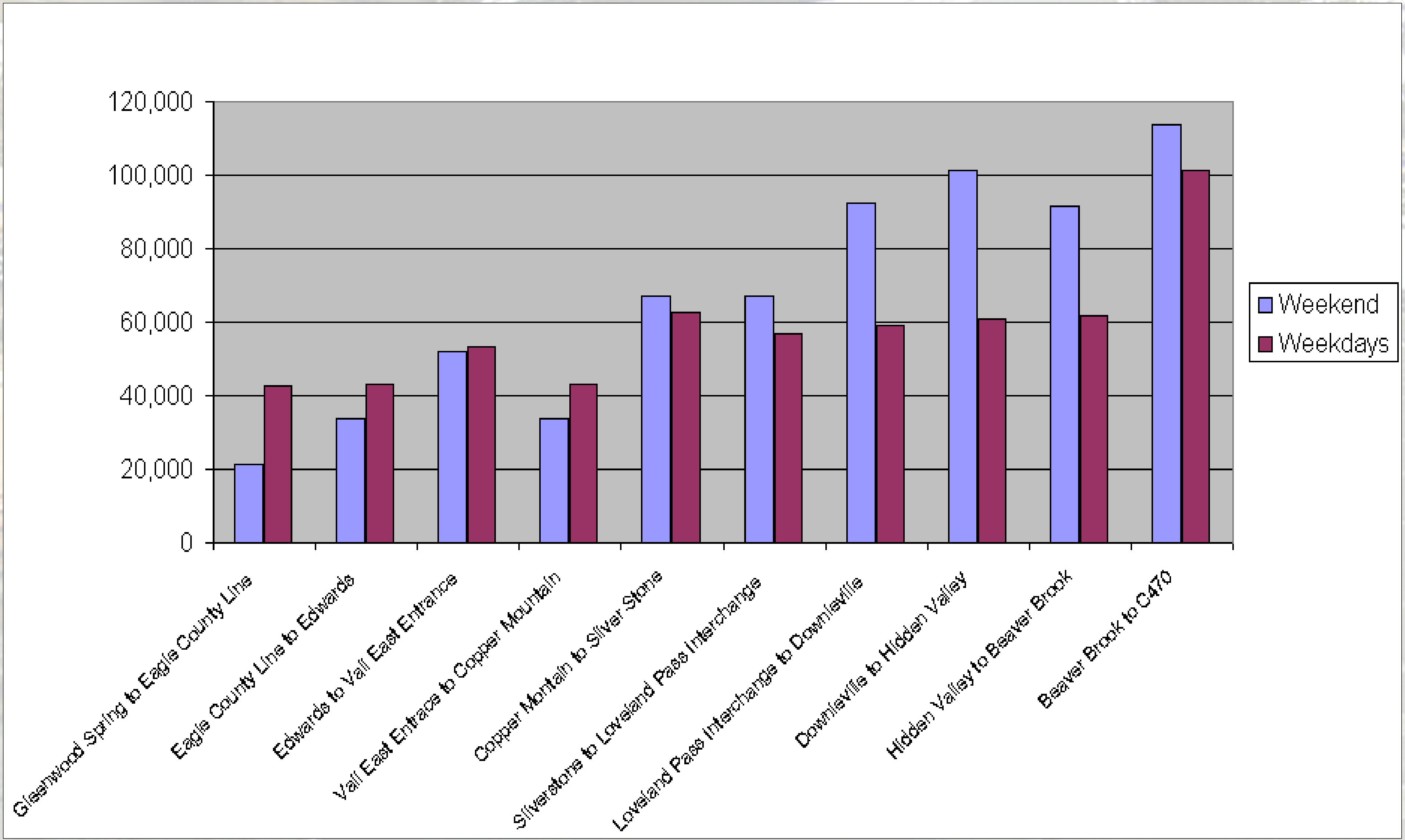
Source: CDOT, www.dot.state.co.us/App_DTS_DataAccess/index.ctm

AADT on I-70



Source: CDOT, www.dot.state.co.us/App_DTS_DataAccess/index.ctm

I-70 Corridor Weekday and Weekend Daily Vehicle Trips



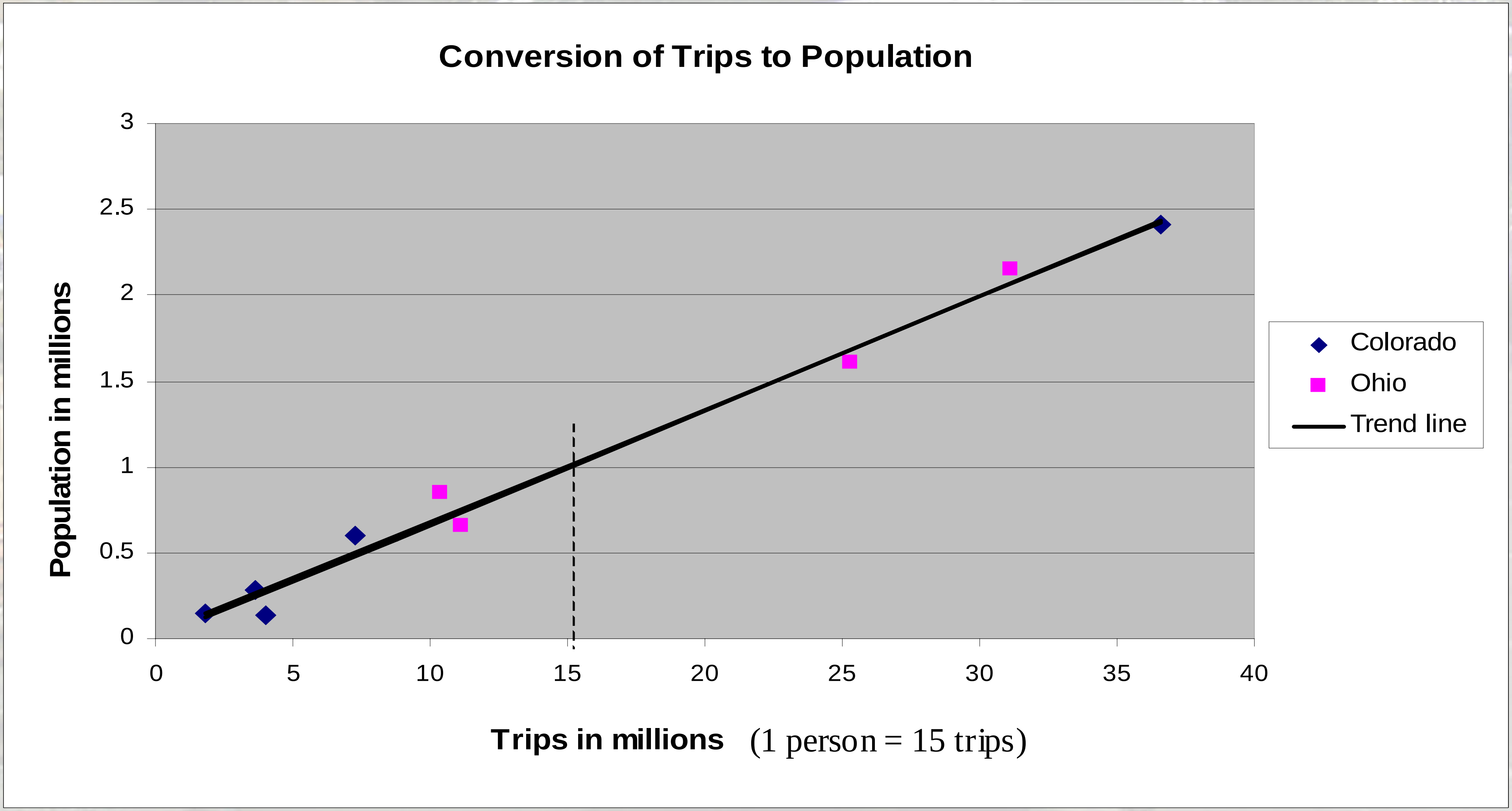
Source: I-70 PEIS

Preliminary Assessment of Major Generation and Attraction Centers for Annual Intercity Trips*

Key Locations for Intercity Trips	
Total Trips Colorado	99 million trips
Total Trips Colorado (overnight)	56 million trips
Total Trips Colorado (day)	43 million trips
Denver Airport (passengers & employees)	44 million trips
Denver	36.6 million trips
Colorado Springs	7.3 million trips
Fort Collins-Loveland	3.6 million trips
Pueblo	1.8 million trips
Boulder-Longmont	3.6 million trips
Blackhawk/Central City	12 million trips
Vail	7.9 million trips
Aspen	7.4 million trips
Breckenridge	8.2 million trips
Keystone	5.7 million trips
Copper Mountain	4.7 million trips
Steamboat	5.1 million trips
Glenwood Springs	3.4 million trips
Avon	4.6 million trips
Grand Junction	4 million trips
Georgetown	1.5 million trips
Winter Park	5 million trips

*TEMS Analysis based on the data from Longwoods International, AADT flows, Denver Airport Master Plan, and Colorado Ski Country USA.

Conversion of Trips to Population



Conversion of Trips to Population

Population = 0.0664 * Trips ($R^2 = 0.9905$)

(t-stat = 29.37)

1 person = 15 trips (including visitors)

1 person = 10 trips (locally generated)

Trips and Population Equivalence of Key Locations in Colorado

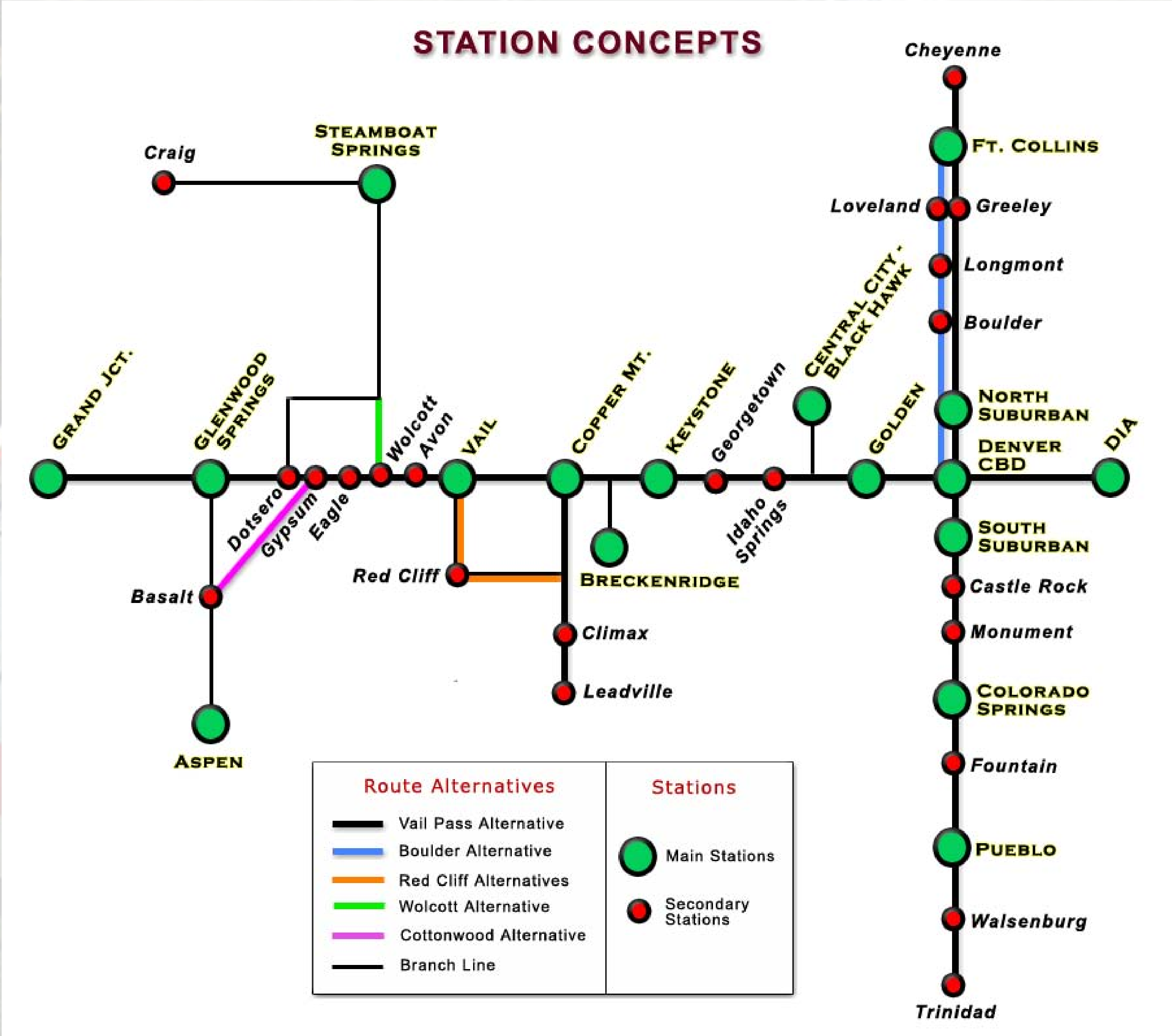
Regions	Places of Attraction	Trips (in millions)	Population	Population Equivalence
DIA	DIA	44.0	0	2,921,600
	Total	44.0	0	2,921,600
Denver	Denver	36.6	2,411,836	2,411,836
	Total	36.6	2,411,836	2,411,836
South of Denver	Colorado Springs	7.3	602,496	602,496
	Pueblo	1.8	152,081	152,081
	Total	9.1	754,577	754,577
North of Denver	Boulder-Longmont	3.6	288,125	288,125
	Fort Collins-Loveland	3.6	281,620	281,620
	Total	7.2	569,745	569,745
Rockies	Blackhawk/Central City	12.0	633	796,800
	Vail	7.9	4,531	524,560
	Aspen	7.4	5,914	491,360
	Breckenridge	8.2	2,408	544,480
	Keystone	5.7	825	378,480
	Copper Mountain	4.7	289	312,080
	Steamboat	5.1	9,815	338,640
	Glenwood Springs	3.4	7,736	225,760
	Avon	4.6	5,561	305,440
	Grand Junction	4.0	134,061	265,600
	Georgetown	1.5	1,088	99,600
	Winter Park	5.0	662	332,000
	Total	69.5	173,523	4,614,800
	Grand Total	**166.4**	**3,909,681**	**11,272,558**

Source:TEMS, Inc.

SOURCES

- "Colorado & Denver 2007 Travel Year" by Longwoods International
- Colorado Ski Country USA
- I-70 PEIS
- CDOT AADT Database
- Colorado Data Book
- Bureau of Transportation Statistics
- Bureau of Economic Analysis
- www.colorado.gov
- www.city-data.com

Station Concepts



RMRA Alternatives Development Workshop

Technology Options

November 1, 2008

High Speed Rail Feasibility Study

Presentation Outline

- **Structure of Assessment**
  - Technology categories
- **Regulatory and Methodology Review**
  - FRA regulations
  - Technology performance parameters
    - Alignment speed evaluation approach
    - Rail Technology Variants
    - Maglev Technology Variants
    - Approach to Novel Technology Evaluation
- **Representative Technologies**
  - Rail and maglev options

Structure of Assessment

Technologies will be Clustered, based on speed capability, into the following five Categories:

	79-mph	110-130 mph	150-220 mph	250-300 mph
Rail	X	X	X	
Maglev		X		X

Within each category the performance capabilities of the vehicles will be very similar. The objective is to develop a representative “Generic Train” specification that characterizes the technology for the purpose of evaluation.

Regulatory and Methodology Review

FRA Safety Regulations

- **FRA Regulations define basic safety rules for window glazing, interior lighting, baggage securement, etc.**
  - **These apply to <u>all</u> equipment, steel wheel and maglev, regardless of track sharing.**
- **Tier I and Tier II crashworthiness standards.**
  - **For Steel Wheel equipment that operates on the US national freight and passenger rail system.**
    - FRA Requires Tier I/II for sharing tracks.
    - Class I Railroads are increasingly requiring it just to share ROW and not tracks (e.g. RTD).
    - Tier I/II not required for vehicles that do not share track or ROW with freight rail.
  - **Technical Requirements:**
    - Buff strength requirement for passenger cars of 800,000# is the <u>same</u> for both tier I and tier II passenger cars.
    - Tier II locomotives need 2,100,000# buff strength.
    - Tier II equipment must be designed for “crash energy management.”
    - Leading unit may not be occupied by passengers in Tier II equipment.

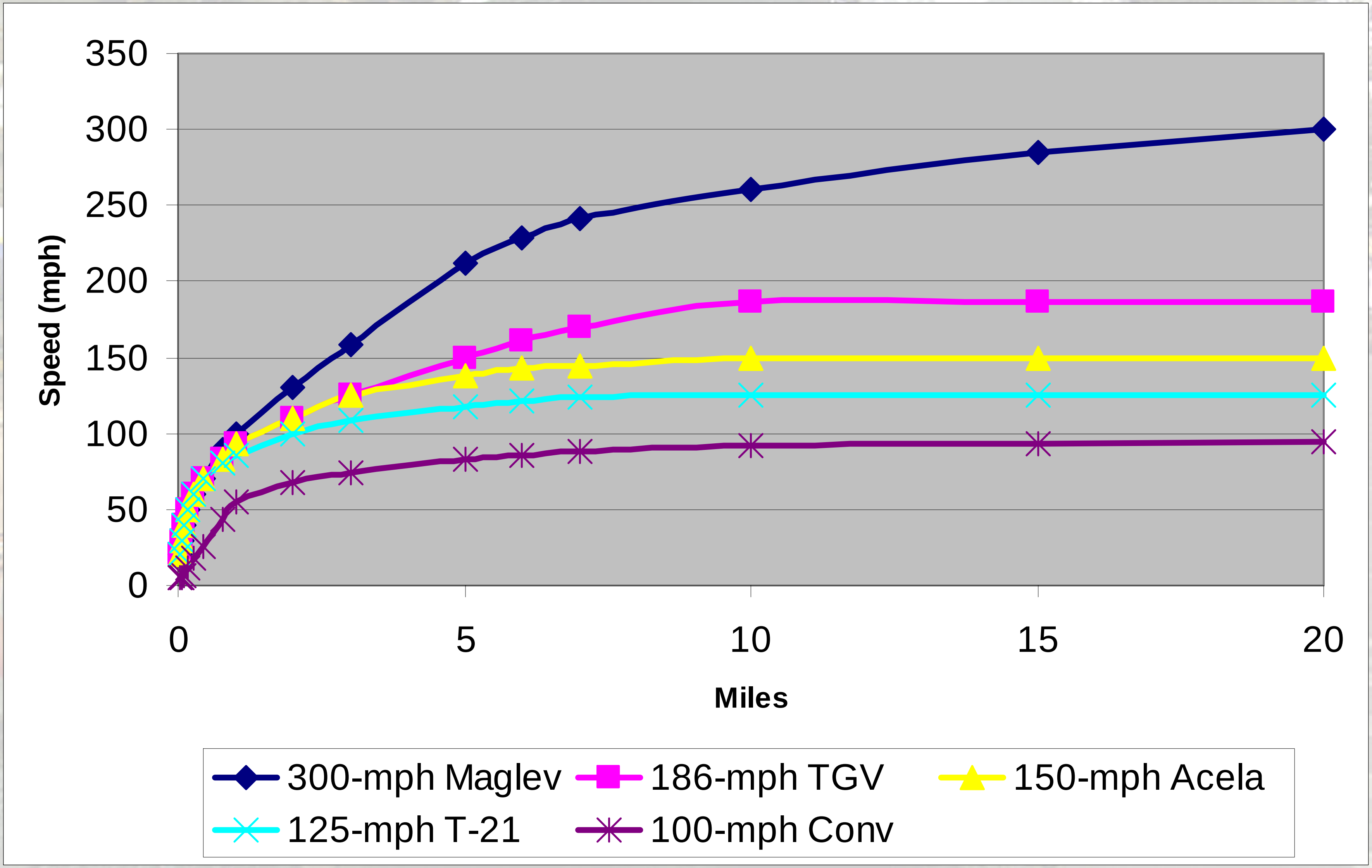
Technology Assessment Process

- **The steel-wheel technology assessment includes both “Compliant” and “Non Compliant” equipment types.**
  – Our evaluation indicates that “Non Compliant” steel-wheel equipment could generally be made “Compliant” to US Standards for about 10% weight penalty over comparable European practice.
  – Within this range it is generally possible to compensate the effect of small added weight by adding power to maintain train performance. With this caveat, the European train performance curves still remain applicable.

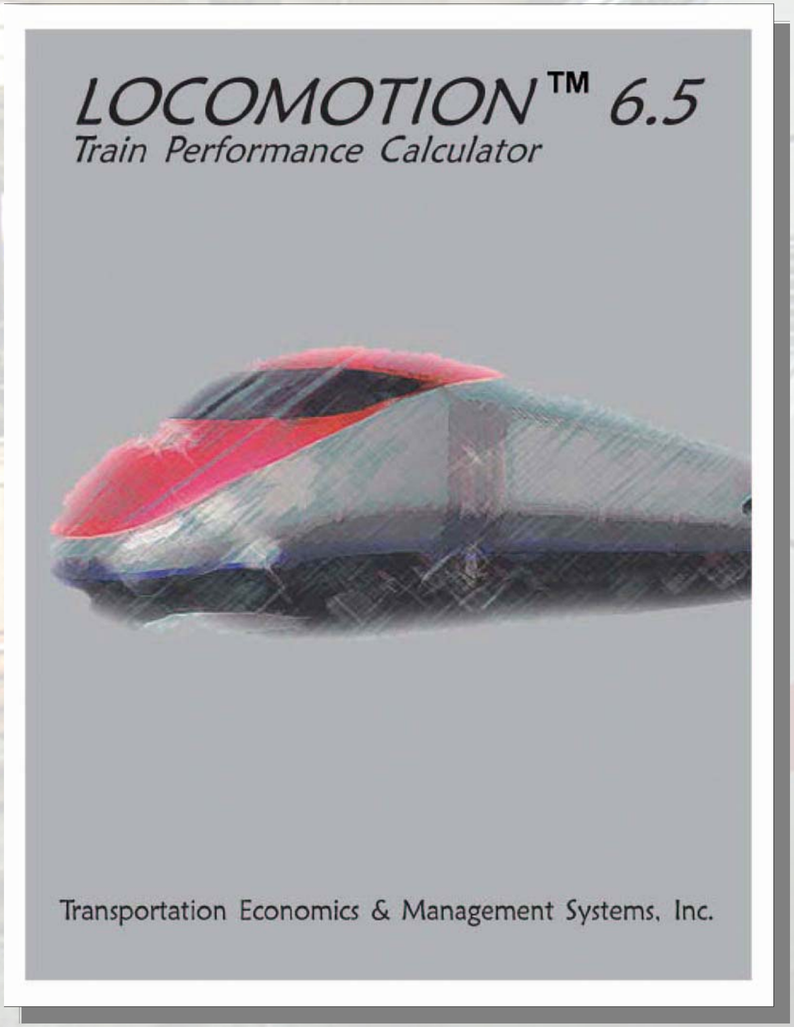
- **The technology assessment includes a range of Maglev equipment types and technologies.**
  – Only the Transrapid system is in commercial High Speed operation today.
  – HSST Maglev is in commercial Low Speed operation today. Conceptually similar systems have been developed by both American Maglev and General Atomics and are on test tracks.
  – We will evaluate Low Speed maglev based on the system parameters that were developed by the 2004 Colorado Maglev Study. It has been estimated that a $400-600 Million R&D effort (in $2003) will be required to realize these parameters in practice.

Maglev and Steel-Wheel Performance

(Straight and Level Track)

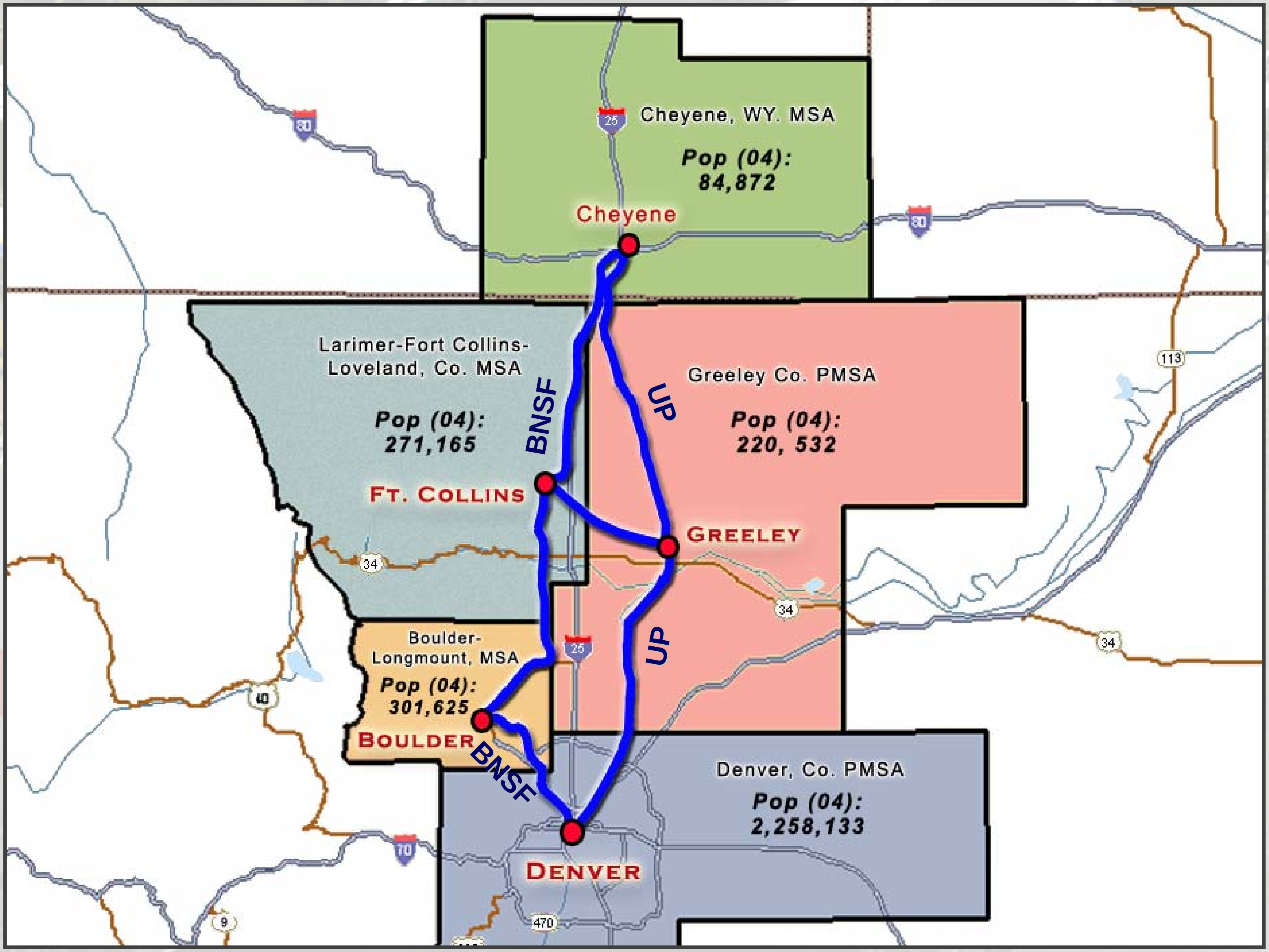


LOCOMOTION™ will estimate Train Speeds and Timetables



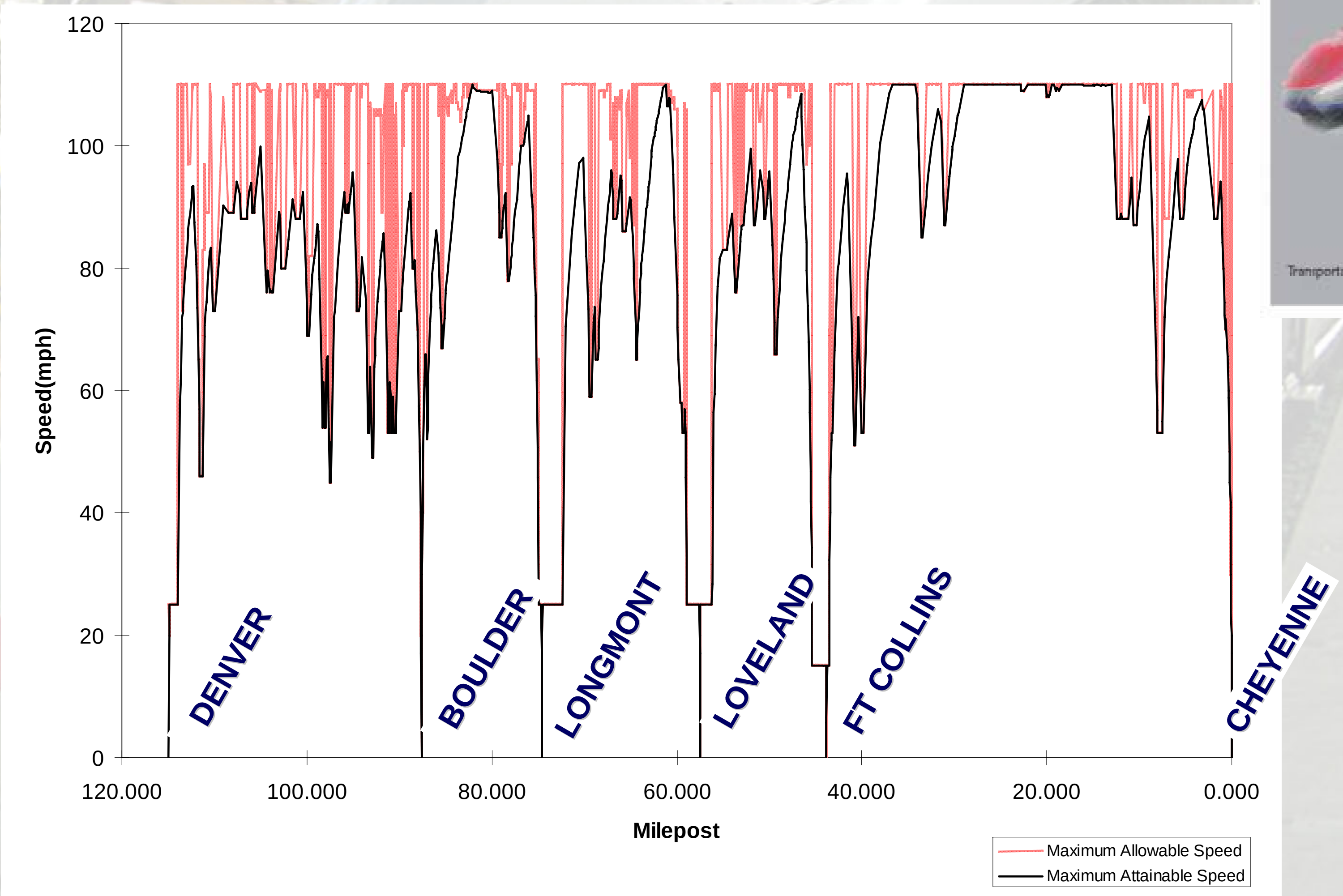
- **LOCOMOTION™** generates optimized timetables for given track infrastructure, signaling systems, and train technologies. It provides milepost-by-milepost graphic output of train performance based on track characteristics and shows the effect on timetables for improving the track, using a different technology.
- Because **LOCOMOTION™** takes account of other passenger and freight traffic using a right-of-way, it can develop stringline diagrams and identify the optimum train path for a new service.

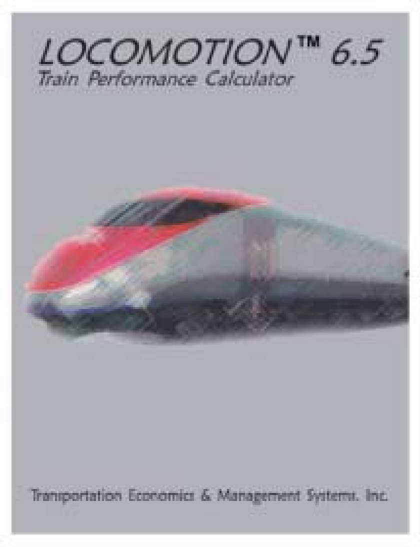
Case Study:
UP vs. BNSF Northern Options



Train Performance Evaluation
("First Cut" and Preliminary)

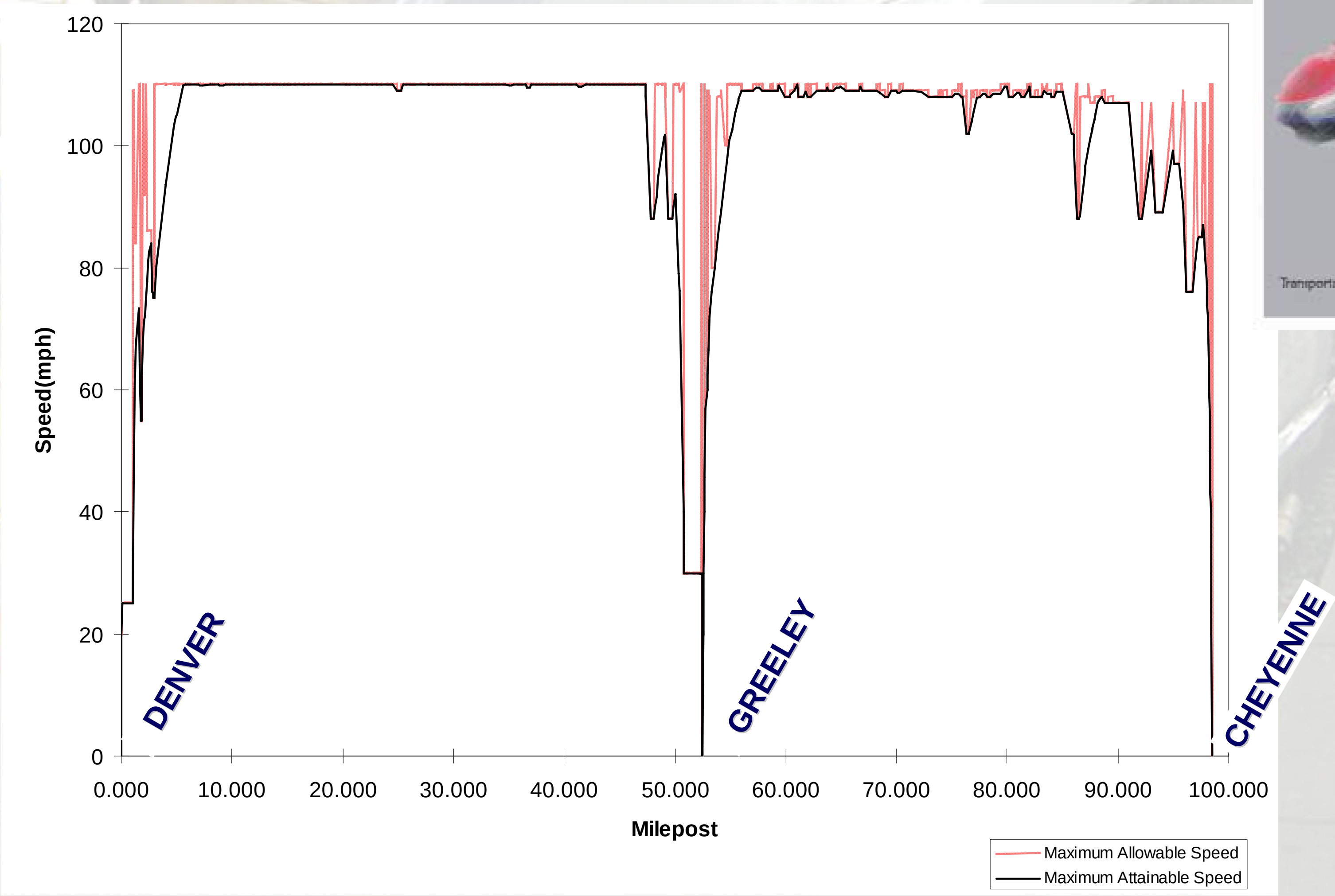
Speed Profile – BNSF Line
115 miles – 1:48 Running Time

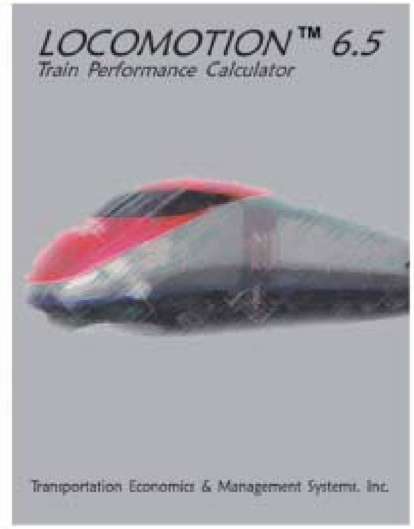




Train Performance Evaluation
(“First Cut” and Preliminary)

Speed Profile – UP Line
98 miles – 1:05 Running Time

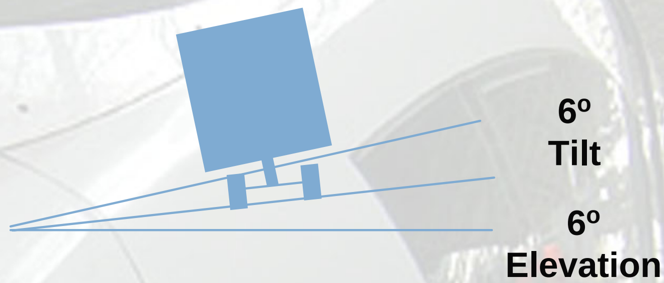




Rail and Maglev Curving Capabilities

MAGLEV

TILT TRAIN



Banking Capabilities

- Maglev and Rail tilt train banking capabilities are both approximately12º within FRA guidelines, practically equivalent to one another.
- Will lead to essentially the same speed restrictions through curves.
- Maglev and Rail tilt trains will both be faster (20-30%) than equivalent non-tilting trains.

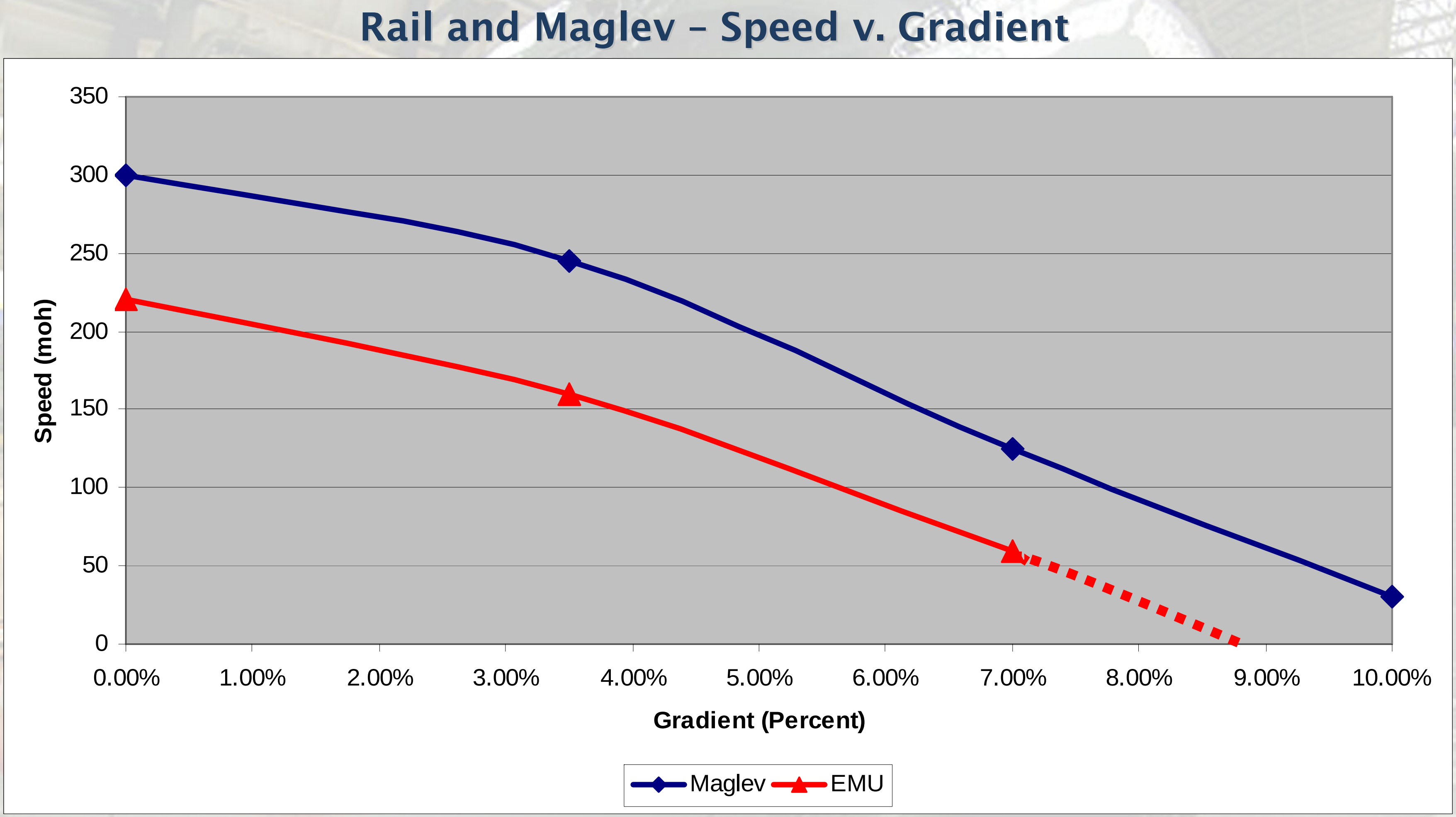
Calculation of Degrees Curvature

Degree	Radius
1	5,730 feet
2	2,865 feet
3	1,910 feet
4	1,433 feet
5	1,146 feet
6	955 feet

Maglev or Tilt Train Speed through Curves

	Passenger Reference Speeds (mph) with 6.0" Deficiency					
	Degree of Curve					
Superelevation (in.)	1	2	3	4	5	6
0	93	65	53	46	41	38
1	100	71	58	50	45	41
1.5	104	73	60	52	46	42
2	107	76	62	53	48	44
3	113	80	65	57	51	46
4	120	85	69	60	53	49
5	125	89	72	63	56	51
6	131	93	76	65	59	53

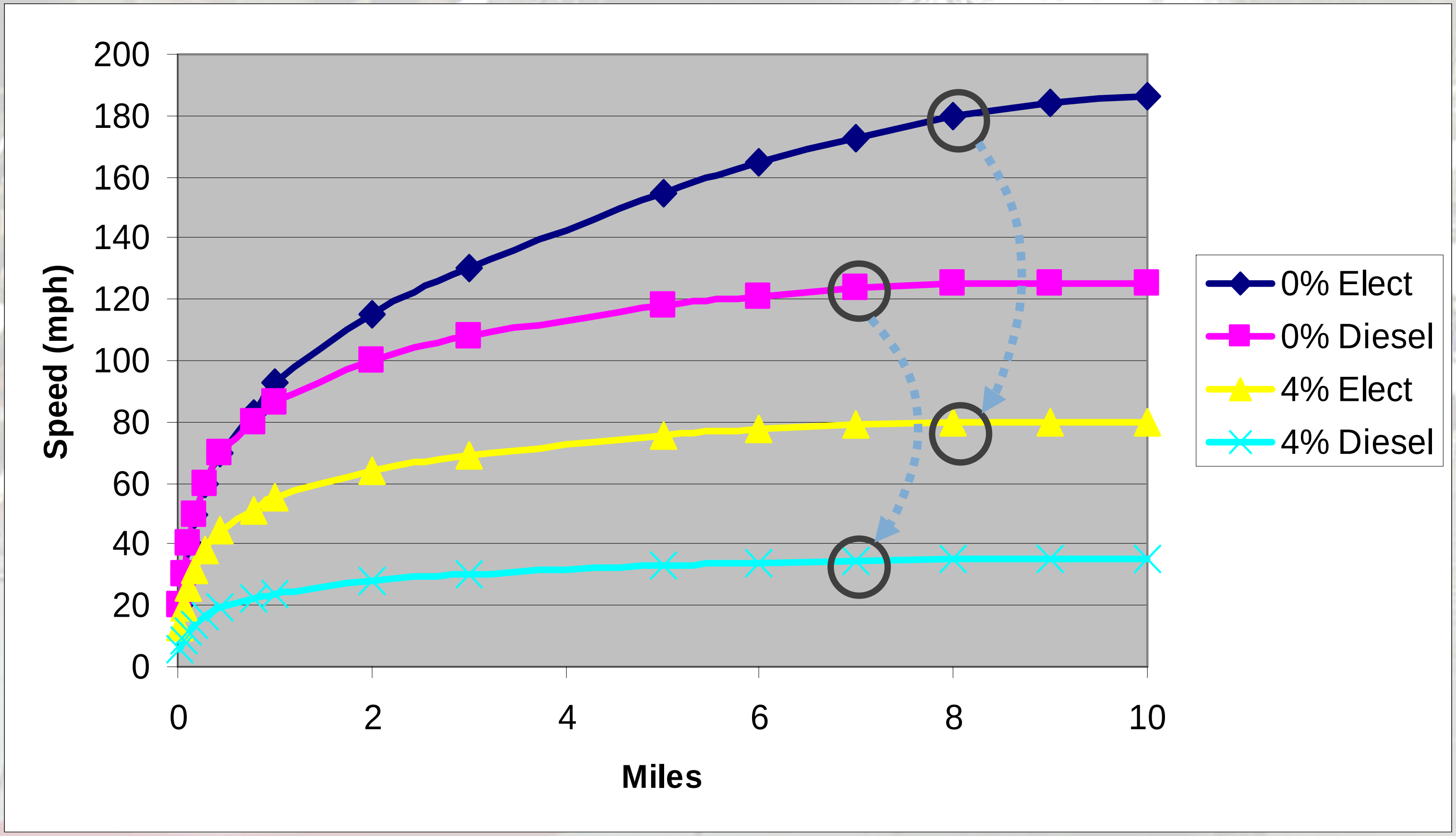
Rail and Maglev Gradient Capabilities



Source: http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/maglev/Chap1+2(p1_16).pdf

- **Maglev is going up 7% grade at 125-mph**
- **EMU is going up a 7% grade at 60-mph**

Rail Technology Issues – Power Source



Train Acceleration On Straight-and-Level Track versus 4% Uphill Grade.
Electric Trains Max Speed 186-mph; Diesel 125-mph

Diesel is ruled out on 4% grade unless 35-mph is acceptable!

Rail Technology Issues – Adhesion

EMU is superior for High-Gradient Applications

1st Generation ICE Train: Loco-Hauled

- Weight of two locomotives: 187 tons
- Total train 2,174,000 pounds for 645 seats
- Assume m = 15% *(A safe assumption for wet rails)*
- Tractive Effort Capability =

  187 x 2000 x 15% = 56,100 pounds
- **Maximum Grade = 56,100 / 2,174,000 = 2.6%**

3rd Generation ICE Train: EMU

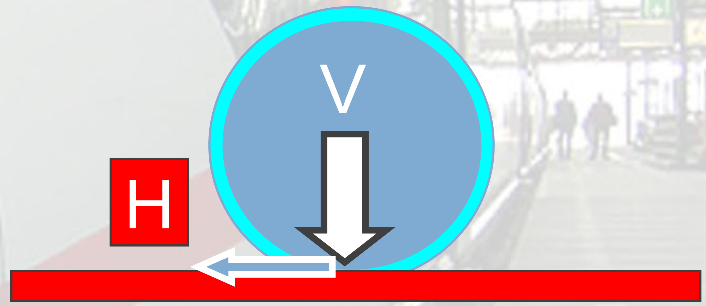
- Train Weight: 1,000,000 pounds for 404 seats
- 50% of axles powered
- Assume m = 15%
- Tractive Effort Capability =

  500 x 2000 x 50% x 15% = 75,000 pounds

  (could be 150,000 pounds if all axles were powered)
- **Maximum Grade = 75,000 / 1,000,000 = 7.5%**

  (**<u>could make 15%</u>** if all axles were powered)

$$H = \mu V$$



μ = Coefficient of Adhesion

V = Vertical Component, Vehicle Weight

H = Horizontal Component, Tractive Effort

Locomotive Hauled vs Self Propelled

- **Locomotive-Hauled**

1st Generation ICE Train: Loco-Hauled

- The locomotive provides a buffer to the passenger compartment in case of a collision – In the US, passenger seating is prohibited in the leading unit of a Tier II passenger train.
- With modifications to add traction under first and last coaches as Eurostar does, could handle a 4% grade. (Eurostar routinely handles 3.5% grades in the Channel Tunnel.)

- **Self-Propelled**

3rd Generation ICE Train: EMU

- Every axle can be powered for more total power, but only 50% were needed in Germany.
- Greater operating efficiency and flexibility.
- FRA Regulations prohibit occupied 1st Car above 125-mph.
- Can handle a 7% grade if sufficient axles are powered.

Maglev Technology Issues – Motor Type

- **LSM Motor (Guideway Based)**

German Transrapid

- Speeds of up to 300-mph proven in daily operation
- In operation at test track and Shanghai airport line
- Very expensive guideway
- It will be difficult to achieve the geometric standards required for a high speed guideway on the I-70 corridor. It may be achievable on a new I-25 greenfield alignment.
- General Atomics has LSM-based system on a test track for low-speed urban maglev application. (LSM is more efficient than LIM for large air gaps.)

- **LIM Motor (Vehicle Based)**

Japanese HSST

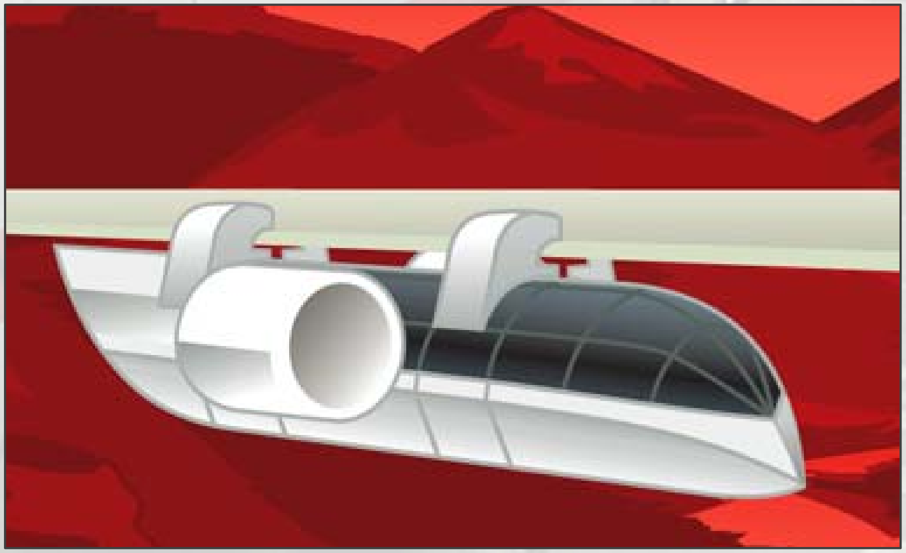
- This type of system was suggested by the 2004 Colorado Maglev study
- Speeds of up to 60-mph proven in daily operation – but speeds of 100-mph are unproven and require system enhancement
- LIM guideway reportedly more economical than LSM
- In operation at test track and Nagoya's Tobu Kyuryo line
- American Maglev has similar technology but no revenue implementation experience

Novel Technologies

Sun Tram

Data Collection is Under Way . . . .

Air Train Global



General Description Data

1. Vehicle Weight and Size
2. Parcel/Baggage Compartment Size
3. Seating Capacity and Configuration
4. Minimum Design Headways and Traffic Safety System
5. Ability to Move Between Cars
6. Ability to Provide Food Service
7. Emergency Evacuation Safety Procedures
8. Propulsion Power Characteristics
9. Station Design and Configuration

Physical Characteristics Data

1. Maximum Gradient capability
2. Maximum Speed capability
3. Acceleration and Braking Curves as a function of gradient
4. Maximum Curve Superelevation
5. Power/Fuel consumption as a function of speed, gradient and load
6. Guideway Strength, Load Bearing and Geometric Alignment Requirements
   - Are these consistent with the design specifications and cost projections for the guide way?
7. Operational Reliability – In Service History

Economic Characteristics Data

1. **Staffing**
   - Train Crew Size and Duties
   - Dispatch/Supervisory
   - Station Staffing and Roles
2. **Operating, Maintenance and Capital Cost History for:**
   - Vehicles
   - Switches and Guideways
   - Stations
   - Power Supply Systems
3. **Regulatory Approvals**

Technology Assessment Approach

- **A non vendor-specific "generic" train profile will be developed**
  - This profile represents the typical performance capabilities of equipment within each speed and performance category.
  - The "Generic Train" profile does not reflect a "best case" scenario; rather, it reflects the broad performance parameters that a variety of technology vendors would be capable of meeting.
  - This develops a conservative and achievable assessment of the operational and financial performance of the system.

- **By not tying the Operating and Financial analysis to any particular vendor's equipment, this approach:**
  - Streamlines the evaluation process.
  - Ensures transferability of the results.
  - Allows for a competitive equipment procurement.

Representative Rail Equipment: Conventional Rail at 79-mph

Conventional Amtrak

Colorado Railcar DMU

Stadler FLIRT EMU

Key Characteristics

- Designed for operation at conventional speeds
- Can be diesel or electric
- Non-tilting

Representative Rail Equipment: High Speed at 110-130 mph

Talgo T21

Flexliner DMU

X 2000

ICE-T EMU

Key Characteristics

- Designed for operation above 100-mph on existing rail lines
- Can be diesel or electric
- Usually tilting unless line is very straight

Representative Rail Equipment: Very High Speed at 150-220 mph

Siemens ICE-3 EMU

TGV Atlantique

Amtrak Acela

Shinkansen

Key Characteristics

- High-Powered - for operation at 150-mph or higher on new lines.
- Electric only.
- Some trains operate on conventional tracks beyond new lines, some tilt train versions have been developed to allow these trains to go around curves faster.

Eurostar

Representative Maglev Equipment: High Speed at 110-130 mph

Proposed Colorado Maglev

American Maglev

HSST

Key Characteristics

- High-Speed derivatives of Urban Maglev designs.
- Some urban maglev systems are operational, but the modifications needed to prove high speed capability are still in the R&D phase.
- For evaluation purposes however, we are treating these systems as if they were operational today.

Representative Maglev Equipment: Ultra High Speed at 250-300 mph

Transrapid Maglev

Key Characteristics

- High-Speed Maglev.
- Only one operational system (Transrapid) in this class today although there are additional concepts in R&D throughout the world.
- For evaluation purposes the Transrapid system will be assumed.

Thank You