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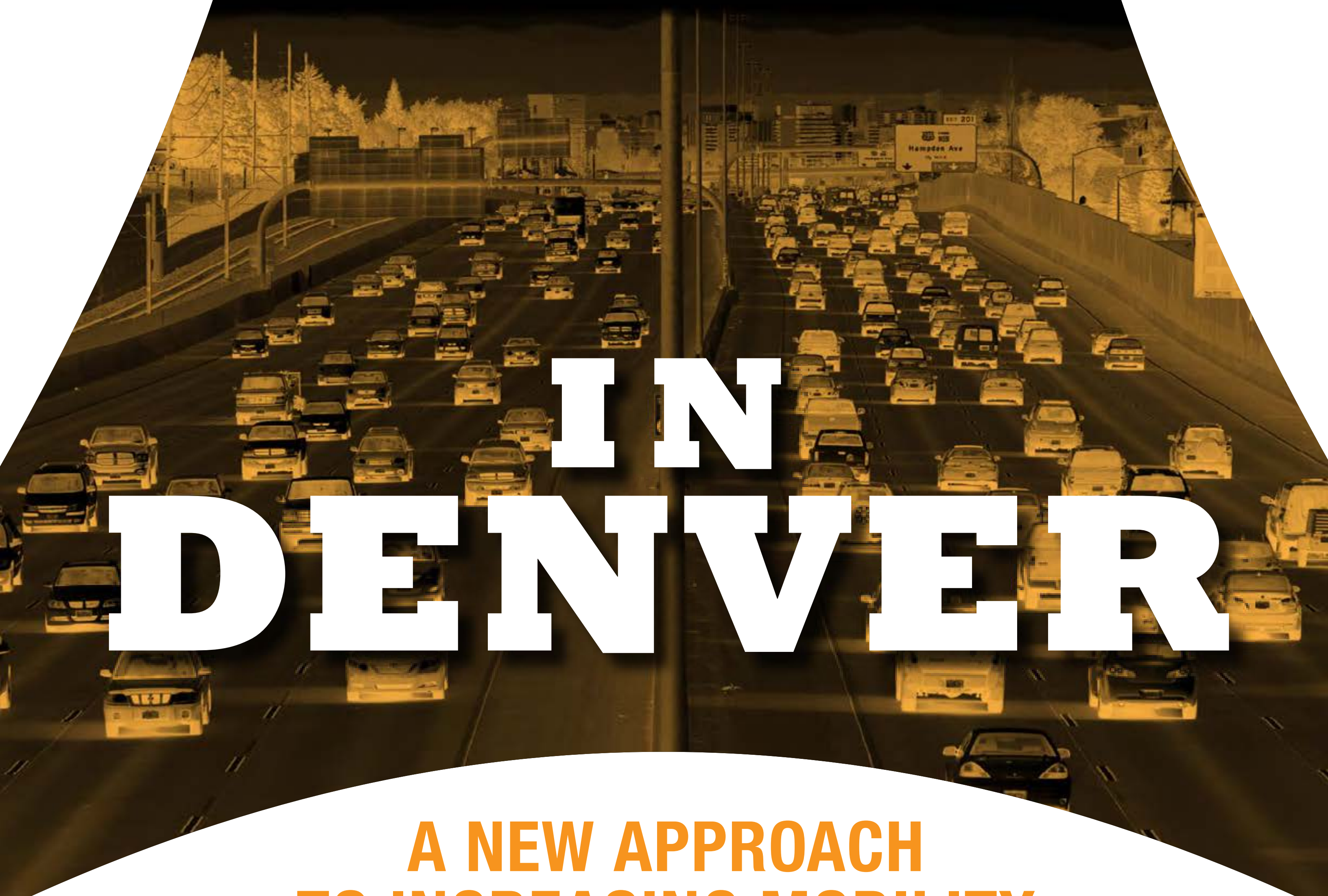
REDUCING CONGESTION IN DENVER



A NEW APPROACH TO INCREASING MOBILITY

PART OF THE GALVIN PROJECT TO END CONGESTION

BY BARUCH FEIGENBAUM

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Reason Foundation

Reducing Congestion in Denver: A New Approach to Increasing Mobility

By Baruch Feigenbaum

Executive Summary

Productive cities are mobile cities, and Denver's productivity is seriously threatened by a lack of mobility. Congestion is increasingly clogging the arteries of metro Denver and threatens to strangle the region over the long term. The ability to move goods and services efficiently, combined with the need to provide a high quality of life for employees and their families, should put eliminating serious traffic congestion at the top of Denver's priorities. While the cost of doing this would be significant, the consequences of ignoring this growing problem would be severe.

Denver is already plagued by significant traffic congestion, the direct cost of which is estimated at more than $1.6 billion per year. But if the current long-range transportation plan is implemented, by 2035 congestion will be much worse. A rush-hour trip that today takes 27% longer than at off-hours (a travel time index of 1.27) will take 86% longer in 2035 (a travel-time index of 1.86), according to the Denver Region Council of Governments (DRCOG). That is far worse than what Los Angeles experiences today.

This study examines metro Denver's congestion problem in detail. Our analysis concludes that Denver's current transportation approach, of investing heavily in fixed-rail transit and land-use changes to reduce the extent of driving, will not significantly reduce traffic congestion in greater Denver. The current long-range plan will lead to a negligible increase in the 9% of commute trips made by carpool, and only a modest two percentage point increase in transit's market share—while overall congestion would soar. Transit, particularly a well-designed bus network, certainly has a role to play, but it is not the key to significantly reducing congestion.

The new approach we recommend addresses the two major sources of congestion. For the half of congestion that is caused by *incidents* (accidents, work zones, weather, etc.), Denver should expand efforts under way such as quicker identification of, response to, and clearance of incidents. On arterial streets, improvements in traffic signal coordination and access management will also help.

For the other half of congestion—the kind that occurs every day during rush hours because demand greatly exceeds roadway capacity—the only alternative to increasing the capacity of the roadway system is to significantly reduce trips, which carries substantial social and economic costs that could irreparably damage Denver' economy. Conversely, expanding capacity without regard to return on investment is a poor use of taxpayer resources. Therefore, expanding capacity in a smart and sustainable way will produce the greatest benefits. Such an approach calls for using variable pricing on most new freeway lanes to keep them free from congestion, as is the case with the I-25 reversible express lanes, which opened to toll-paying traffic in 2006. Our goal is to create a *network* of these *priced lanes*. We also recommend adding electronically priced bridges and/or tunnels to allow motorists to bypass signalized intersections on selected arterials, thereby turning them into *managed arterials*. The bridges/tunnels would give arterial users, including bus rapid transit (BRT) and express buses, the option of faster, less-congested travel on those important components of the transportation system. This will provide commuters with two alternatives to driving in congested traffic. If they need the flexibility of the automobile, they can choose to pay for the free-flowing new lanes. Or they can choose fast, reliable region-wide bus rapid transit (BRT) and express bus service using the network for the line-haul portion of their trips.

Our modeling (using the DRCOG traffic model) shows that this kind of lane capacity addition over the next 25 years can substantially reduce congestion. It would eliminate most of the worst congestion by 2040. To supplement the express toll lane network added to the freeway system, we propose completing the missing link in the Denver beltway, which we have labeled the Jefferson Parkway.

The estimated cost of all the priced lane additions is $10.6 billion. By using value-priced tolling on nearly all of this new capacity, we estimate that more than 60% of the cost could be financed based on the projected toll revenues. And to reduce the risks inherent in such mega-projects, we recommend that they be carried out under long-term concession agreements in which the private sector partners would bear the risks of cost overruns and revenue shortfalls. Public-private partnerships (P3s) of this scale have been successfully employed in Florida, Texas, Virginia and around the world.

There would be significant benefits from implementing this approach. Valuing the time saved at DRCOG's average value of time per hour, $15.50 for automobiles and $46.50 for trucks, (2012 dollars), the time-savings over 20 years to users would be $27.6 billion. That means the time-saving benefits alone would be almost triple the $10.6 billion cost. But there would also be major economic benefits. Reduced travel times allow employers to recruit from a larger area and employees to seek jobs within a larger area; this better matches skills with needs and in so doing makes a metro area's economy more productive.

Individual motorists would benefit every day, as average trip times would be shorter than they are now, rather than considerably longer. With a network of congestion-free priced lanes on the entire freeway system, everyone who signed up for an electronic payment system using a transponder or other device would have the peace of mind of knowing that he or she had a time-saving option available, whenever it was important to get somewhere on time.

As noted, the network of congestion-free express lanes would facilitate a large expansion of public transit. The region's transit providers would gain the equivalent of a network of exclusive busways, since the priced lanes would permit reliable, free-flowing bus operations at all times. Yet unlike the FasTracks rail projects, for which funding is constrained, a major portion of the infrastructure cost of this busway system would be paid for by motorists who choose to use the express lanes. This would give the Regional Transit District (RTD) a new option for corridors without existing transit service. Denver's region-wide mobility center, which currently coordinates demand-response service for the elderly, can help coordinate bus routes to create a seamless transportation network.

Denver has come to a crossroads in transportation policy. Continuing down the status-quo path will lead to a future with an incomplete rail transit system and an undersized highway system, resulting in much worse congestion than today. The path suggested in this study accepts the reality that cars and trucks will continue to be the primary means of transportation in Denver. It therefore would expand the highway infrastructure in smart, new ways to cope with that reality, while facilitating and promoting affordable, region-wide express bus and bus-rapid transit service. This path promises a future of significantly less congestion than today, and of new mobility options—for motorists, for transit users, and for goods movement.

“Congestion results from poor policy choices and a failure to separate solutions that are effective from those that are not,” said former Transportation Secretary Norman Mineta. We hope Denver will make wise policy choices for greatly increased mobility.

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Part 1

Denver's Congestion Problem and Current Plans

Denver's transportation system is inadequate. Neither the highway nor the transit network is fully developed. Further, as a result of the gas tax's declining purchasing power, funding is limited. Unfortunately, continuing down the same track will not solve Denver's transportation issues.

According to the *2012 Urban Mobility Report* from the Texas A&M Transportation Institute, Denver's average annual peak travel time delay has ballooned from 16 hours in 1982 to 45 hours in 2011. In that same period, Denver's travel time index (TTI) grew from 1.04 (ranking 26th most congested metro area in the country) to 1.27 (making it the nation's eighth most congested metro area).[1]

Future prospects are not encouraging. These increases occurred despite the Great Recession. Between 2012 and 2035, vehicle hours of delay are expected to increase 213.5% while roadways with three or more hours of daily congestion are expected to increase 196.2%.

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Congestion and its rapid growth are not new problems in Denver. In 1944, engineers were hired to address traffic conditions on the then already clogged Santa Fe Drive (US 85). This led to the construction of the Valley Highway, the full length of which, from 52nd Avenue to Evans Avenue, opened in 1958. Within six years, traffic on the Valley Highway nearly doubled as motorists shifted from overloaded local roads.

In 1958, state transportation officials projected that the Valley Highway would one day handle 127,000 vehicles per day. However, in 1998 it was at times carrying 230,000 vehicles a day. The 12-mile length of I-225 was built to accommodate 50,000 vehicles per day. Today it carries as many as 120,000 daily vehicles between Mississippi Avenue and I-25.

Delays from even the current level of congestion impose significant economic costs, in addition to wasted time, on individuals, businesses and the regional economy. The *Urban Mobility Report* estimates that the 45 hours Denver commuters spend stuck in traffic each year amount to a cost of $937 per commuter of travel delay and excess fuel consumed, for a total cost of $1.1 billion to metro residents.[2] Since Denver is a logistics crossroads, traffic creates substantial freight delays. Truck costs for 2011 totaled $316 million.[3]

Business leaders remain especially concerned with Denver's traffic congestion. Much of metro Denver's growing congestion problems are due to its expanding population, slow growth in highway capacity and a lack of funding for core infrastructure. Further, with the Great Recession over, Denver has resumed its rapid population growth. Denver is the sixth fastest growing metro area in the country with a one-year gain in population of almost 2% between 2013 and 2014.[4] Continued population growth will put a major strain on transportation infrastructure. "CDOT recognizes this problem in its 2035 transportation plan, which states that "rapid population growth, increasing traffic congestion and funding shortfalls all post obstacles to the seamless, efficient and rapid movement of people, goods and information."

Much of metro Denver's growing congestion problems are due to its expanding population, slow growth in highway capacity and a lack of funding for core infrastructure.

Denver's transit system also has problems. The regional transit district (RTD) provides most of the service. RTD operates a network of commuter rail, light-rail and bus lines. Local transit operators provide local bus services in rural areas and demand-response services for seniors and those with disabilities. There have been considerable challenges with the FasTracks rail expansion program. When approved in 2004, the program was expected to take 12 years and cost $4.7 billion. However, over the last 10 years the cost has expanded to $7.8 billion.[5] The transit agency still has no realistic funding for the Northwest rail line planned to operate from Denver to Boulder and Longmont.

There are two plans, one regional and one statewide, that govern transportation mobility improvements:

- The Denver Region Council of Governments (DRCOG) Metro Vision 2035 (DRCOG is the federally designated metropolitan planning organization (MPO) in the Denver region); and
- The Colorado Department of Transportation's (CDOT) 2035 Statewide Transportation Plan

DRCOG describes Metro Vision 2035 as, "the region's long-range plan…[It] serves as the foundation for an ongoing conversation about how best to protect the region's quality of life. Metro Vision Guiding Vision was adopted in 1992 with regional cooperation as the keystone. The plan is outcomes-oriented and outlines goals and strategies to help realize the regional vision." [6] Further, the "Metro Vision includes several elements oriented around planning for a sustainable future linking mobility, land use and development." Much of the plan is based on the following goals adopted by the region:

- Direct 50% of new housing and 75% of new employment into urban areas between 2005 and 2035;
- Increase the rate of construction of alternative transportation facilities;
- Reduce the percent of trips to work by single occupancy vehicles (SOV) to 65% by 2035;
- Reduce the regional per capita vehicle-miles traveled (VMT) by 10% by 2035; and
- Reduce the annual per capita greenhouse gas emissions from the transportation sector by 60% by 2035.

DRCOG's goals are all reasonable. However:

- Restricting development is not the most effective way to reduce congestion. Metro areas with strict development restrictions such as Portland, Oregon have far higher congestion than metro areas with similar populations and looser restrictions such as Tampa, Florida or Sacramento, California.[7]
- Restricting development is not needed to protect the environment and reduce greenhouse gas emissions. Modern vehicles and modern houses have fewer emissions. Today's vehicle fleet generates 98% fewer hydrocarbons, 96% less carbon monoxide and 90% fewer nitrous oxides than cars 30 years ago.[8] Businesses also emit fewer pollutants. A study in

central Ohio found greenhouse gas emissions from power plants decreased 27% from 2000 to 2012.[9]

- Restricting development hurts the economy by increasing housing costs and decreasing the quality of life. Housing costs in Tampa are 51% less than in Denver. Even housing in Sacramento is 18% less than in Denver.[10]

CDOT is implementing the 2035 Statewide Transportation Plan, *Moving Colorado: Vision for the Future*. According to CDOT, "It includes a set of key strategies … to address critical needs in the immediate future." These include strategies to increase funding and improve planning. CDOT also has a list of specific corridors that need improvement. The funding solutions include making greater use of tolling, adjustments to the gas tax, and local initiatives to create Special Improvement Districts and Rural Transportation Authorities that would contribute local funds to transportation projects. The planning solutions include completing access management plans to preserve capacity, enhance safety and encourage joint planning between counties and the state.

Since DRCOG handles most of the planning in the Denver Region, this study more closely examines the funding and policies in Metro Vision 2035. Table 1, below, details the amount of funds DRCOG is planning on spending in each system category. Current and projected revenue fund only 70% of the projects that DRCOG plans to build. Therefore, DRCOG is going to need a significant tax increase to build all of these projects. Long-range plans are by law supposed to be fiscally constrained; projects without realistic funding should not be included in the fiscally constrained long-range plan. DRCOG also plans to spend more money building new transit lines than building new roadways. In a region where 85% of commuters drive and only 4% use transit a larger percentage of funds should be spent on improving the roadway network. Finally, while some categories such as Transit Service and Debt Service are 100% funded with existing resources, others such as roadway preservation and operational strategies are less than half funded by existing resources. DRCOG should focus on maintenance first, operational projects second and new construction last. While there is a strong political demand for ribbon-cutting projects, such projects should not be the first priority.

Table 1: Metro Vision Transportation System Costs and Fiscally Constrained 2035 RTP Expenditures (from 2012 to 2035 in FY '08 $ millions)

System Category		Total Estimated Cost	Fiscally Constrained Revenue	Percentage of Costs Covered
1. Preservation and Maintenance	**Total**	**$35,100**	**$23,370**	**66.6%**
A. Regional Roadway System:				
-Resurfacing, Maintenance		$11,400	$7,290	63.9%
-Toll Operations		$630	$370	58.7%
-Road Reconstruction (Specific Projects + Pooled Projects)		$3,720	$2,450	65.9%
-Bridge (Specific Projects + Pooled Projects)		$3,630	$1,110	30.6%
B. Off Street Bicycle/Ped. Facility Maintenance		$35	$30	85.7%
C. Non-Regional Roads		$15,000	$11,780	78.5%
-Non-Regional Bridges		$640	$340	53.1%
2. Base Transit Services	**Total**	**$14,800**	**$14,070**	**95.0%**
-Regional Transportation District (RTD) System Facilities and Fleet		$2,030	$2,030	100%
-Base RTD Bus/Rail Service		$10,710	$10,710	100%
-Base RTD Specialized ADA Service		$710	$710	100%
-Maintain Other Transit Services (E&D, Rural)		$1,300	$620	47.7%
3. Management, Operational and Air Quality	**Total**	**$4,200**	**$2,190**	**52.1%**
-Roadway Operational, Multimodal, RR Grade-Separated		$910	$370	40.7%
-Transportation Management, Intelligent Transportation Systems (ITS), Signal Systems		$340	$190	55.9%
-Maintain and Operate Management, ITS, Signals		$2,400	$1,180	49.2%
-Safety Specific Improvements		$350	$340	97.1%
-Transportation Demand Management (TDM) Program + Ridearrangers		$130	$66	50.8%
-Air Quality Conformity Programs and Purchases		$90	$39	43.3%
4. Capital Improvements: Capacity Expansion	**Total**	**$66,200**	**$42,250**	**63.9%**
A. Regional Roadway System:				
-Additional General Purpose Lanes		$11,651	$3,280	28.2%
-Interchange (New and Upgrade)		$3,200	$1,080	33.8%
-Bus/High Occupancy Vehicle Lanes		$684	$490	71.6%
-I-70 Mountain		$1,290	$590	45.7%
B. New Regional Transit:				
-FasTracks Rapid Transit/Bus Rapid Transit Stations/Denver Union Station		$6,080	$6,080	100%
-Other Regional Rapid Transit (Tier 2 Part)		$3,560	$0	0%
-Other Conceptual Rapid Transit Lines (Tier 3)		$3,870	$0	0%
-RTD Bus Capital Expansion (FasTracks Bus + CMAQ)		$480	$480	100%
C. Other:				
-New Bicycle/Pedestrian Facilities		$900	$590	65.6%
-Other Enhancement		$40	$10	25%
-Front Range Commuter Bus		$40	$0	0%
-State Intercity Corridors (Tier 2 Part)		$3,580	$0	0%
-Eastern Freight Rail Bypass + UPRR Improvements		$230	$0	0%
New UPRR and BNSF Intermodal + DRIR		$980	$0	0%
New Minor Arterials and Collectors		$11,390	$11,390	100%
New Local (Developer) Streets		$18,260	$18,260	100%
5. Debt Service (Tollways and RTD)	**Total**	**$5,850**	**$5,850**	**100%**
-RTD FasTracks Debt Service		$3,500	$3,500	100%
-Toll Highway Debt Service		$2,350	$2,350	100%
6. Aviation Facilities		**$6,410**	**$6,410**	**100%**
Grand Total	**Total**	**$132,560**	**$93,180**	**70.3%**

Source: Compiled from Denver Regional Council of Government Documents

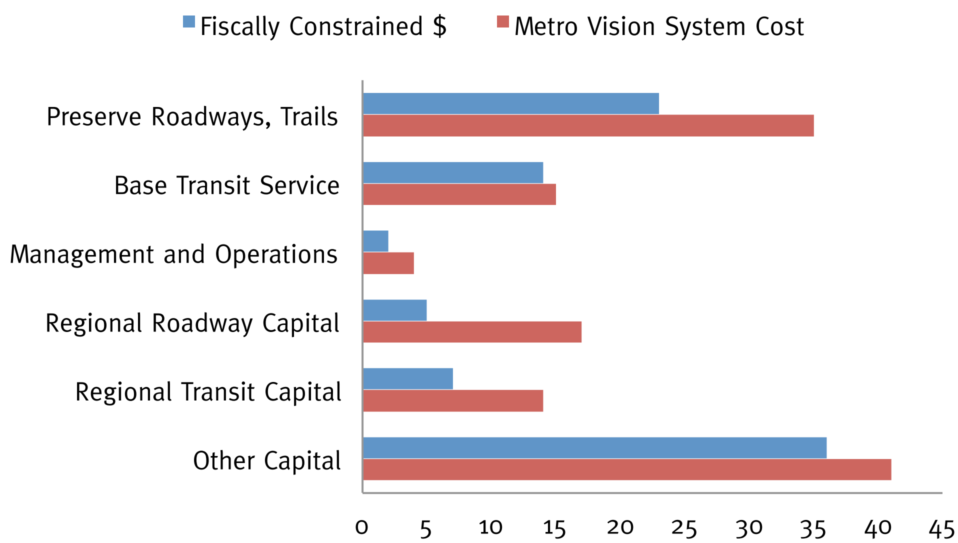
Table 2 provides the units (miles, hours of service, etc.) in the DRCOG plan. Denver is adding a significant amount of capacity (both road and rail). While capacity is important, if Denver lacks resources it should consider adding less capacity and making greater use of operational strategies. For example, bus rapid transit and traffic signal priority could substitute for some of the rail capacity. The region is adding a number of transit stations without parking. With the exception of the central city many transit users drive and park at the transit stations. A lack of parking could reduce transit ridership.

Table 2: Fiscally Constrained 2035 RTP System Characteristics (units)

System Characteristic	2010	2035 Fiscally Constrained	2035 Metro Vision
Regional Roadway Lane-Miles (Includes Reclassified Roads)			
▪ Freeways/Tollways	1,935	2,154	2,374
▪ Major Regional Arterials	1,042	1,103	1,242
▪ Principal Arterials	3,960	4,768	5,405
▪ *Total Regional Roadway System Miles*	*6,937*	*8,025*	*9,021*
Interchanges			
▪ On Freeways/Tollways	221	235	241
▪ On Arterials, not Freeways	24	32	56
Rapid Transit Centerline-Miles			
▪ Light Rail	36	63	63
▪ Commuter Rail	0	92	92
▪ Undetermined Rail Technology	0	0	290
▪ High-Occupancy Vehicle/Bus Facilities	34	37	71
Bus Fleet (Fixed-Route Systems)	1,130	1,480	1,480
Bus Hours (Millions in Annual Revenue Service)	2.4	3.3	48.3
Bus Miles (Millions in Annual Revenue Service)	36.8	48.3	48.3
Rail Cars	49	311	undetermined
Transit Stations and Park-n-Ride Lots (Number of Parking Spaces)			
▪ Rapid Transit Stations with Parking	31 (19,766)	63 (44,059)	undetermined
▪ Rapid Transit Stations without Parking	15 (0)	28 (0)	undetermined
▪ Transit/Transfer Centers	4 (0)	5 (0)	undetermined
▪ RTD Park-n-Ride Lots	41 (7,021)	48 (9,020)	undetermined
▪ CDOT Carpool Lots	6 (926)	6 (926)	undetermined
Total	(27,713)	(54,005)	

Source: Compiled from Denver Regional Council of Government Documents

Figure 1: 2035 Metro Vision RTP Total Vision System Cost and Fiscally Constrained Revenues by Expense Category



Source: DRCOG Fiscally Constrained 2035 Regional Transportation Plan, Figure 25, p. 120.

Table 3 displays the amount and percentage of funding spent in each system category. Roadway expansion is the largest category and transit expansion is the second largest. As previously mentioned, spending such a large percentage on capital projects may not be the most logical priority. More troubling, Denver spends very little transit funding on maintenance. Many of the rail lines currently in operation will need significant maintenance by 2030, yet the plan devotes practically no money whatsoever to such maintenance.

Table 3: Funding Percentage by Mode from 2012 to 2035 in FY '08 ($ millions)

Mode	Funding Total	Percentage of Total
Roadway Expansion	$49,371	37.2%
Roadway Maintenance	$35,065	26.4%
Roadway Debt Service	$2,350	1.8%
Transit Expansion	$29,514	22.3%
Transit Maintenance	$0	0%
Transit Debt Service	$3,500	2.6%
Bicycle/Pedestrian	$935	0.7%
Aviation Facilities	$6,410	4.8%
Freight	$1,210	0.9%
ITS	$2,740	2.1%
Miscellaneous	$1,520	1.1%
Total	$132,615	

Source: Compiled from Denver Regional Council of Government Documents

The 2035 Regional Transportation Plan has several strengths. It includes detailed projects in the Transportation Improvement Program (TIP) and Long Range Plan (LRP). It develops a robust bus transit network and a detailed roadway arterial network—important transportation backbones that are not detailed in MPO plans of regions twice Denver's population. For example, Denver's 2035 plan includes detailed plans to expand or build 10–20 new roads to build out its surface arterial network. Atlanta, a metro area more than twice the size of Denver, is not planning to add any new roads to its undeveloped arterial network.

However, the plan has a significant funding hole. It makes several assumptions of future revenue that seem unrealistic. The transit plan component assumes that taxpayers will increase the sales tax 0.4% to pay for future rail expansions. Yet in 2011 RTD directors refrained from putting a sales tax increase on the November ballot because a dozen political consultants in a unanimous decision said a tax increase would be unwinnable.[11] Assuming voters will approve a sales tax increase for transit in the near future seems unrealistic. Further, the plan assumes that federal funding will remain constant. Yet in 2014 the U.S. Congress transferred general fund revenue to the highway trust fund to keep the highway trust fund solvent. Transferring revenue is a short-term gimmick and most experts expect Congress to increase taxes and to reduce spending to right-size the trust fund. It is impossible to predict how much transportation funding the federal government will provide to states in five years, but many experts think it will be a smaller amount of funding than today.[12]

Even assuming that voters approve a sales tax increase and that federal funding continues at its current level, there is still a shortfall of over $40 billion between the $93 billion in fiscally constrained revenue available to implement Metro Vision 2035 and the $132 billion total estimated cost. According to the plan only $11.2 billion of the needed $19.4 billion will be available to preserve the regional roadway system (Table 1, Category 1A). Only $12.1 billion of the needed $15.6 billion will be available to preserve non-regional roads and bridges (Table 1, Category 1C). Further, there is a $730 million gap for operating and maintaining existing transit, primarily bus service (Table 1, Category 2). Preserving existing infrastructure is critical. It is more important than building new capacity. Such major gaps are simply unacceptable. Denver needs to reprioritize the projects it funds.

Yet even if Denver were able to find the additional more than $40 billion to fund the entire plan, congestion would still be worse in 2035 than in 2014. The average vehicle speed is expected to drop 10% during off-peak daytime hours. In rush hour the average vehicle speed is expected to drop more than 15%. And these estimates of increased highway congestion may be low since the plan assumes unrealistically high increases in transit usage. The plan assumes that rail transit boardings will increase 326%, total transit trips 86% and person-miles traveled on transit 131%. Predicting future travel trends is challenging, but since the end of World War II no U.S. metro area has seen such enormous numerical gains in transit travel in any 20-year period, even market areas with high transit usage such as New York City or Washington D.C. Moreover, even these optimistic forecasts of transit growth represent a shift from driving alone to transit of just two percentage points by 2035. Close to 80% of work trips will still be made by car in 2035 under current transit-focused plans.

Metro Vision 2035 also suffers from two common political problems. The first—Part A—has two components. Component A focuses on specific corridors: the plan emphasizes making specific improvements to specific highways and places less emphasis on the transportation system as a whole. As a result, improvements are made in isolation, not as part of a continuous system or *network*. Typically, this is a result of politics. Improving the *network* would encompass multiple political municipalities, some of which are not interested. Plan implementers need to involve all municipalities even if this requires trade-offs in the final plan. Component B is the pushback from influential citizens both in support of a certain project (money to be made by owning land) and against a certain project (not-in-my-backyard NIMBYists.)

The second political problem is the preoccupation with every constituent receiving something. The FasTracks expansion is a good example of this issue. Only parts of the Southeast and Southwest lines have been built. This allowed politicians to provide rail service to as many voters as possible. However, from a technical standpoint it would have been far better to build one entire line and then move on to another line.

Denver can better use its resources by financing instead of funding most of its new transportation projects.

This study proposes a transportation plan that is more fiscally realistic and far better at reducing congestion, while also keeping the many good elements of the Denver 2035 Plan in place. Our plan also tries to minimize the role of politics, by choosing the individual road and transit projects that fit together to build a comprehensive highway and transit network.

Our plan also addresses the biggest weakness of the current Denver plan—funding. It details several innovative funding sources and explains how Denver can better use its resources by financing instead of funding most of its new transportation projects.

Part 2

Lack of Mobility and Its Consequences

A lack of mobility is more than a nuisance. It hurts the economy, degrades the environment and harms residents' personal lives.

A. Overview of Congestion

Table 4: Denver's Work Trip Distribution: 1990, 2000 and 2010

Travel Mode	1980 Share %	1990 Share %	2000 Share %	2010 Share %	Mean 2010 Travel Time (in minutes)
Total Workers	859,989	1,026,847	1,346,025	1,255,938	N/A
Drive Alone	65.3	75.0	75.6	76.3	25.3
Carpool	20.2	12.5	11.5	9.6	28.4
Transit	5.8	3.9	4.3	4.1	46.6
Bicycle	4.7	0.7	0.7	0.8	N/A
Walk	N/A	3.4	2.4	1.9	N/A
Work at Home	N/A	3.7	4.7	6.2	N/A

Source: U.S. Census Bureau

Increasingly, commuters are voting with their cars and choosing to drive to work. If Denver wants to have the most effective future transportation plan, it will focus primarily on roadways to best help commuters. A lack of mobility is more than a nuisance. It hurts the economy, degrades the environment and harms residents' personal lives. Traffic congestion is not a new problem in Denver. But Denver's congestion is worsening compared to metro areas with similar populations. Figures 2 and 3 below indicate that in 1990 Denver had travel time indices similar to large metro areas across the country. But from 1992 to 2002 and 2002 until 2011, Denver's TTI continually worsened compared to other large metro areas.[13] In 1990, Denver was the 23rd most populated metro area but ranked 42nd in congestion: in other words it had relatively little congestion. By 2011, Denver had grown to the 19th most populated metro area but ranked eighth worst in congestion.

Minneapolis, the 16th most populated metro area, has also experienced rapid growth adding more than 1,000,000 people in 30 years.[14] Yet it ranks 25th worst in congestion. Tampa, the 18th most populous metro area also gained more than 1,000,000 people in 30 years. Yet it ranks 27th in congestion, a major improvement from its sixth place ranking in 1982. San Jose, has added 500,000 people over 30 years. In 1982 it ranked 11th worst in congestion; today it ranks 17th. Denver's congestion is worsening not only in comparison to 20 years ago but also in comparison to its peer cities and competitors. While other cities with similar spatial structures and transit systems are decreasing congestion, just the opposite is happening in Denver.

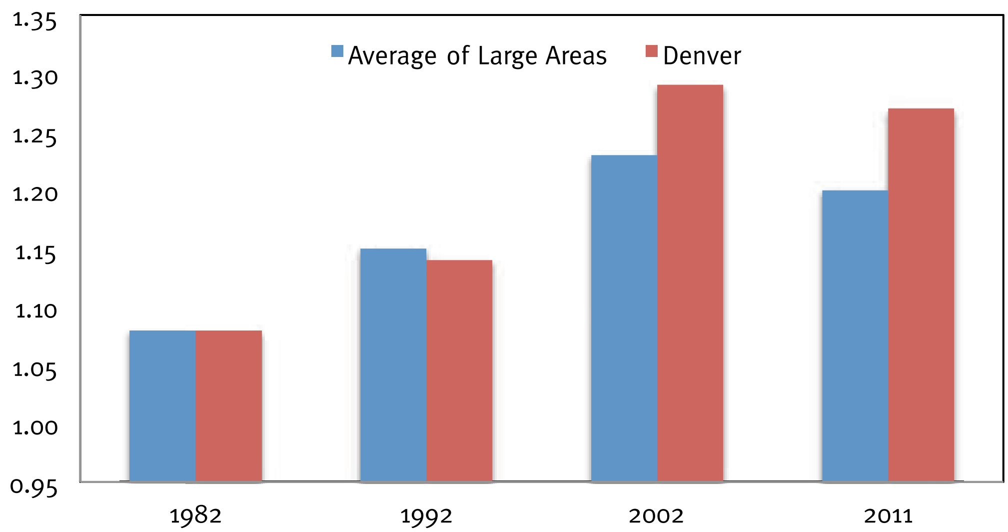
Denver does not fare much better in other measures of congestion. It is 15th worst in cumulative delay and 13th highest in delay per commuter.[15] The commuter stress index ranks 10th while the planning time index—the ratio of travel time at the 95th percentile compared to the time required to make the same trip at free-flow speeds—ranks ninth. Gridlocked traffic also leads to more carbon dioxide than travel at 55 miles per hour. Denver drivers release 695 million pounds of excess carbon dioxide, the 15th worst in the country.[16] All these rankings are substantially worse than a metro area with Denver's population should have.

Denver drivers release 695 million pounds of excess carbon dioxide, the 15th worst in the country.

Denver's annual congestion totals $1.6 billion in excess costs, or $937 per each driver. This is the equivalent of driving an additional 7,675 miles per year with gasoline priced at $3.00 per gallon in a vehicle that averages 24.5 miles per gallon. Truck congestion costs total $316 million and lead to $76.7 billion in lost economic activity.[17] This lost economic activity is equivalent to buying a new Toyota Camry for every person in the Denver, Boulder and Greeley metro areas with plenty to spare. Clearly, there are significant costs to metro areas with congestion, especially lost economic activity.

The travel time index is the ratio of time required to travel a certain distance at rush hour versus that same distance with no traffic. If the number is 1.1 that means it takes 10% longer to travel during rush hour. Figure 2 displays the travel time index. Denver's travel time index has increased significantly over the last 30 years both absolutely and compared to other large metro areas.

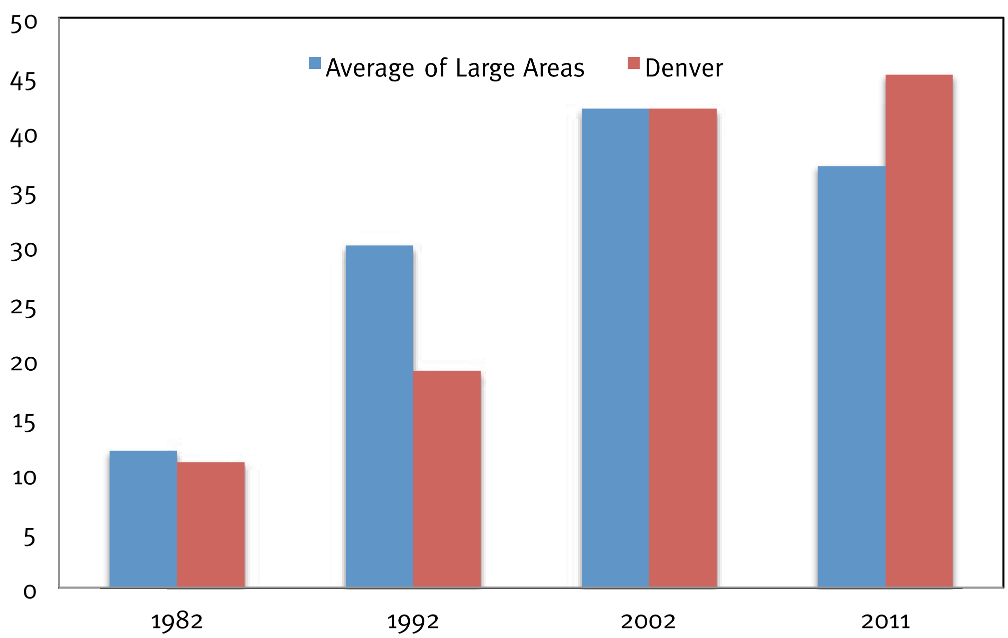
Figure 2: Growth in Denver's Travel Time Index



Source: Texas A&M Transportation Institute

Figure 3 displays the increase in delay in hours per driver. Similar to the travel time index, Denver's delay per driver has increased significantly over the last 30 years both absolutely and compared to other large metro areas.

Figure 3: Growth in Denver's Delay per Peak Traveler (in hours)

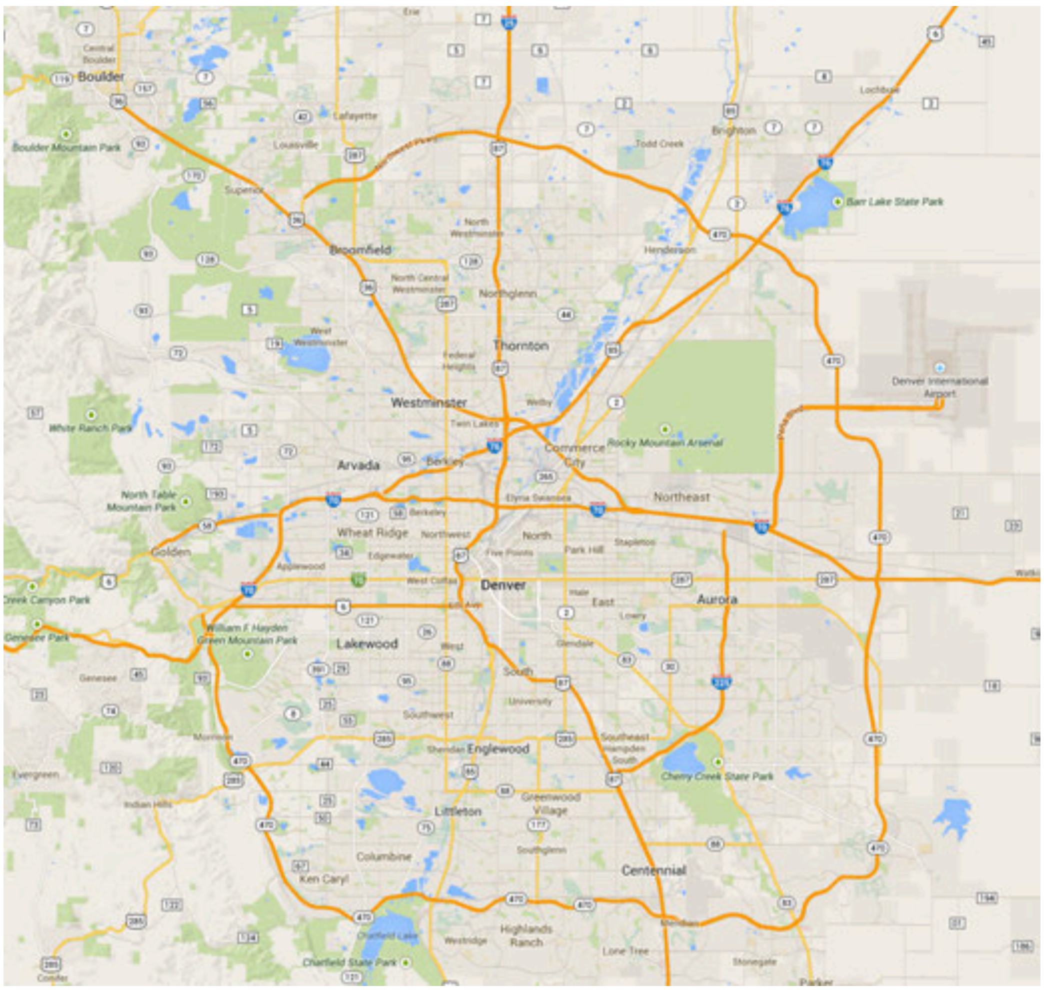


Source: Texas A&M Transportation Institute

The preceding numbers detail Denver's congestion issues. But to actually fix the problem, we have to understand why Denver's current system is not working.

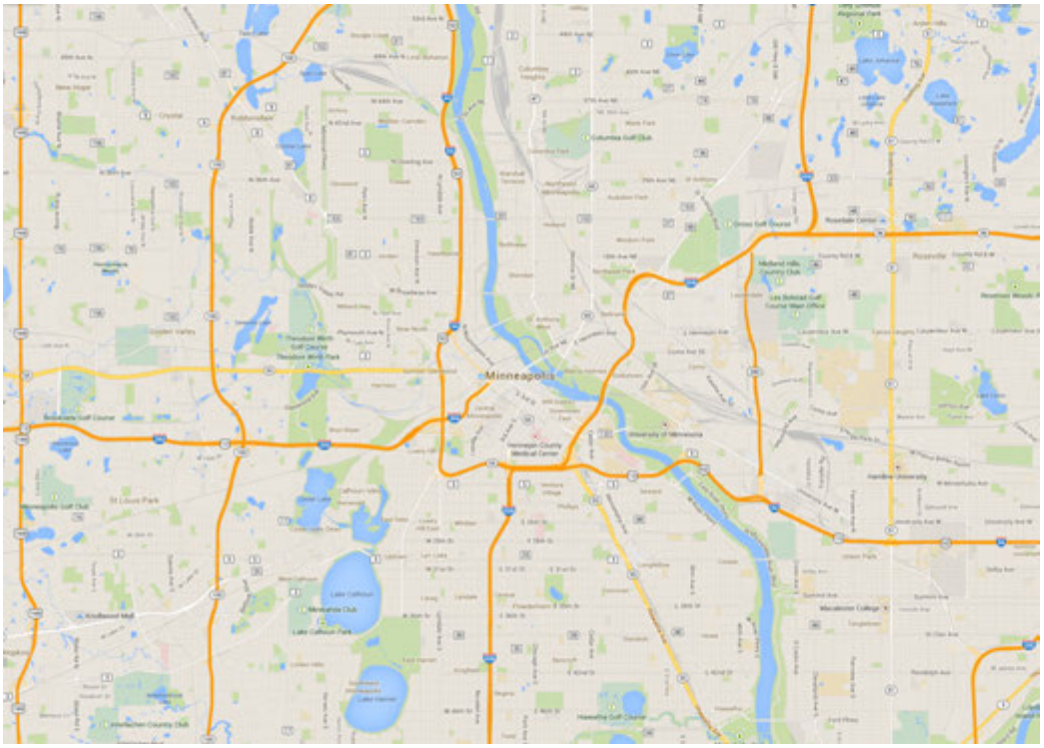
Denver lags behind many of its competitors in its freeway and surface transportation networks. Figures 4, 5, 6 and 7 compare Denver's highway system with those of other large post-World War II metro areas. Some of these metro areas have better suburb-to-suburb connectivity due to a more extensive freeway network and a more complete grid of arterials.

Figure 4: Map of Denver



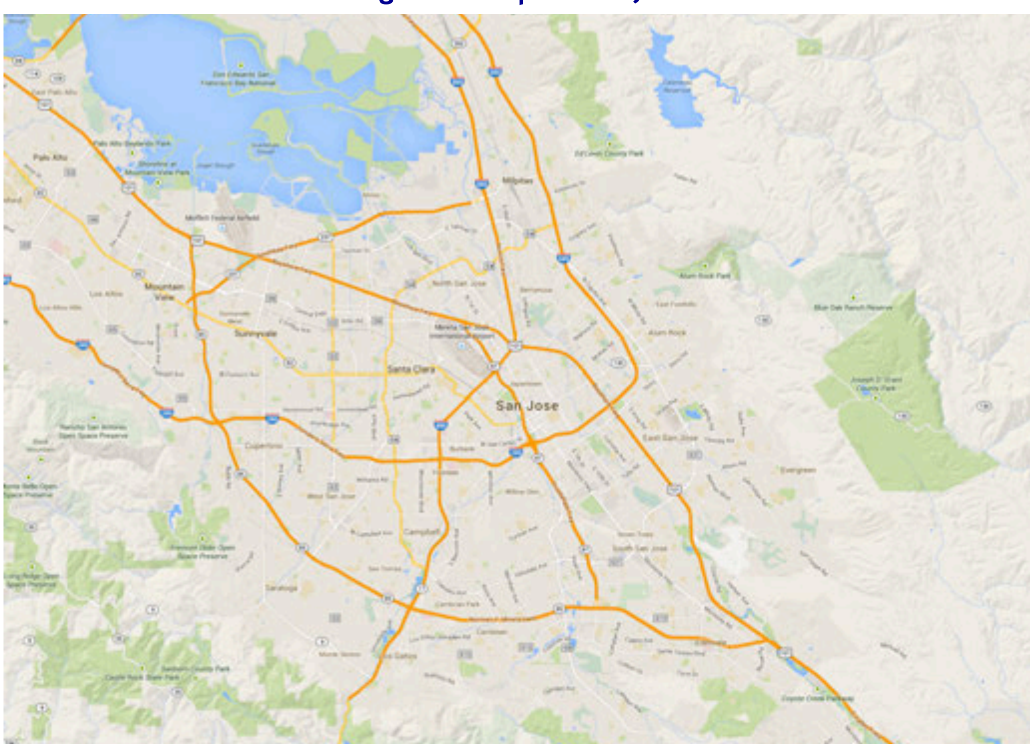
Source: Google maps

Figure 5: Map of Minneapolis



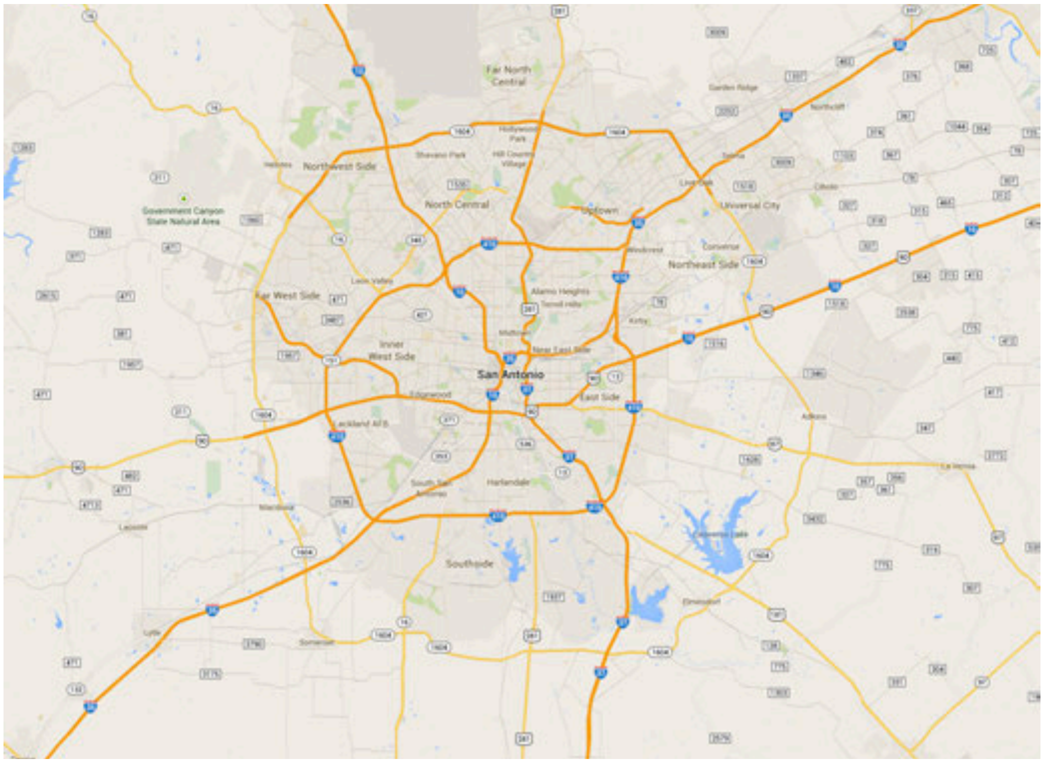
Source: Google maps

Figure 6: Map of San Jose



Source: Google maps

Figure 7: Map of San Antonio



Source: Google maps

The following table compares the lane-miles and vehicle-miles traveled in Denver and other large post-World War II metro areas. While Denver's freeway and surface roadway system is not the worst, it has significant room for improvement. Denver's well-developed arterial system carries a far higher percentage of vehicle-miles traveled, (49%) than most others arterial systems (40-45%)(see Table 6).[18] Only Tampa's much larger arterial network carries a higher percentage of vehicle-miles traveled. However, the arterial system cannot make up for the lack of freeway lane-miles.

Table 5: Comparative Data on Freeways and Arterials, Large Urban Areas, 2011

Urban Area	Pop. (000)	Daily Freeway VMT (000)	Freeway lane-mi	Freeway VMT/ lane-mi	Arterial VMT (000)	Arterial lane-mi	Arterial VMT/ lane-mi
Minn/St Paul	2,757	30,383	2,054	14.792	23,919	5,289	4.522
Baltimore	2,523	26,805	1,561	17.172	18,338	3,252	5.639
Tampa	2,393	14,360	1,016	14,134	28,370	3,897	7.280
Denver	**2,348**	**22,205**	**1,463**	**15.178**	**21,575**	**3,840**	**5.618**
Cleveland	1,700	18,569	1,580	11.753	12,222	3,111	3.929
San Jose	1,838	17,146	896	19.136	16,563	2,425	6.830
San Antonio	1,558	19,114	1,248	15.316	13,345	3,035	4.397

Source: Texas A&M Transportation Institute, "congestion data" spreadsheet at http://mobility.tamu.edu

Table 6: Freeway Loading vs. Arterial Loading, 2011				
Urban Area	Freeway VMT per capita	Arterial VMT per capita	Percent Freeway	Percent Arterial
Minn/St. Paul	11.02	8.68	56%	44%
Baltimore	10.62	7.27	59%	41%
Tampa	6.00	11.85	34%	66%
Denver	**9.46**	**9.19**	**51%**	**49%**
Cleveland	10.92	7.19	60%	40%
San Jose	9.33	9.01	51%	49%
San Antonio	12.27	8.57	59%	41%

*Calculations based on Table 5.

It is no mystery why Denver's congestion has worsened. Roadway improvements have failed to keep pace with the rapid increase in population. Figure 8 below shows that even as Denver's freeway lane-miles expanded by 84%, the roadway growth was not proportional to the freeway vehicle-miles traveled growth, which increased by 149%. Figure 9 shows a similar story for arterials. While lane-miles grew by 42%, daily arterial vehicle-miles of travel grew by 87%.

It is no mystery why Denver's congestion has worsened. Roadway improvements have failed to keep pace with the rapid increase in population.

Figure 8: Freeway Lane-Miles (in Tens) versus Freeway Daily Vehicle-Miles of Travel

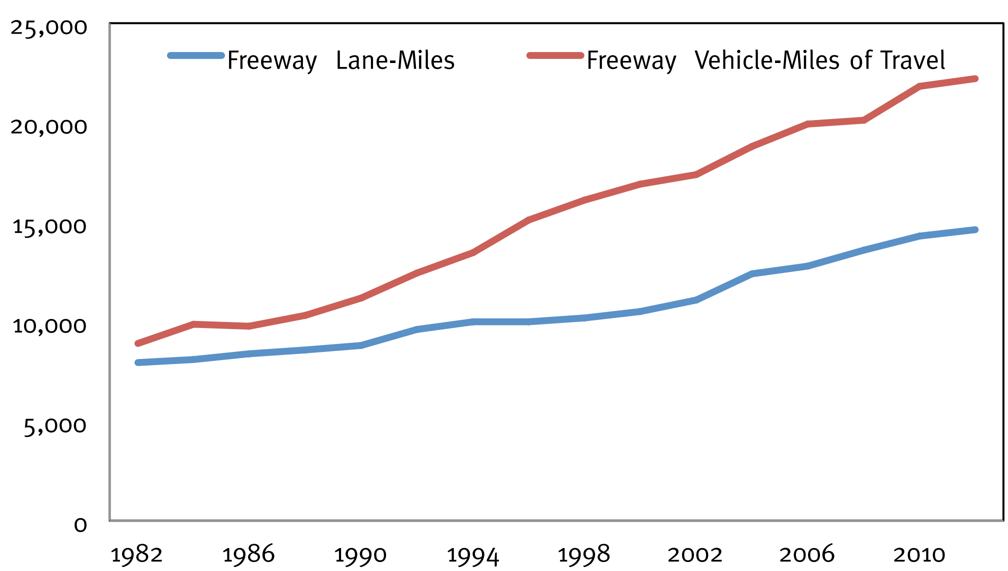
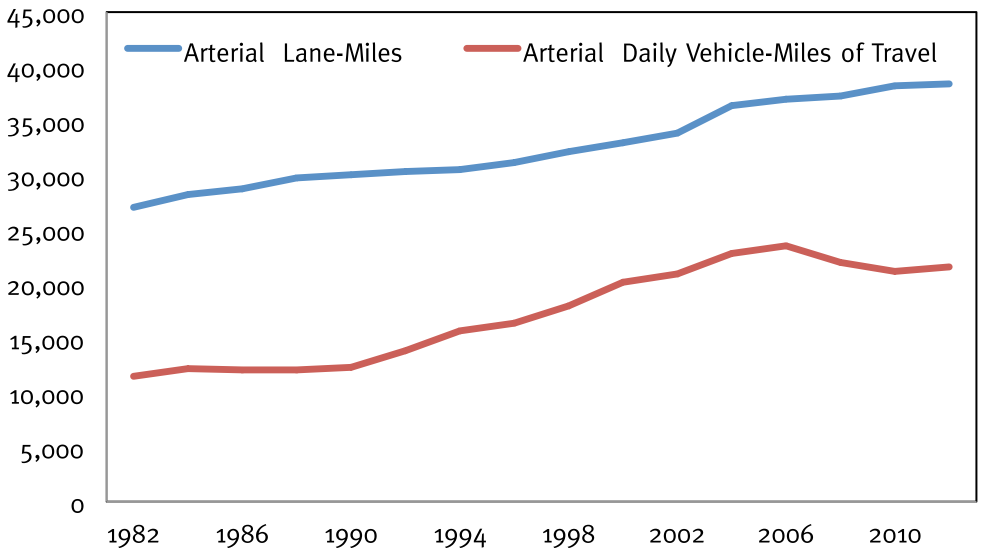


Figure 9: Arterial Lane-Miles (in Tens) versus Arterial Daily Vehicle-Miles of Travel



Denver's congestion adversely affects transit as well. The backbone of any transit network is local bus service. The Denver region also features limited-stop bus, bus rapid transit, express bus and demand-response service. Many of these buses travel on congested roads. Reducing congestion would allow buses to travel their routes in less time and on a more regular schedule. This would increase the popularity of bus routes and allow transit officials to decrease the headway between buses. It would allow suburban transit users who drive to existing rail, BRT and express bus park-and-ride lots to have easier access to transit service, increasing transit usage.

The Economic and Social Costs of Congestion

There are many different ways to measure the costs of congestion, which affects automobiles, truckers and transit vehicles alike. Importantly, congestion can increase bus travel times and reduce reliability, making transit significantly less appealing. The Texas A&M Transportation Institute (TTI) estimates direct congestion costs of approximately $121 billion nationwide.[19] However, this only accounts for the direct costs. The U.S. Department of Transportation estimated annual indirect congestion costs of $38 billion in 2006 due to productivity losses, another $38 billion due to unreliability, $3.8 billion due to cargo delay and $12.6 billion in safety and environmental costs. Combining both the direct and indirect costs, total congestion costs exceeded $200 billion ($213.4 billion) annually.[20]

Several years ago, the National Cooperative Highway Research Program funded pioneering research attempting to get a handle on the cost of congestion to regional businesses.[21] This research found that congestion interferes with just-in-time delivery systems, thereby increasing inventory costs. It reduces the availability of skilled workers, and raises payroll costs needed to attract such workers. It shrinks the market area for local firms' products and services and it reduces the range of job opportunities for workers.

The NHCRP research team used Chicago and Philadelphia to gather data, with which to do some modeling. On the logistics effects the team estimated that a 10% reduction in congestion would save businesses $1,274 million per year in Chicago and $312 million a year in Philadelphia in 2013 dollars. The labor market effects were estimated at $455 million in Chicago and $260 million in Philadelphia in 2013 dollars.

Congestion affects the labor market because most people will not spend more than a particular amount of time each day on the journey to work.

Congestion affects the labor market because most people will not spend more than a particular amount of time each day on the journey to work. As congestion increases, the number of miles they can travel within this amount of time decreases. Imagine a person's home in the center and a range of employers, some five miles away, some 10 miles away and some 20 miles away. When congestion is low or zero, commuters can reach every point within a 20-mile circle, but in a highly congested region such as Denver some people can only reach the points within the 10-mile circle. Others may be able to reach only points within the five- mile circle. According to basic geometry, the area of a 20-mile radius circle is four times that of a 10-mile radius circle. If work possibilities are randomly distributed across the landscape, the 20-mile circle will include four times as many job opportunities as the 10-mile circle. And the same applies in reverse for an employer. It will have four times as many potential employees within a 20-mile "opportunity circle" as a 10-mile circle.

In a large and diverse metro area, economic productivity depends on matching skilled employees with employers who can make the best use of their abilities. When Remy Prud'homme and Chang-Woon Lee studied this question using data on travel times and labor productivity for French cities, they reached several conclusions.[22] They found a robust relationship between the effective labor market size (the size of the available circle, as defined by acceptable travel time) and the productivity of that city. Specifically, when the effective labor market size increased by 10%, productivity (and hence economic output) increased by 1.8%.

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Congestion costs are a major issue for manufacturing and distribution businesses. And understanding the total congestion costs can be challenging. While the Texas A&M Transportation Institute counts truck congestion, the corresponding value reflects only the hourly operating cost of trucks, not the value of trucking services to shippers. Truck congestion affects more than time; congestion wreaks havoc on the reliability of truck pick-up and delivery schedules, a substantial cost that is not included in TTI's *Urban Mobility Report* figures.

There are many other ways that congestion harms Denver citizens beyond those discussed above. With the roads gridlocked, emergency vehicle response time could be seriously affected; paramedics may not arrive in time to save a life, or firefighters may be delayed in getting to a fire. Congestion also increases stress. After-work congestion causes people to avoid places (restaurants and theaters) that become too much of a hassle to reach. It shrinks circles of opportunity. In addition to narrowing entertainment possibilities, recreation and social life are similarly affected. Computer dating services report many subscribers being unwilling to match up with prospects who live more than a certain number of miles away because congestion simply makes it too difficult to develop a relationship.[23]

Finally, congestion decreases Denver's economic competitiveness. Denver is home to nine fortune 500 companies and serves as a regional headquarters for many others. Efficiently moving goods and services is essential to these companies' bottom line: Fortune 500 companies that choose to expand outside of Denver often cite traffic congestion as the primary reason.[24]

Denver is falling behind other major metro areas as a place to live, work and do business. Direct competitors such as Austin, Las Vegas, Phoenix, Sacramento, Salt Lake City, San Jose and Seattle have invested in improving their transportation systems. Austin was spurred to act when Dell announced it would no longer expand its facilities in Austin due to unacceptable traffic congestion.[25] Regional competitors such as Phoenix, San Jose and Seattle have developed detailed frameworks for improving their transportation systems and reducing congestion.

Major congestion is a significant problem in metro Denver, and the economic and social costs are often understated.

In short, major congestion is a significant problem in metro Denver, and the economic and social costs are often understated. Congestion can harm citizens' social life *and* limit economic growth.

Different Types of Congestion

There are two primary types of congestion. This section explains the differences between non-recurrent and recurrent congestion and why it is vital for Denver to reduce both types.

The first of these is what most people encounter every day on their trips to and from work—the overloading of the roadways with more vehicles than they can handle. Researchers refer to this as *recurrent* congestion, resulting from a basic mismatch of highway capacity with vehicles during peak periods. This type of congestion is costly—but at least it is predictable.

Non-recurrent congestion, which makes up as much as 60% of Denver's total congestion, has many causes, including mostly unpredictable events (breakdowns and crashes), partially predictable events (weather) and very predictable events (construction work zones).[26] Since incident-related congestion occurs randomly and without warning, it adds unreliability to trips. The rubbernecking resulting from a fender-bender may add 30 minutes to a 45-minute trip. When these incidents occur frequently, commuters often add extra "buffer time" to their trips. The Texas A&M Transportation Institute has recently added a "planning time index" to its standard measures of congestion, reflecting the growing time cost to travelers.[27]

A recent National Cooperative Highway Research Program report examined the sources of congestion in large urban areas such as Denver. In most large metro areas such as Denver about 50% to 60% of all traffic congestion is caused by incidents.[28] Table 7 details the sources of congestion in large urban areas.

Table 7: Sources of Congestion in Large Urban Areas	
Source of Delay	Percentage Contribution*
Demand greater than capacity	37%
Poor signal timing	5%
Total Recurring Congestion	*42%*
Crashes	38%
Breakdowns	7%
Work zones	8%
Weather	6%
Special events, other	0% (Less than 1%)
Total Non-Recurring Congestion	*58%*

Source: Steve Lockwood, "The 21st Century Operations-Oriented State DOT," 2006.
* As a result of rounding, percentages do not total to 100%.

Part 3

Operations Management

Operations management is the set of strategies used to make the most of existing infrastructure and to reduce congestion. Operations management alone cannot make up for needed capacity or eliminate recurrent congestion. But operations management can significantly improve mobility, typically at a very low cost. For example, the California DOT estimated a package of system operations measures to have a benefit-cost ratio of 8.9 to 1.[29] By contrast, the addition of conventional highway capacity had a benefit-cost ratio of 2.7 to 1. While both need to be completed, the low-hanging fruit is the system operations measures, which have the advantages of being (1) relatively inexpensive, and (2) implementable within a matter of years, rather than decades.

In many areas, operations management can substitute for some needed capacity. Using dynamic traffic management system data, ramp metering, variable speed limits and other "intelligent transportation systems (ITS)" can help increase mobility by increasing the number of cars a given stretch of pavement can accommodate.

The following section discusses the role of dynamic traffic management systems in operations management. It then details how the components of freeway operations and arterial operations reduce congestion.

A. Dynamic Traffic Management Systems and Intelligent Transportation Systems

Dynamic traffic management systems are cost-effective systems that improve traffic flow on freeways and arterials. Dynamic traffic management systems use simulation models combined with real-time traffic information to predict the effects of various management strategies.[30] Route time, travel time and departure time are collected from sources of real-time information such as loop detectors, roadside sensors and GPS devices. This travel information is used with simulation models to predict network flow patterns and travel times, given the combination of management strategies including incident management, ramp metering, signal control and traveler information. Based on these predictions, the system selects optimal strategies and suggests travel time predictions and route recommendations to travelers. These programs have been successfully deployed in Europe and Japan resulting in capacity improvements on major freeway corridors of up to 30%.[31] Significant increases in trip predictability and safety have also been realized.

Intelligent transportation systems (ITS) comprise the most popular subset of dynamic traffic management systems. U.S. engineers have been implementing ITS for over two decades and have installed vehicle sensors and message signs, as well as backbone communications systems, on many major urban freeway corridors and selected arterial highways.[32] These sensors gather data about traffic conditions on a 24/7 basis, and this information is collected, compiled and distributed to the motoring public in near real time through a variety of public and private information channels.

Many metro areas use several ITS systems that operate in *static* mode. However, ITS systems would be even more effective if they operated in a *dynamic* mode. In "static mode" freeway incident management and service patrols quickly *observe, respond to* and *clear* accidents from travel lanes. But in "dynamic mode" ITS systems *prevent* accidents by reducing speed limits and warning of congestion. Traffic signs that detail congestion provide valuable information to motorists. However, traffic signs that detail congestion and suggest alternative routes and where to exit the highway to avoid congestion, a.k.a. "dynamic mode," are even more useful. While Colorado is using some dynamic systems, such as converting a shoulder to a direct exit lane near the I-25/C-470 intersection, the state needs to complete its transition from a static plan to a dynamic operations plan. The following paragraphs detail several leading dynamic ITS technologies.[33]

Ramp metering uses a traffic control device, typically a red and green traffic light, and a signal controller that regulates the flow of traffic entering freeways at current traffic conditions.[34] Ramp metering restricts the total flow of vehicles entering freeways by temporarily storing them on an on-ramp. Ramp metering decreases congestion by reducing demand and eliminating platoons of cars jamming up the right-most freeway lane. Most major metro areas use static ramp metering. Metro areas need to adapt active ramp metering systems calibrated to adjust to traffic in a demand-responsive mode. Imagine a two-lane highway on-ramp that at 7:00 AM has 20 cars in the left lane and five in the right and at 8:00 AM has seven cars in the left lane and zero cars in the right. With a static ramp meter one car from each lane of an on-ramp would enter a highway per green signal for the entire morning rush hour. At 7:00 AM, with an active ramp meter, four cars would enter from the left lane per green signal for every car that entered from the right lane per green signal. At 8:00 AM, with a different traffic pattern, the ramp meter would turn green for the left lane but stay red for the right lane since there is no traffic in the lane. Active ramp metering does much more to reduce congestion.

Static *queue warnings* are electronic signs that detail travel speeds and travel times that may change due to congestion, traffic construction or an accident. They can be used for traffic control on congested facilities or to enhance safety during major incidents. Dynamic queue warnings offer the same features. But they also suggest alternative routes and provide detailed guidance on when the congestion starts. Dynamic signs are often placed at freeway entrances so drivers can choose an alternative route before they enter the highway.

Dynamic signs are often placed at freeway entrances so drivers can choose an alternative route before they enter the highway.

CDOT has a partially dynamic traffic monitoring system, COTRIP, that provides updated information on changeable travel signs. The website provides traffic cameras and information on travel alerts, weather, road conditions, speeds, road work, detours and information to truckers. CDOT also has mobile updates for both the I-25 and I-70 corridors.

Speed harmonization uses variable speed limits to smooth traffic flow and improve safety.

Also, some states have *converted shoulders* to general purpose lanes and allow traffic to use them 24 hours a day, seven days a week. Shoulder lanes are used to increase capacity on constrained highways. Using shoulders for hard shoulder running involves upgrading shoulder pavement quality and opening shoulders to traffic during rush hour.

Junction control uses signs, typically red and green electronic signs, to open and close lanes based on conditions. For example, if there is an accident in the middle lane of three lanes, road operators may place a red X in the box over the middle lane to indicate that it is closed and drivers should move to the right or left.

The most effective active transportation systems use multiple technologies together. For example, queue warnings are used in conjunction with speed harmonization to slow speeds and warn drivers of congestion ahead.

Enforcement of these dynamic roadway systems is important. While traditional enforcement—a police officer sitting in a patrol car—is still used, automated enforcement is much cheaper and safer. Many states use automated traffic cameras to ensure drivers obey dynamically imposed operating signs. If drivers do not obey the signs, the enforcement system mails a ticket to a violator's home address.

Since comparative dynamic ITS traffic system data are limited, we have assessed Denver's system based on the data available. But Denver is encouraged to upgrade to more dynamic ITS systems wherever possible.

B. Freeway ITS Assessment

The Texas A&M Transportation Institute's annual *Urban Mobility Report* provides summary data for each urban area on operations strategy measures, estimating for each one what contribution it is making toward reducing the travel time index.[35] Four basic measures are reported, two for freeways and two for arterials. The freeway measures are the extent of ramp metering and the percentage of the system under active incident management efforts. The most recent freeway data for Denver are shown in Table 8.

Table 8: Denver Freeway Operations Management

Operations Strategy	2008	2009	2010	2011
Ramp Metering				
Percent of miles of roadway	30	29	30	30
Annual delay reduction, 1000 hours	241	270	290	295
Freeway Incident Management				
a) Cameras				
Percent of miles of roadway	27	26	27	27
b) Service patrols				
Percent of miles of roadway	51	50	51	52
Annual delay reduction, 1000 hours	1,141	1,274	1,370	1,394

Source: Texas A&M Transportation Institute

Ramp metering applies to only about a third of the freeway system. Yet estimates of the impact of widespread ramp metering (such as in Minneapolis/St. Paul) suggest that it can have a significant effect on recurrent congestion. For example, the Texas A&M Transportation Institute's latest report estimates that ramp metering (which covers 91% of freeway-miles in the Twin Cities) has saved over 1.5 million hours of delay per year—seven times as much as the ramp metering in Denver.[36] With a freeway system roughly three-quarters the size of that of the Twin Cities, Denver might save 1.1 million hours of delay per year with larger scale ramp metering. Since ramp metering costs much less than significant lane additions, this under-used tool clearly represents "low-hanging fruit" in reducing Denver's congestion. Some of Denver's older freeways (e.g., elevated I-70 east of I-25) would require significant upgrades, due to severely constrained right of way, before they could provide enough "storage" for vehicles in on-ramp queues. But most Denver-area freeways have adequate space for multi-lane on-ramps needed to support ramp metering.

Since ramp metering costs much less than significant lane additions, this under-used tool clearly represents "low-hanging fruit" in reducing Denver's congestion.

Incident management has become a popular tool used to combat recurrent congestion in large metropolitan areas. Two key elements include equipping the freeways with cameras, so that incidents can be identified quickly and appropriate units dispatched, and creating and operating freeway service patrols that can respond rapidly to minor incidents (breakdowns and fender-benders). On the former, Denver still has a ways to go, with only 27% of freeway-miles equipped with traffic surveillance cameras as of 2011, compared to an average of 52% for other large metropolitan areas.[37]

Fortunately, Denver also has freeway service patrols in place, covering 52% of freeway-miles. Their duties include detecting freeway incidents by patrolling metro freeways and quickly responding to and removing incidents (pushing disabled vehicles using push bumpers and removing debris) from the traffic lanes. They are also responsible for providing traffic control and scene security at crashes, assisting first responders with first aid at crash scenes and assisting motorists with emergency vehicle repairs. Service patrols also clear stalled vehicles and debris in the roadway. The congestion from these incidents is responsible for causing about 15% of all freeway crashes, known as "secondary crashes."[38] Every minute a highway lane is blocked can cause four to five minutes of additional delay, so it is critical to clear the roads as quickly as possible.[39]

Several states have analyzed the congestion created by incidents and the advantages of better incident management systems. The Washington State DOT estimates that the throughput on a six-lane freeway (three per direction) can be cut 20% by a car out of gas on the shoulder, 50% by a disabled car blocking one lane, and 85% by an accident blocking two lanes.[40] Rapid response and rapid clearance of such incidents can significantly reduce the duration of such congestion, allowing the freeway's capacity to be reclaimed. The Bay Area Toll Authority estimates a benefit/cost ratio for such projects as 8:1.[41] Such projects typically involve advanced video systems for quickly spotting incidents, dispatch centers to send appropriate response crews, and freeway service patrols to quickly deal with minor incidents.

Table 9 below illustrates the cost-effectiveness of Denver's Safety Patrol program.

Table 9: Freeway Service Patrol Data

City	Annual Cost ($ million)	Miles Covered	# Vehicles	Benefit/ Cost*
Los Angeles, CA	$23.1	411	146 tow trucks	15:1
San Francisco Bay Area, CA	$6.0	362	60 tow trucks	11:1
San Diego, CA	$2.4	203	26 tow trucks	7:1
Chicago, IL	$5.5	80	35 tow trucks	17:1
Houston, TX	$1.4	190	18 vans	6.6:1 to 23:1
Denver, CO	$1.3	60	12 tow trucks	20:1 to 23:1
Minneapolis/St.Paul, MN	$1.0	220	10 pickup trucks	15.8:1

Source: Regional Transportation Management Center

*The benefit/cost calculations are not directly comparable due to the differing assumptions and methods used between agencies. MnDOT's benefit/cost ratio was calculated more conservatively than other metro areas.

C. Institutional Conflict

One challenge with incident management is institutional conflict. Public safety agencies tend to have one set of priorities while transportation agencies have a different one. Besides tending to the injured and dealing with fuel spills, public safety agencies are concerned about thoroughly investigating and documenting major accidents, which can take considerable time, closing lanes or roads for longer periods. Transportation agencies are concerned with the huge delay costs impose on cars, buses and delivery trucks that use the highways, which are exacerbated by lane and road closure. In most states, including Colorado, public safety agencies are either legally or de-facto in charge at incidents, which means that minimizing delay to the traveling public does not receive priority. This is less the case on certain toll roads (e.g., Florida's Turnpike and California's 91 Express Lanes), which take a different approach to clearing incidents. The National Cooperative Highway Research Program published a synthesis report on safe, quick clearance of traffic incidents that detailed four steps municipalities can take to minimize the accident delays:[42]

- Quick clearance legislation;
- Hold harmless law for incident responders;
- Fatality certification law;
- Interagency agreements (open roads policy).

Quick clearance is the process of rapidly and safely removing temporary obstacles including wrecked vehicles, debris and spilled cargo. All states have some type of quick clearance legislation.

A hold harmless law is formal legislation that protects responders and in many cases all on-scene responders from liability "in the absence of gross negligence" as a result of their actions. Colorado has a basic hold harmless law that protects first responders. It should be amended to protect all qualified on-scene responders.

Only a few states (not including Colorado) permit the certification of a fatality and removal of the body by anyone other than a medical examiner—yet such policies can make a major difference in accident clearance times. Jurisdictions with such policies include the city of Chicago and the states of Maryland, Tennessee and Texas.

Likewise, only a few states have developed enhanced interagency agreements that make quick clearance the overarching priority, commonly termed an "open roads policy." At least six states—Connecticut, Florida, Georgia, Maryland, Tennessee, Washington and Wisconsin—have such policies.

Colorado policymakers should pursue the enactment of a fatality certification law and development of an open roads policy among CDOT and public safety agencies.

D. Operations Management and ITS in Critical Freeways Situations

ITS systems can help reduce congestion and increase safety on most every road in most any situation. However, there are two situations—highway construction zones and winter weather—where they are especially useful.

Highway construction zones are a key source of delay, as well as a safety concern.[43] There are two different types of highway construction: routine resurfacing and major reconstruction projects. ITS systems and operations management plans can minimize the delay caused to motorists. CDOT currently makes every attempt to schedule and perform work during off-peak periods and at night.

Routine resurfacing must be completed periodically to maintain the life of the pavement, thereby preventing major reconstruction before it is really necessary. On highly congested freeways, such resurfacing operations should not be completed during peak traffic periods, because the loss of lane capacity imposes too great a cost on users. But since "peak" periods in Denver are approaching eight hours each weekday, this means such resurfacing must be completed at night and on weekends. The additional cost of night and weekend operations is far less than the delay costs that would otherwise be imposed on highway users.

Major reconstruction projects affect roadways for a substantial period of time—typically several months to many years. When possible, all lanes on major freeways should be kept open. This might entail building temporary lanes, narrowing lanes and/or restricting certain vehicles. If lanes must be closed, the construction work should be carried out on a round-the-clock basis (24/7), with the idea of limiting the duration of construction to as short a time as possible.

ITS systems in the vicinity of construction work zones can reduce delay and improve safety by reducing accidents and the delays associated with clearing them. Using design-build contracts to build these projects can limit delays because such contracts contain financial incentives to complete the work on or before a target date.

Winter weather is another substantial concern in Colorado. CDOT posts traffic congestion and weather advisories. It could augment the program by suggesting alternate routes and quickly closing local roads that cannot be speedily treated.

E. Arterial ITS Assessment

Currently, two principal operations strategies for arterials are traffic signal coordination and arterial access management. The Texas A&M Transportation Institute's data for Denver's use of these strategies is presented in Table 10.

Table 10: Denver Arterial Operations Strategies				
Operations Strategy	2011	2010	2009	2008
Signal Coordination				
Percent miles of roadway	67%	66%	65%	66%
Annual delay reduction (1000 hours)	543	533	496	525
*Access Management: Raised Medians**				
Percent miles of roadway	54%	53%	52%	53%
Annual delay reduction (1000 hours)	1,974	1,939	1,804	1,909

Source: Texas A&M Transportation Institute

* As the Texas A&M Transportation Institute only measures raised medians, this understates the amount that access management reduces congestion

1. Traffic Signal Coordination

Denver did not progress much during the last decade with traffic signal coordination. In 2007, 70% of metro Denver traffic signals were coordinated and by 2011 only 67% of traffic signals were coordinated.[44] Yet it was not the only city earning a bad grade. In a survey carried out by the National Traffic Operations Coalition (based on voluntary self-reporting) the average score nationwide was in the low 60s.[45] Many metro areas have 80%–90% of their signals coordinated, which is a significant improvement.

Increasing traffic signal coordination on arterials with a high flow in the peak direction is relatively simple if authorities use progression band signal coordination. In a recent signal timing study, the Bay Area Toll Authority in California found that progression band signal coordination ("rolling green") in the peak direction, can significantly reduce travel times. For arterials where flow is very directional, the benefit-cost ratio can be as high as 35 to 1, according to the Bay Area Toll Authority.[46] Such signal timing is less effective on arterials where traffic is heavy in both directions. On these arterials, officials can minimize the phase length of the side-streets or increase the total length of the traffic-light cycle. Reducing congestion by synchronizing traffic signals is a very cost-effective solution.

In a recent signal timing study, the Bay Area Toll Authority in California found that progression band signal coordination ("rolling green") in the peak direction, can significantly reduce travel times. For arterials where flow is very directional, the benefit-cost ratio can be as high as 35 to 1.

Traffic Signals and Queue-Jumps

Optimized Traffic Signal Timing: The biggest congestion factor for all arterial highways is intersection capacity, which defines arterial capacity.[47] Traffic signals that are used to control vehicular movements at the intersection of two roadways must, by design, reduce the capacity of both roadways by reducing the number of vehicles that can travel through an intersection during a particular time period. Thus, optimizing and synchronizing traffic lights is critical.

"Green time" is the time allotted to a certain movement (i.e., all vehicles at one intersection going from one point of the intersection to another), and it is usually expressed as a percentage. For example, if an arterial highway has a capacity of 1,800 vehicles per hour per lane if there were no traffic signals, that same arterial highway would have a capacity of 1,080 vehicles per hour per lane if that movement received green time for only 60% of the hour. Sixty percent is a relatively large amount of green time for any one movement to have. Taking into account the cross street through movements, protected turning movements and lost time for clearance intervals, the amount of green time for major movements can easily fall below 50%. In fact, it is common for a signaled arterial lane to have less than 50% of the capacity of its uninterrupted-flow counterpart.

To reduce congestion, the base traffic light cycle must offer as much green time to the peak direction as possible. Traditionally, traffic engineers have used long traffic signals to extend green time on major arterial highways. As signal timing has become more precise, some engineers have shortened cycles to reduce delays on side streets while still maintaining a higher percentage of green time on arterial highways. This has the advantage of reducing wait times on side streets. But regardless of the approach chosen, it is imperative that traffic light cycles offer a high percentage of green time to traffic on arterial highways—especially the major arterial highways suggested in this report.

One way to give the peak direction as much green time as possible is to "educate" the signal on traffic configuration at any given time, so that it can customize signal timing to serve that traffic at that time most efficiently. Effective traffic signal optimization changes traffic light signals based on traffic conditions. Highways are fitted with traffic cameras and in-road loop detectors that monitor traffic speeds and congestion. And the pavement near most traffic lights is fitted with loop detectors to notify the traffic light when a car is on a side street. The light will then not turn green for the side street unless the loop detects a car on the side street. Engineers in traffic control centers use the data from these devices to dynamically adjust traffic signals and other traffic control devices such as reversible traffic lanes. The sophistication of these systems continues to increase while the cost continues to decrease.

Traffic Signal Priority: ITS systems also enable transit (or traffic) signal priority (TSP), an operational strategy that reduces the delay transit vehicles experience at traffic signals.[48] TSP enables communication between buses and traffic signals, allowing a priority green light as they approach. There are many different types of TSP. These include extending greens on the existing phase, altering phase sequences, and adding new phases that do not interrupt the overall traffic signal synchronization loop. TSP has a limited effect on signal timing because it adjusts to normal timing and logic to serve a specific vehicle type. In this way, TSP can improve transit reliability, efficiency and mobility. It is important to remember that with TSP, a signal change is always optional; the computer or a traffic engineer in a control center can override the request. Moreover, the light cycle will include all phases for all movements—some of these phases may be shortened, but none will be eliminated.

Queue Jumps: Most TSP systems also use queue jumps. A queue jump is a roadway feature that provides a preference to certain vehicles—often transit vehicles—enabling them to bypass long queues (lines) at signalized intersections. Queue jumps are typically paired with signal-priority treatments, which give buses an early green light or extend a green light. An intersection with a queue jump provides an additional travel lane that can be dedicated to transit vehicles or shared with right-turning vehicles on the approach to a signal. Specifically, queue jumps:

- Help buses to re-enter the traffic stream when a bus lane is ending;
- Allow buses to jump to the front of a queue at a traffic signal after they have picked up passengers at a bus stop; and
- Assist buses in crossing lanes ahead of other traffic to reach a left-turn lane without obstructions.

How does a queue jump work? When a bus reaches a red light in the right-turn lane with a queue jump and decides to use it, the bus receives a special signal to continue through the intersection. Sometimes the signal is instantaneous; other times the bus may have to stop completely and wait for a short period of time. The signal typically precedes the signal for other traffic in the same direction. Sometimes it will interrupt a signal for cross-traffic or for traffic turning left.

2. Arterial Access Management

There are several access management strategies that reduce congestion and increase safety on arterials.

Access management refers to the control of vehicles entering or exiting the road or highway.[49] There are several types of access management strategies, although the Texas A&M Transportation Institute only measures *raised medians*.

Raised medians are often the most controversial strategy. Because they prevent left-turns at certain intersections, usually those without traffic signals, raised medians can make it more challenging to access businesses on arterials. From a traffic management standpoint, during heavy traffic conditions such medians can increase recurrent congestion, due to the limits on storage capacity of left-turn bays. Once they become full, additional left-turning traffic spills into the through lanes, adding to delays. But because raised medians also increase safety by reducing the number of conflict points (thereby reducing accidents), they reduce incident-related congestion. When analysts crunch the numbers, they find a net decrease in congestion from the addition of raised medians and the safety benefits outweigh the left-bay storage capacity and business accessibility issues.

Another access management strategy is *consolidating driveways* to minimize disruptions to traffic flow. An Iowa State survey recommends only two to three driveways for a 500-foot city block for roads with a 35 mile-per hour speed limit.[50] Roads with higher posted speed limits should have even fewer driveways.

Adding *median turn lanes* can also improve traffic flow and safety. The Federal Highway Administration found that left-turn lanes increase roadway capacity. A shared left-turn and through lane has about 40% to 60% of the capacity of a standard through lane.[51] Roadways that add a left-turn lane increase capacity by 25%. The same study also reported that left-turn lanes at intersections substantially reduce rear-end crashes. The research synthesis found that exclusive left-turn lanes reduced crashes by 50% while reducing rear end collisions 60% to 88%.

Exclusive left-turn lanes reduced crashes by 50% while reducing rear end collisions 60% to 88%.

Overall, this report recommends that, to reduce congestion, primary arterial highways should feature fewer access points. Left-turning motions should be limited to grade-separated ramps and traffic signals. Intersections with side streets should either feature a traffic signal or allow right-turn access from the side street onto the primary regional arterial highway only. A median or other barrier should separate traffic traveling in opposite directions. To compensate for fewer turning locations, turn lanes should be lengthened and all traffic signals should allow U-turn motions. Left-turn cycles should be lengthened to reduce queue time.

Where possible, primary arterial highways should also feature *grade separations* at major side streets. (For the purpose of this study, major side streets will typically have at least four through lanes and average annual daily traffic volumes above 30,000 vehicles.) There are several potential grade separations. The first is a full interchange with direct ramps for all turning motions. While this is the best option for two extremely busy roads, costs, aesthetics and neighborhood sentiments may make building full interchanges less than desirable in most situations. Another option is to build a grade separation where the main lanes of the major primary arterial highways travel over or under the side street. Side-street movements and vehicles turning left or right from the major primary arterial highway onto the side street will use a traffic light. Since through traffic on the major primary arterial highway will use the grade separation, the traffic light can offer longer traffic signals for all other traffic movements, reducing congestion.

Some of the techniques discussed in this chapter also have been quantified in the NHCRP report referred to in Table 11.

Table 11: Leverage of Systems Operations and Management on Congestion

Problem	Percent of Total Delay	Strategy/Tools	Potential Effect (% of Total Delay)
Uncoordinated Signals	4-13%	Region-wide re-timing	2-5%
Crashes and Breakdowns	20-42%	Integrated freeway service patrol, incident management program	10-20%
Work Zones	8-27%	Advanced work-zone traffic control; automated speed control	4-13%
Weather Impacts	5-10%	Prediction/advisory, pre-treatment	2-5%

Source: *NCHRP Project 20–24, Research Program Design*

It is clear that various operations measures and ITS systems can address incident-related congestion, which is an important element of the region's overall congestion problem. Nevertheless, they can do little to resolve the large and growing mismatch between roadway capacity and travel demand that manifests itself as recurrent congestion.

Part 4

Principles for Improving Denver's Roadway and Transit Systems

Given the challenges facing Denver's transportation system, it would be easier to start with a clean sheet of paper and design a new, state-of-the-art system. But such an approach is clearly not feasible in an already developed metropolitan area; augmenting and improving existing systems is the only practical way forward.

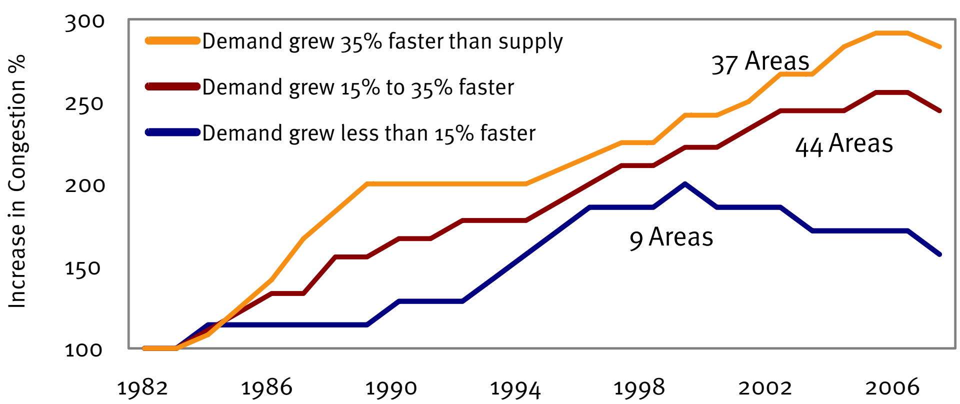
This section explores the various roadway and transit improvements that Denver can undertake to reduce congestion and increase mobility. These include the addition of general freeway capacity, the elimination of bottlenecks, and the construction of two new kinds of variably priced roadway capacity—managed lanes and managed arterials—as well as the establishment of a modern, efficient transit network designed to take advantage of this new construction.

But first, we must address a preliminary issue. Is it true, as some suggest, that Denver does not actually *need* additional roadway capacity, and that demand reduction strategies emphasizing transit and "smart growth" can eliminate traffic problems on their own?

Data from the Texas A&M Transportation Institute for America's 90 largest urban areas suggests otherwise (see Figure 10). [52] In effect, the U.S. has run a large national experiment over the past two decades, testing whether demand reduction or capacity expansion would do better at easing congestion. Most metro areas such as San Francisco, Portland and Washington D.C. have relied primarily on demand reduction (and therefore have added little freeway capacity); these metro areas have experienced the greatest increases in congestion. Expanding transit facilities and services has to some degree increased the number of riders, but the massive growth in population and VMT has overwhelmed all of the investment, and there has been no appreciable reduction in the mode share of solo driving. By contrast, the few metro areas that focused more on capacity expansion, such as Houston and Phoenix, have experienced the smallest increases in congestion.

The clear implication of this is that policymakers wishing to reduce congestion and increase urban mobility must inevitably add capacity to their roadway systems. The question is how and where to do it.

Figure 10: The Relationship Between Congestion Growth and Expansion of Highway Capacity



Source: TTI 2009 Urban Mobility Report, exhibit 12.

A. Adding General, Unpriced Roadway Capacity

David Hartgen and M. Gregory Fields of The Hartgen Group worked with the transportation modelers at DRCOG to estimate how many lane-miles would be needed to eliminate all severe congestion in the Denver area (what DOTs define as Level of Service F, usually written as LOS F) by 2035. This exercise was run on the DRCOG's traffic assignment model. The results were that a total of 807 lane-miles of all types (freeway, arterial, collector and other) would need to be added by 2035.[53] Freeway lane-miles were 170 or 21% of this total.

A total of 807 lane-miles of all types (freeway, arterial, collector and other) would need to be added by 2035

However, things may not be so simple. Non-priced capacity improvements alone cannot solve the problem of urban congestion. Experience suggests that new general lane capacity quickly fills up in growing metro areas, with previous congestion levels reasserting themselves two to five years after the non-priced capacity improvement project is completed. This phenomenon of highways becoming congested soon after they are widened is labeled "induced demand" and occurs for two reasons.

First, most metro areas are growing; while the highway may have sufficient capacity for current residents it does not have extra room for growth. Most large-scale roadway expansions provide congestion relief in the short-term and medium-term (depending on how fast the region grows), but become congested again in the long-term.

Second, residents often have unmet travel goals. If there is severe congestion consumers may choose to eat at home instead of at a restaurant or watch a Colorado Rockies game at home instead of at the stadium, or even forgo taking advantage of a better job farther away. But when congestion is reduced, these residents will make these trips. Infrastructure improvements that induce residents to travel farther are good from an economic development perspective. However, they undermine congestion relief.

Adding non-priced lanes is not realistic for other reasons: large-scale construction projects are politically challenging because they require the acquisition of significant right of way via eminent domain proceedings and displace significant numbers of businesses and residences. Moreover, the costs of such undertakings are very high, likely exceeding available funding.

As such, adding non-priced lanes is not the best solution to any urban area's transportation problems. However, we do recommend adding a very small amount of non-priced capacity to certain corridors in Denver that are either exceptionally congested or inappropriate for priced lanes. Specific capacity-addition projects are addressed in Part 6 of this report, but do not form a major part of our approach to reducing congestion and increasing mobility in metropolitan Denver.

B. Eliminating Freeway Bottlenecks

Another aspect of a successful approach to capacity expansion is *bottleneck elimination*. A freeway bottleneck is a specific point in the freeway network where traffic becomes clogged due to physical limitations of the system. Freeway bottlenecks occur where the number of lanes suddenly decreases and traffic has to squeeze into the remaining lanes, or where on- and off-ramps are too close together, resulting in excessive weaving as cars cross each other's paths getting on and off the freeway.

Fixing bottlenecks is not simple, but it is not overly complex either. In many cases, the interchange design is obsolete, in addition to the capacity being inadequate. Bottleneck interchanges of this sort are being redesigned and rebuilt nationwide, as money can be found to pay for these major projects.

Table 12 lists some recent projects to reconstruct bottleneck interchanges around the country. The Florida I-595 project includes a considerable addition of adjacent freeway lane-miles, many in the form of braided on-ramp/off-ramp additions, making the reported cost higher than just the cost of rebuilding the interchanges alone.

Table 12: Recent Interchange Bottleneck Reconstruction Projects

Interchange	Project Description	Costs	Lane-Miles Added	Construction Dates
San Francisco SR 92/I-880	Replace 2 Cloverleaf ramps with direct access ramps	$245 million	0	10/07-10/11
Washington D.C. I-495/I-95S	Rebuild interchange ramps Including express lanes	$676 million	0	10/03-07/07
Houston I-610/I-10W	Reconstruction of interchange and bridges	$262.5 million	0	10/04-01/10
South Florida I-595 between I-75 and I-95	Build three new lanes, rebuild bridges, rebuild entry/exit ramps	$1.2 billion	41 miles	02/10-06/14

Source: California Department of Transportation, Florida Department of Transportation, Texas Department of Transportation and Virginia Department of Transportation.

Many of Denver's freeway interchanges were not designed for the current level of peak-period traffic. Fixing these bottlenecks is a priority for CDOT as it continues to modernize the freeway system. According to a national study by Cambridge Systematics, the Tech Center Interchange (I-25 at I-225) was one of the worst bottlenecks in the country.[54] Fortunately, many of the bottleneck issues associated with this interchange were addressed as part of the $1.6 billion T-REX project that was completed in November 2006. This project, which included improvements to eight interchanges, was designed to address congestion in the region of this Tech Center interchange. The current *2035 Metro Vision Regional Transportation Plan* identifies the need for nearly $3 billion for new and upgraded interchanges, but the fiscally constrained plan can identify less than half the needed funds for interchange improvements.

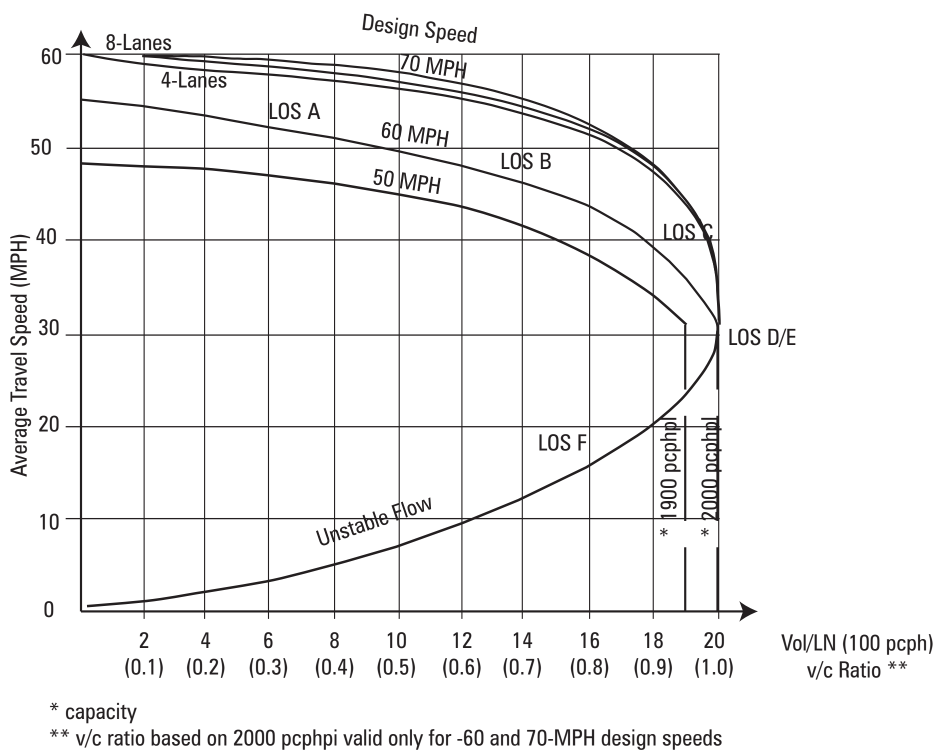
C. Establishing an Express Toll Lane Network

Specific non-priced capacity increases and bottleneck eliminations, then, can certainly help ease congestion. Nevertheless, the smartest approach to dealing with roadway congestion, especially in fiscally constrained circumstances, is to make targeted capacity increases and use "dynamic pricing" to keep traffic flow within the capacity of the new roadway. Lanes that use dynamic pricing are typically referred to as "managed" or "express" lanes."[55]

How Express Toll Lanes Function

Functional capacity can be increased by managing traffic flow in roadway lanes to prevent a severely congested state, often referred to as hyper-congestion.[56] When traffic flow breaks down in that manner, speeds become chaotic and inconsistent. When traffic flows become congested, the throughput (number of vehicles per lane per hour) of the freeway decreases considerably. Whereas a freeway full of traffic moving steadily at 40 mph may have a throughput of 2,000 to 2,500 vehicles/lane/hour, if more vehicles try to crowd onto it, the flow rate can degenerate to 1,500, 1,200 or even less as speeds drop into the zero to 20 mph range. These conditions are shown in the traffic engineers' speed/flow curve, in Figure 4-2. Traffic engineers recognize six levels of service (LOS), ranging from A (uncongested free flow) to F (hyper-congestion). The kind of throughput associated with each is indicated on the figure.

Figure 11: Traffic Throughput Versus Traffic Speed



Source: Highway Capacity Manual 2000.

Figure 11 shows traffic speed on the vertical axis and traffic volume on the horizontal axis. At the top left, when traffic volume is low, speeds are high and consistent. Engineers refer to this kind of flow as Level of Service (LOS) A. As volume gets higher and cars get somewhat closer together, speeds decline somewhat, and we have traffic at LOS B—still flowing fairly well. Moving to the right, as volume continues to increase, speed declines and we reach the maximum rate of flow that each lane can handle with minimal congestion, designated LOS C. At that point, if more vehicles enter the lane, speed decreases but throughput still increases, called LOS D. If even more vehicles try to enter, speed declines further, and flow volume is only minimally increased, for LOS E. Once LOS E is reached, if more vehicles enter, the flow degenerates into stop-and-go traffic. This results in both low speed *and* low volume—called LOS F. Under LOS F conditions, the ability of the freeway to move traffic is hampered at precisely the time it is needed most. Once a freeway gets into severe LOS F, it can sometimes take an hour or more for it to recover.

In a system of dynamic pricing, the price for using express lanes falls if the lanes are clear. But if the express lanes become congested, the price for using them rises. By deterring drivers who are unwilling to pay the demand-responsive toll, dynamic pricing keeps traffic within the capacity of the tolled roadway, limiting the number of vehicles entering the lane so that traffic always flows at a specified level of service (perhaps C or D during peak periods). Traffic engineers have described this as maintaining traffic at the "sweet spot" represented by the upper right-hand portion of the speed/flow curve.

Dynamic pricing keeps traffic within the capacity of the tolled roadway, limiting the number of vehicles entering the lane so that traffic always flows at a specified level of service.

Dynamic pricing is not just a matter of theory. Many freeways such as I-635 in Dallas, I-95 in South Florida, I-85 in suburban Atlanta, and I-10 in Los Angeles feature dynamic pricing. Dynamic pricing that encourages users to carpool, vanpool or ride the bus have proven successful. During the busiest peak periods on California's 91 Express Lanes (a priced dual-lane facility), the two priced lanes handle 49% of the peak-direction throughput on this six-lane freeway, even though they represent only 33% of the *physical* lane capacity.[57] Thus, priced express lanes operating at LOS C during rush hour have about 50% more *functional* capacity (throughput) than the highly congested (LOS F) general purpose lanes alongside. A single-lane facility of this type can maintain non-congested conditions with about 1,800 vehicles/lane/hour, while a dual-lane facility can handle 2,000 vehicles/lane/hour. This type of heavy, but smoothly flowing traffic is referred to by traffic engineers as LOS C. As a result, dynamically priced facilities are free from congestion 24 hours a day 7 days a week.

Toward Road Tolling in Denver

Road tolling is not a new concept in Denver. Back in June 2006, CDOT tolling entity Colorado Tolling enterprise opened seven miles of HOT lanes on I-25, which had been converted from HOV lanes. Its successor, the High Performance Transportation Enterprise (HPTE) is building new express toll lanes on US 36 and converting existing HOV lanes between Denver and Boulder.[58] HPTE is also considering other express toll lane projects in the metro Denver area. Our recommendations in this study build on discussions that are already underway in Denver.

One important question for transportation policymakers to consider is which vehicles, if any, will be allowed to use express lanes free of charge. CDOT's HOT lanes analysis for Denver compared the performance and revenue-generating potential of HOT lanes under three different access policies: allowing HOV-2 vehicles continued free access, restricting free access to HOV-3 or greater or restricting it to HOV-4 or greater.[59] The report found that the higher the occupancy level required for free passage—i.e., the less capacity that is given away to HOV vehicles—the greater the potential revenue that is generated to help pay for the new lanes (with HOV-4 being the preferred approach). Accordingly, we propose charging *all* personal automobiles and light trucks (pickups, SUVs, etc.) the same market price, reserving free access only for super-HOVs (buses and vanpools) and emergency vehicles. There are several reasons for this recommendation.

The revenue produced by charging all light vehicles will make it possible to more quickly build additional express lanes, since robust toll revenues will allow development to be *financed*, rather than funded out of pocket as construction occurs.

First and foremost, the revenue produced by charging all light vehicles will make it possible to more quickly build additional express lanes, since robust toll revenues will allow development to be *financed*, rather than funded out of pocket as construction occurs. The greatest benefit from express lanes comes when they are sufficiently built out to form a *network* across the metropolitan area. More toll-paying customers will allow the network to be completed sooner. Denver could complete an express lanes network by 2045 if it charged all light vehicles to use the lanes. Other metro areas across the country, such as Atlanta and Dallas, have made a similar decision to charge most vehicles on their new express lanes.

Second, pricing access for all but transit and emergency vehicles in these lanes provides for more reliability of traffic flow and ensures the lanes remain popular enough with toll-paying customers to produce stable toll revenue. Third, enforcement is much easier (and cheaper) when all light vehicles have to pay the same toll; monitoring a mixture of identical-looking free and paying autos is difficult, leading to high enforcement costs or significant losses of revenue.

Express Toll Lanes Offer "Congestion Insurance"

Most of the impetus for various forms of priced lanes around the country is spurred by the driving public's demand for relief from freeway congestion. Variable pricing works by preventing the priced lanes from being overloaded with vehicles during peak times, maintaining what traffic engineers call free-flow conditions. To the extent that traffic increases over time, future rush-hour prices will be higher than prices in the early years, but the pricing mechanism is sustainable, long term. This means that motorists can be assured that no matter how bad traffic gets, they will always have a congestion-free option available when they need it.

Some have begun to call this concept "congestion insurance." People purchase insurance to guard against life's other hazards (fire, theft, accidents); similarly, with a network of express lanes drivers will be able to purchase insurance to guard against being late. The initial cost of this "insurance" is very low: simply the cost of opening an account and installing a transponder on the car's windshield.[60] From that point on, the account-holder has the peace of mind that whenever she is running late and really needs to be somewhere on time, she has a means of buying that faster trip for a small price.

What kinds of trips might these be?

- Getting to the day care center on time, before costly per-minute late fees start to mount up;
- Getting to work on time, when the boss has said one more late arrival will be grounds for termination;
- As a tradesperson, getting one more job accomplished that day, rather than spending the time stuck on the freeway;
- Getting to the airport on time to leave on a business trip or family vacation.

Data from the express lane projects in California, Florida, Georgia, Texas and Virginia support the premise that most people don't use these lanes twice a day, every day. Rather, the large majority use the lanes in the "congestion insurance" mode, once or twice a week. The 91 Express Lanes in Orange County have 176,000 account-holders, but on any given day, only about 33,000 of them use the lanes. And only a small fraction of those 33,000 are every-day commuters; most are those who, on that particular day, had a trip that was worth the several dollars toll.

Express Toll Lanes Promote Higher Overall Vehicle Occupancy

The goal of higher overall vehicle occupancy (originally intended to be realized via HOV lanes) can be better achieved via an express lanes network for several reasons. First, a region-wide set of priced lanes offering major time savings during peak periods gives people an incentive to carpool, so as to split the toll two, three or even four ways. Second, the availability of such a network may spur a large revival of interest in company-sponsored vanpools, since these priced lanes will remain congestion-free indefinitely, unlike HOV lanes which fill up over time and provide little or no time-saving advantages. The long-term sustainability of free-flow conditions makes it worthwhile for companies to invest in vanpooling programs. Third, a region-wide uncongested network makes an ideal guideway for region-wide express bus service and BRT. In fact, if a policy decision is made to *reserve* a fraction of the capacity of these lanes for such bus services, and if RTD planned much of its express bus service around use of this network, then the network would meet the definition of a Virtual Exclusive Busway network.[61] In other words, it would provide the virtual equivalent (in terms of bus performance) of a network of exclusive bus lanes. We will return to the synergy between transit and dynamically priced lanes, also known as "managed lanes," later in this section.

The long-term sustainability of free-flow conditions makes it worthwhile for companies to invest in vanpooling programs. Third, a region-wide uncongested network makes an ideal guideway for region-wide express bus service and BRT.

Express Toll Lanes May Prove Popular in Denver

Are the people of greater Denver ready to pay for congestion relief on a voluntary basis? Survey data suggest that this is the case. Denver-based Corona Research did a random-digit dial phone survey of 384 metro Denver residents in 2006 regarding their commuting habits and preferences. More than three-quarters of the respondents said that traffic congestion was a problem, and 78% supported the idea of adding tolled express lanes to congested freeways. Almost 70% said it would be better to build the lanes with tolling now, rather than waiting 10 years in hopes of building them with tax money. Asked if they, themselves, would use the new lanes during times of freeway congestion, 56% said they would (compared with 42% who said they would not). The most interesting results show that nearly three-quarters of the respondents would prefer tolled express lanes over taxes to pay for building new lanes, and that in fact, tolling is by far preferred over any other method to pay for expansions.[62] Similar surveys have shown similar results. A 2014 nationwide survey shows tolling as the most popular funding option for expanding freeways.[63]

A 2014 nationwide survey shows tolling as the most popular funding option for expanding freeways.

Building Express Toll Lanes with Public Private Partnerships

In their 2004 *Blueprint 2030* report on reducing congestion in Atlanta, authors Cox and Pisarski recommend that, because of the large size and jurisdictional diversity of the 20-county Atlanta region, a major congestion reduction program should be administered by a "state implementation corporation."[64] This entity could be similar to the toll road authorities in other states and in some metro areas such as Houston. It should have bonding authority secured by toll revenues, be insulated from political influences and be solely committed to developing the set of projects needed to achieve the congestion-reduction goal.[65]

Along these lines, the Colorado legislature and governor created the Colorado Tolling Enterprise (CTE) in 2002. The CTE used a feasibility framework to determine which new freeways should be constructed. The CTE studied adding tolled express lanes to I-25, I-70, I-225, I-270 and US 36. In early 2009, the legislature and governor replaced CTE with a new entity, the High Performance Transportation Enterprise (HPTE). The main difference between the two agencies is the board's composition, although HPTE also has a statewide governing board and a broader project scope. Similar to CTE, HPTE has the power to levy "user fees" to support transportation projects and can "pursue public-private partnerships and other innovative means" of building projects. It may also accept grants for up to 10% of its revenues. Because some portions of the express lanes network proposed in this report would not be self-supporting on a stand-alone basis, it is important that a public agency such as HPTE be able to issue toll revenue bonds based on the toll revenues and financial strengths of the entire set of toll projects. CDOT has converted the I-25 HOV lanes to HOT lanes, and two other agencies—the E-470 Authority and the Northwest Parkway Authority—have also developed toll road projects. However, none of these projects was a true public-private partnership.

In order to maximize taxpayer resources, Colorado should use public-private partnerships (PPPs, or P3s) funded by long-term toll concessions to build toll roads where feasible. Colorado's first P3 concession for the construction of express lanes on US 36 has experienced challenges. The project encountered opposition due to the length of the contract, the amount of public input into the process and the number of alternative fuel vehicles that can use the lane.[66] Several bills that would have restricted P3s were introduced by the legislature. While one died in the General Assembly, SB 14-197 passed and then was vetoed by the governor. The governor did address the justifiable concern that CDOT did not include enough public involvement nor provide enough public information by issuing new guidelines. But some of the vetoed bills' draconian P3s restrictions came from a lack of understanding.

Under P3 concessions, the private partner takes major responsibility for financing the project, investing equity for perhaps one-quarter to one-third of the project cost.

Under P3 concessions, the private partner takes major responsibility for financing the project, investing equity for perhaps one-quarter to one-third of the project cost. And it takes long-term ownership responsibility for a defined period of years (e.g., 50 years), during which it must build, operate, manage and maintain the toll road or toll lanes at its own risk. The most important advantage to taxpayers is the limitation of the state's risk by shifting much of that risk to the private-sector partner.[67]

The Express Toll Network, whether built as a single project or a series of projects, meets the definition of being a "mega-project." The two major risks frequently seen with such projects are cost overruns and traffic/revenue shortfalls.[68] Design-build contracts shift much of the cost-overrun risk to the private partner. But they do not shift traffic and revenue risk, nor do they ensure that the initial design is optimized for lowest life-cycle cost. A long-term concession does both.

Traffic and revenue risk are serious issues for new toll roads. Recent reports by two of the leading bond rating agencies, Fitch and Standard & Poor's, point to a tendency of such forecasts to be overly optimistic, which puts the bondholders at risk.[69] Several recent PPP projects of the type noted above, in which the private sector develops the project but does not take on ownership-type risks, have all experienced serious shortfalls in early-years traffic and revenue: Colorado's Northwest Parkway, South Carolina's Southern Connector and Virginia's Pocahontas Parkway. The Northwest Parkway has been rescued by means of a long-term concession agreement, under which a global toll road company refinanced the project and took on full ownership-type risks for 99 years. The Pocahontas Parkway is being handed back to the state of Virginia to operate, since it cost more to operate than initially expected. The Southern Connector, after failing to find significant private-sector interest, filed for bankruptcy in January 2010.

Minimizing life-cycle cost is also facilitated by a long-term concession approach. If the same enterprise that is designing and building the toll road also must operate it profitably for 50 years, it has every incentive to build it right in the first place, rather than cutting corners to get the initial cost down. Spending an extra 10% to 15% on a more durable pavement in the first instance generally pays for itself several times over in lower ongoing maintenance costs over the roadway's lifetime. But neither traditional public-sector project development nor the design-build PPP model is able to internalize this incentive effect, since operating and maintenance costs are not the responsibility of the entity designing and building the roadway.

Cost-sharing is possible under a concession agreement, for those projects that cannot be fully supported by toll revenue financing. In such cases, the public sector (e.g., CDOT or HPTE) would have to make an "equity" investment for, say, 30% of the project cost, with the balance being financed out of toll revenues, and the responsibility to collect and manage these toll revenues falling to the concessionaire. In most cases, with this type of mixed funding, the concession company agrees to share toll revenue above a certain level with the state agency. This type of mixed financing is being used currently for several mega-projects in Texas (with Texas DOT and/or local Regional Mobility Agencies being the counterparts of CDOT and HPTE). The FHWA PPP agenda considers using mixed financing, including congressional authorization for public-sector agencies to issue up to $15 billion in tax-exempt, private activity (revenue) bonds in support of toll projects to be developed under long-term concession agreements.[70]

P3s have very specific terms on the length, pavement quality and operating characteristics.

Regardless of the type of P3, government still has an active oversight role. P3s have very specific terms on the length, pavement quality and operating characteristics. Government monitors the concessionaire to ensure that he is adhering to all parts of the contract. If the concessionaire does not adhere to all conditions in the lease, penalties up to termination of the lease can occur. As a result the concessionaire has a strong incentive to provide good customer service. Below are some other important details of P3 projects.

- **Highway and transit projects developed by international companies increase the number of Colorado residents employed in the active construction industry.** Other countries have many companies with decades of experience in PPPs because those countries do not have a dedicated gasoline tax to build infrastructure. With increasing gas mileage and materials costs, and more fuel-efficient vehicles reducing gas consumption, the U.S. is facing the same problem. PPP experiences in the U.S. show that international companies hire mostly U.S. workers. Transportation projects need construction workers, and workers in Spain cannot build a construction project in Colorado. As PPPs provide almost 50% of the resources for large projects, they increase local employment in the construction sector by 40%. U.S. engineering companies such as Parsons Brinckerhoff and HNTB Corporation are also involved in PPPs, and with increased use of PPPs in the U.S., these companies will gain more experience. On the finance side, U.S.-based investment firms such as Morgan Stanley and JPMorgan Chase are creating their own infrastructure funds to invest in PPPs. Many city- and state-owned pension firms are also investing in PPPs.

- **PPPs do not commit future generations any more than lottery, union or other state contracts.** State governments regularly make commitments that burden taxpayers for longer than 50 years. Bonding for infrastructure and changing public-employee pension benefits are two examples. Because the capital costs for major infrastructure projects are so high, it is necessary to finance them over long periods of time. And PPP documents are flexible. All concession agreements have detailed provisions to permit changes during their term. These provisions deal with such matters as negotiating and arbitrating disputes and employing independent parties to make fair financial estimates. Typically, the only limit to changes to the concession is that neither side be financially disadvantaged by the changes. With long-term commitments come long-term benefits. In the absence of funds, using PPPs to deliver new transportation infrastructure enhances the mobility of current and future generations and benefits the economy over the long term.

- **Today's PPP deals do not include rigid non-compete clauses that prevent state and local officials from building nearby competing roads.** While some early proposals had such clauses, today's proposals allow Colorado to build everything in its current long-range transportation plan. Political challenges and funding make it very challenging for CDOT to build new non-tolled lanes in the Denver area. If new lanes are built, today's PPPs spell out a compensation formula for some portion of toll revenue under any conceivable circumstances.

- **Government (and taxpayers) is protected if the private party in a PPP goes bankrupt.** In the event of a corporate bankruptcy by the private sector investor-operator, the asset reverts back to the project lenders who, with permission from the state, would select a new operator. Under certain scenarios, the state receives the highway for free. The lenders have strong financial incentives to continue to properly operate and maintain the road, since they risk losing the value of their investment. The state must approve any contract changes.

D. Expanding the Arterial Network

The Denver metro region is fortunate in that it has a well-developed arterial network. However, as growth continues it is important to continue extending, modernizing and widening the network. Modernizing the freeway system is important, but regional leaders should not neglect needed improvements to the arterial system.

This report focuses on creating an enhanced network of major regional primary arterial highways, some of which will be managed. Our plan uses grade separation, traffic-signal optimization, access management, strategic capacity expansion and operations management strategies to upgrade selected primary arterials into a network of arterials that offers an alternative to the existing freeway network.

While minor arterials and local roads are a vital part of the roadway network, they are beyond the focus of this study.

The Role of Managed Arterials

"Managed arterials" combine dynamic traffic management systems, as discussed in Part 3 of this study, with pricing to offer drivers a premium travel option. A managed arterial offers drivers the choice of using an overpass or underpass to bypass the intersection and traffic light.[71] Because overpasses and underpasses are costly to build, this option will require a small variable charge, generally between $0.25 and $0.50 per intersection, based on traffic volume and congestion. Drivers can also choose to continue on the main road through the intersection for free.

Managed arterials were first studied in Lee County, Florida (Fort Myers) in 2002 under the Federal Highway Administration's Value Pricing Pilot Program. The Value Priced Queue Jump Study examined the possibility of using grade-separated overpasses at congested intersections to allow drivers who were willing to pay a toll to bypass the traffic signal and its queue.[72] The study examined operational issues, public acceptance and cost feasibility. It found that, from an operations standpoint, such grade separations are feasible. There are no technical or operational issues that would prohibit their use. With some non-tolled, grade-separated intersections already in existence in Lee County, and in Broward and Palm Beach Counties, also in Florida, this finding was not surprising. For proper operation, any tolling must be accomplished via all-electronic tolling.

The study used both focus groups and return-mail surveys, and public acceptance was positive.[73] The grade separations were presented as a choice. Drivers could remain on the free road and proceed through the intersection as usual or pay a small toll to bypass congestion. The element of choice was a major component of public acceptance. The tolls presented were relatively small, ranging between 10 cents and 50 cents per grade separation. The study presented varying the toll by time of day, which the public found acceptable.

Managed arterials improve traffic flow because they use overpasses or underpasses to bypass the signalized intersections. A six-lane arterial has a rated capacity of 51,800 vehicles per day (vpd), based on Florida DOT standards. Widening it to eight lanes increases that to 67,000 vpd.[74] As an alternative to widening, the addition of four-lane overpasses or underpasses (two lanes per direction) with one through lane at grade level each way would provide a capacity of 87,600 vpd. In situations where the costs and political difficulties of acquiring additional right of way for widening are high, the addition of grade separations may be a more feasible (or even the only) way to increase capacity, albeit at a somewhat higher cost (though it would often require some additional right of way in the vicinity of the intersection). On the other hand, tolling each overpass could provide a revenue stream to cover at least a portion of the cost. Figure 12 illustrates the arterial overpass concept and Figure 13 illustrates the arterial underpass concept.

Figure 12: Arterial Overpass Queue Jump

Source: Increasing Mobility in Southeast Florida, Reason Foundation

Figure 13: Arterial Underpass Queue Jump

Source: Increasing Mobility in Southeast Florida, Reason Foundation

The managed arterial concept is an accepted method for solving traffic congestion. The National Academy of Sciences Transportation Research Board (TRB) presented an overview of managed arterials at its 2012 annual meeting, and TRB's journal, *Transportation Research Record,* published a paper on the subject in issue number 2297.[75]

E. Improving the Transit Network

Transit ridership has been increasing in Denver. Trips per capita increased from 40 in 1985 to 47 in 2008.[76] However, this represents a relatively small subset of the population. In 1980 5.8% of the metro area commuted to work via transit. By 2010 this number had decreased to 4.1%. What explains the conflict between these numbers? Parts of the metro area are very well served by transit. Those residents who take transit do so often. However, other mostly suburban areas are not well served by transit. The challenge is to increase transit ridership in these areas.

Transit in Post-World War II Metropolitan Regions

Substantial research has been conducted into the best way to operate transit service. Geographical orientation of service is one key aspect. Several studies conducted over the past decade have shown that multi-destination transit networks (grid networks) are most efficient in attracting passengers and are cheaper to operate than downtown-based systems (radial networks).

Multi-destination transit networks (grid networks) are most efficient in attracting passengers and are cheaper to operate than downtown-based systems (radial networks).

In 2008, Gregory Thompson, chair of the Transportation Research Board Light Rail Committee, and Jeffrey Brown, associate professor of transportation planning at Florida State University, studied 45 U.S. metro areas to determine whether radial or grid networks offer better service.[77] The authors also separated metro areas into those that have bus service only and those that have both rail and bus service. They found that the grid or multi-destination areas that used both rail and bus transit performed better. The radial approach connected neighborhoods to the central business district (CBD), but made reaching jobs outside of the CBD difficult. The multi-destination approach, while not as good at connecting neighborhoods to the CBD, was much better overall because it offered reliable transit service to more parts of the metro areas. Further, from 1984 through 2004, the grid metro areas experienced much smaller productivity declines (single digit) than the radial metros (25%). (Productivity refers to the number of people using the transit system compared to the cost to operate that service.) There was also a smaller increase in per-capita costs for the grid service compared with the radial service.

Thompson and Brown studied two bus-only systems in more detail: Broward County Transit (BCT) in Fort Lauderdale, Florida, and the T in Tarrant County, Texas (Fort Worth), which cover similarly sized areas with similar growth patterns. While the T has a radial pattern, BCT has a grid focus. BCT had 31.72 boardings per hour, which was almost double the T's 16.45. Operating expenses for BCT were also substantially lower, while load factor—the percentage of seats and standing room on a transit vehicle occupied—was substantially higher.

Figure 14 shows the difference between Broward County's grid service on the left and Tarrant County's radial service on the right.

Figure 14: Transit and Employment Access
Broward County, FL and Tarrant County, TX

Source: Jeffrey Brown and Gregory Thompson,
Hubs, Spokes, the Grid, and the Future of Transit

That study also highlights the differences between Denver and other U.S. metro areas. New York, Chicago and several other major Northeastern metro areas experienced their fastest period of growth before World War II. Pre-World War II metro areas developed around walking and rail. They have higher population densities and are typically more compact and more centralized. Denver, Houston, Phoenix, Salt Lake City and other southern and western metro areas experienced their fastest growth after World War II. These metro areas developed around the automobile. They have lower population densities and occupy a larger geographic area.

Some post-World War II cities, such as Portland, have tried to duplicate the characteristics of pre-World War II cities using urban growth boundaries. Such boundaries limit the physical area of development, creating denser communities. The downside is they also drive up housing costs. Moreover, such boundaries have in fact had minimal success in increasing transit usage. Similarly, it is unlikely that Denver could successfully engineer transit-supporting densities through regulation. For all its regulations aimed at creating denser communities believed to get travelers out of their cars, Portland's transit usage is not much higher than that of Denver or Salt Lake City or San Diego—comparable cities with less stringent land-use restrictions.

Another challenge is the prevalence of traditional Euclidean zoning, separating residential and commercial uses.[78] In Euclidean-zoned communities people tend to live further away from where they work than in mixed-use communities. This increased distance between home and work limits the effectiveness of rail. And while mixed-use zoning has become popular in in-town areas of Denver, the majority of the Denver region is still zoned into traditional residential, commercial and industrial areas and considerable opposition exists to changing traditional zoning. Furthermore, while some residents are content to pay higher housing prices to live in a denser area with more transit options, most residents still prefer a location in the suburbs. The upshot is that regardless of policy, Denver will never have the transit ridership of New York City because of the fundamental structure of cities built up after World War II.

What does this mean for Denver's transit system? For one thing, it suggests that we should be skeptical of expensive new rail projects and additional FAStracks expansion. Transit officials hoped that FAStracks would increase the percentage of people who ride transit substantially. However, the percentage of folks riding transit has increased only slightly.

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More importantly, FAStracks costs have increased. When voters approved a 0.4% sales tax increase, the Denver Regional Transit District (RTD) expected to build 122 miles of light rail over the course of 12 years for $4.7 billion. However, construction is behind schedule.[79] The cost has increased from $4.7 billion to $7.8 billion, which is typical for rail projects.[80] New funds are difficult to procure. In 2012, the agency declined to put a sales tax increase on the ballot because polling indicated voters would reject it.

This report accepts the need to finish FAStracks lines currently under construction. But it also outlines a new approach to transit, based on establishing a comprehensive network of express bus, bus rapid transit, limited-stop bus and local bus service across the Denver metropolitan area. In so doing, it replaces some planned rail lines with express bus and bus rapid transit. The great advantage of a bus-based transit system of this sort is that for the cost of two or three new rail lines serving just a handful of commuter corridors, the region can create a comprehensive transit system for the entire metro area. What's more, this comprehensive system could be implemented in just five years—decades before a rail network would be completed.

Of course, the traditional problem with buses is that traffic congestion has an impact on bus travel times and thus severely dampens transit's time-savings competitiveness with the automobile. Since buses travel in the same traffic lanes as cars, automobile drivers can travel the same route in less time than bus users, thus substantially diminishing time-related incentives to use transit as an alternative. Fortunately, express bus service and bus rapid transit can take advantage of toll-free access to the express lanes and managed arterials outlined earlier in this section. This allows for fast, reliable travel times and in this way completely changes commuters' cost-benefit calculations—shifting the balance toward transit, without ever penalizing motorists.

While some may question whether bus service will ever be as popular as rail service, current I-25 express lane numbers show promising results. In a recent report HPTE revealed that approximately 40 buses use the express lane every hour during the morning commute period.[81] This is an average of one bus every 1.6 minutes. A total of almost 6,000 people commute by bus in the I-25 express lanes during the morning commute period.[82] Meanwhile, a total of 15,687 people combined use the six light rail lines.[83] Therefore on average the I-25 express lane carries twice as many commuters as each rail line (some rail lines operate together in certain locations). Yet the express lane is cheaper to operate, build and maintain than any one rail line.

On average the I-25 express lane carries twice as many commuters as each rail line (some rail lines operate together in certain locations). Yet the express lane is cheaper to operate, build and maintain than any one rail line.

The Characteristics of Express Bus and Bus Rapid Transit

High-quality limited-stop bus services typically operate as express bus on freeway and other high-speed arterials, and as bus rapid transit on arterials and local streets. There are differences between these two types of services.

Express bus is a bus service that provides point-to-point service from one of many park-and-ride lots in the suburbs to various business districts throughout the metro area.[84] Metro areas have several different bus routes serving a park-and-ride area or have intermediate stops where commuters can transfer from one bus to another. Express bus service is used mostly during rush hour when choice ridership is higher. Express bus mainly operates on freeways or expressways, making its service characteristics similar to commuter rail.

Bus rapid transit (BRT) is an enhanced bus service that operates with characteristics of a dedicated guideway.[85] As a result BRT operates at faster speeds, provides greater service reliability and increased customer convenience.[86] BRT operates mainly on arterials, has frequent stops along the transit line (every 1⁄4 to 1⁄2 mile) and serves multiple origin and destination pairs. Its service characteristics are similar to heavy or light rail.

To more effectively differentiate from local bus, BRT often has the following features:[87]

- Running ways that give buses priority
- Unique station design
- Larger vehicles
- Electronic smart card/off-board fare collection
- Intelligent transportation systems such as priority signaling
- More frequent service especially during rush hour
- Specific branding

Since BRT runs on arterial and local streets, it may have additional features to help it fit into the community. These include land use or area-specific zoning and elevated boarding platforms level with the station.

Since the term BRT has come to encompass a considerable range of service types, a recent research report from the Federal Transit Administration sought to provide some clarity by separating BRT into two basic types:[88]

- “BRT-heavy” refers to BRT systems that operate in dedicated rights of way
- “BRT-lite” refers to BRT systems that lack dedicated rights of way. Such services have many of the components of BRT heavy but use fewer enhancements. These services may be as basic as limited-stop arterial express service with signal priority.

BRT-Heavy, BRT-Lite, Express Bus and Virtual Exclusive Busways

Our basic premise—that express bus and BRT can produce more transit bang for the buck in Denver—is generally valid. However, the more popular express bus operating in a dedicated lane concept has two significant drawbacks. First, obtaining an exclusive right of way is expensive, in both land costs and pavement costs. Second, since very few corridors can support more than 10 such buses per hour (one every six minutes) and usually only during peak periods, for the vast majority of the time that expensive right of way is empty and unproductive. Even with one-minute headways (60 buses per hour), that exclusive bus lane could handle at least 1,600 vehicles per hour at uncongested LOS C conditions. Thus, 1,540 spaces are going to waste if that lane is used exclusively for bus service.

This is borne out by experience. In the 1970s various state DOTs experimented by dedicating a freeway lane in each direction to express bus service. The result was a waste of a full highway lane. This waste led to the conversion of original transitways for express bus service, such as the Shirley Highway in Northern Virginia, to HOV (high occupancy vehicle) lanes.[89] Initially, vanpools were allowed in, and when that measure failed to use all the capacity, three-person carpools. In most metro areas that took this path, the eventual result (as on I-95 in Miami) was HOV lanes filled with two-person carpools. Unlimited numbers of HOV-2s led to congestion, greatly reducing the "express" nature of the bus service.

This is precisely where priced lanes (such as our proposed express lane and managed arterial network) can make a significant difference. Variable pricing can keep such lanes flowing at a high volume with no congestion (at LOS C). Therefore, a properly run priced lane can provide express buses with performance comparable to what they get from an exclusive busway. Because of this, some have termed a priced lane that provides guaranteed access for express bus service a "virtual exclusive busway" (VEB).[90]

A properly run priced lane can provide express buses with performance comparable to what they get from an exclusive busway.

VEBs have been implemented in Denver. The RTD's express bus service on I-25 is an example of a (VEB). The dynamically priced lanes provide free passage to buses, vanpools and emergency vehicles but charge a variable toll based on congestion to automobiles. Denver plans to add this type of service to US 36 once the express lane is extended to Boulder. Every Denver-area freeway that has express lanes can offer this high-speed, high-quality bus service.

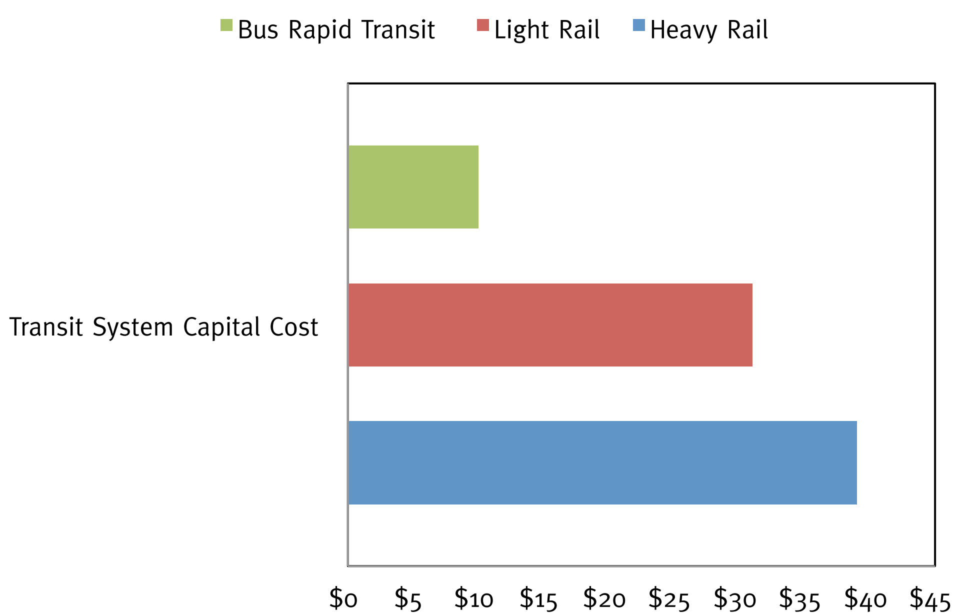
In some metro areas the DOT and transit operator enter into an agreement to build and operate the express lanes together. Denver's transportation agencies should consider such a partnership. Texas DOT and Houston Metro's transit agency have an agreement to operate service on Houston's Katy Freeway (I-10).[91] The $250 million project added four priced lanes to the median of the freeway, replacing a single reversible HOT lane as part of a larger-scale project that rebuilt and widened the freeway. It is a public-public partnership between Harris County Toll Road Authority (HCTRA), the local transit agency (Metro) and the Texas DOT, with the approval of FHWA and FTA. HCTRA financed the priced lanes and will operate and maintain them, using the toll revenue for debt service and operation and maintenance costs. Metro is guaranteed up to 25% of the priced lanes' capacity, for any combination of buses, vanpools and carpools. In a memorandum of understanding (MOU), it agreed to increase the HOV occupancy level over time, as needed, to stay within its 25% usage. HCTRA, in turn, agreed in the MOU to use variable pricing to maintain LOS C conditions, thereby limiting the number of toll-paying vehicles using the priced lanes.

To get a better idea of the cost-effectiveness of such networks, the Government Accountability Office compiled data from the FTA's New Starts and Small Starts programs on recent BRT, light rail (LRT) and heavy rail (HRT) projects. The average cost per route-mile was $124 million for LRT and $154 million for HRT.[92] If a metro area wanted to build a region-wide LRT or HRT system, encompassing 250 route-miles, the cost would be $31 billion for LRT or $38.5 billion for HRT. A comparable VEB network would require 500 lane-miles, with one lane per direction. If all 500 lane-miles had to be added as new construction (i.e., if there were no HOV lanes to convert, at modest cost), the cost would be $5 billion if the average cost were $10 million per lane-mile or $10 billion if the average cost were $20 million per lane-mile.

Thus, the capital cost of a VEB network would be between *one-sixth* and *one-fourth* that of a rail system of comparable size.

Thus, the capital cost of a VEB network would be between *one-sixth* and *one-fourth* that of a rail system of comparable size (though that comparison does not include the cost of additional buses to make full use of the new network). Furthermore, the LRT or HRT capital costs—$30 billion to $40 billion—would all have to be raised as federal, state and local tax money. Passenger fares would not cover any of that, and would cover only a portion of the operating and maintenance costs. By contrast, the VEB network's capital costs would be partly covered by motorists paying the variable-priced tolls. Thus, transit capital funds would likely be needed only for the express bus vehicles and any off-line stations and park-and-ride lots developed to enhance express bus on priced lanes service.

Figure 15: Transit System Capital Costs of Heavy Rail System, Light Rail System and Bus Rapid Transit (in billions $)



On managed arterials, BRT heavy has the same problems as express bus service operating in dedicated lanes: acquiring land for a dedicated lane is expensive and few corridors support more than 10 buses per hour. Instead we recommend a BRT-lite service best exemplified by the Metro Rapid program implemented by the Los Angeles County Metropolitan Transportation Authority starting in 2000.[93] It offers limited-stop bus rapid transit service in specially marked buses along major arterials. In addition to making stops about 0.7 miles apart (vs. 0.2 miles between stops on conventional bus routes), the service increasingly operates with traffic signal priority at intersections. The initial Metro Rapid line 720 increased transit ridership in that corridor by 40%. Others have seen even greater increases: 794 has increased ridership by 65% and 770 by 70%. That success has led to the rapid expansion of the service to 20 other major arterials in Los Angeles County, as of 2014, encompassing 380 arterial-miles and 500 buses.[94]

A recent Transportation Research Board paper compared Metro Rapid service on Ventura Blvd. in LA's San Fernando Valley with parallel BRT-heavy service on the area's then-new Orange Line exclusive busway. The travel times were about the same for both, but the capital cost per boarding was only $1,300 for the BRT-lite versus $16,800 per boarding for the BRT-heavy service, primarily because of the exclusive-guideway cost for the latter.[95]

BRT-lite appears to be a highly cost-effective way to expand transit service on arterials.

BRT-lite appears to be a highly cost-effective way to expand transit service on arterials. And just as express bus is well-suited to operate on express toll lanes on freeways, BRT-lite could take advantage of managed arterials to operate faster than what is possible on ordinary arterials. This addition would expand the network of region-wide BRT to the corridors with managed arterials, in addition to the express lane network. BRT-lite service can be added on traditional arterial roads with grade separations. Services on traditional arterial roads will not offer the same speeds as those operating on managed arterials, but will still be considerably faster than local bus.

A 21st Century Approach to Transit in Denver

Denver's transit network can be improved in three simultaneous steps. First, BRT and express bus service should be extended to parts of the metro area that lack rail service. Second, existing local bus networks need to add new routes and increase the frequency of existing routes. Finally, the existing bus and rail schedules should be tweaked to make connections as easy as possible.

Part 5

Managed Lane and Freeway Capacity

The first part of solving metro Denver's mobility problems involves adding limited general purpose capacity and an express toll lane network.

The challenge is determining where to add additional freeway capacity and whether to price it. We relied on projections of traffic in individual freeway corridors, provided by DRCOG and adjusted based on current traffic projections. They showed projected traffic in each direction during the AM and PM peak periods through 2035. Based on that data we can estimate which corridors need additional lanes, how many lanes are needed, whether the lanes should be priced and whether they should be reversible or operate in one direction.

A. The Express Toll Lane Network

The first part of the plan includes a comprehensive express toll lane network on the existing freeway system that provides reliable uncongested travel for buses, vanpools, emergency responders and single-occupant commuters or carpools. This express lane network will add toll lanes to various portions of I-25, I-70, I-76, I-225, I-270, US 6, US 36 and C-470. These projects will add a total of 450 new ETL-miles of capacity to the system, while the widening and conversion of I-70 to a toll road from the Twin Tunnels to the Eisenhower Tunnel and the completion of the beltway via the Jefferson Parkway toll road project would create another 252 lane-miles and 96 lane-miles respectively. Table 13 depicts the system as it would exist when completed by 2040. Figure 16 shows the express toll lanes network.

Table 13 shows the proposed expansion of the freeway network, in five phases. The first phase concentrates on adding express toll lanes to the most congested portions of the freeway system, where relief is needed most. Phase 2 includes the further development of the ETLs, some additional general purpose capacity, and the construction of the Jefferson Parkway and widening and tolling of the I-70 mountain corridor. Phase 3 includes further improvements to I-25, I-70 and I-

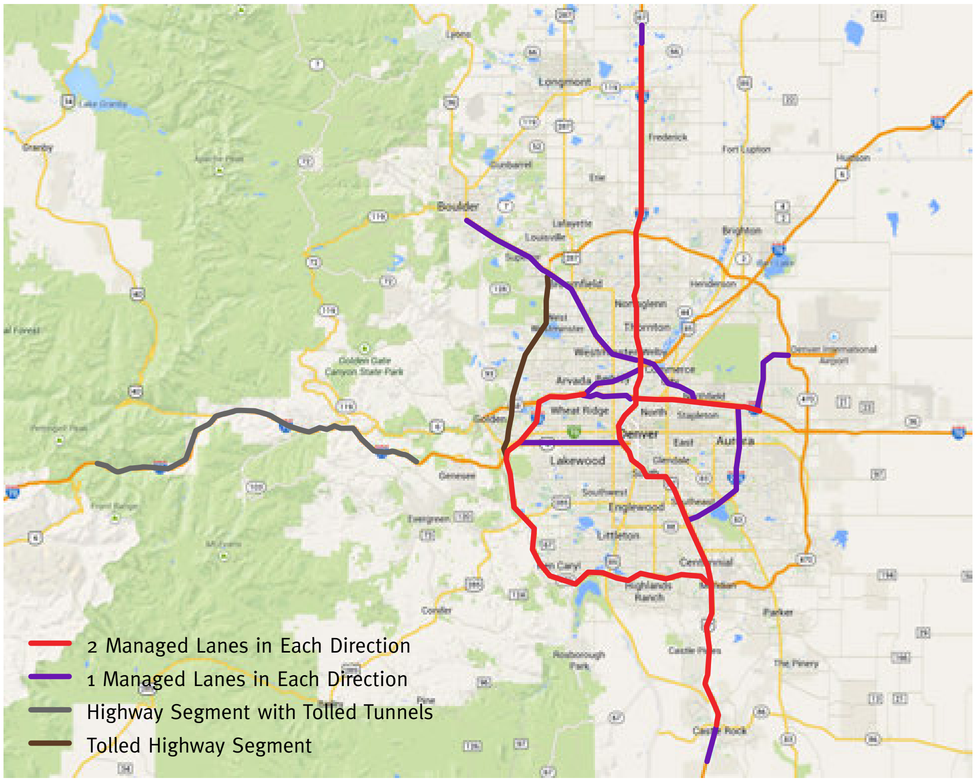
76. The fourth phase adds additional ETLs on portions of C-470, US 6 and Pena Blvd. The final phase would add ETLs to I-25 and I-225. Some of the freeways sections detailed in this report stretch outside the Denver metropolitan area to Fort Collins, Monument and Silverthorne. However, since the majority of the affected segment is in metro Denver, these segments are included in this report.

Table 13: Proposed Denver Toll Lane Network Expansions

Phase 1: 2015–2020 Express Toll Lanes		In Long Range Plan	Cost
I-25	Add 2 reversible express toll lanes between the C-470/E-470 Interchange and Wolfensberger Rd Castle Rock and 1 express lane per direction between Wolfsenberger Rd and Plum Creek Parkway (26 lane-miles)	Yes	$594M
I-25	Add 2 reversible express toll lanes between E. 84th Ave and SR 66 and 1 reversible express toll lane between SR 66 and CR 34. (51.4 lane-miles)(24.2 lane-miles in Weld County)	Part	$880M
I-25	Add 1 express toll lane per direction between Speer Blvd and E 84th Ave. (14 lane-miles)	No	$235.2M
I-70	Add 2 express toll lanes per direction between I-25 and Pena Blvd (38 lane-miles)	Yes	$1,400M
Phase 2: 2020–2025 Express Toll Lanes			
I-270	Add 1 express toll lane per direction between I-25 and I-70 (12 lane-miles)	Different Solution	$200M
Phase 2: 2020–2025 Toll Roads			
I-70 West	Add 1 lane per direction between Eisenhower Tunnel and Bus. 70/Colorado Blvd (Exit 241A) Westbound and US 40 (Exit 247) Eastbound (59 lane-miles) and toll Eisenhower and Twin Tunnels	Different Solution	$1,600M
NW Parkway Phase 2	Construct a new 4-lane toll road to complete the Denver beltway (96 lane-miles)	Part	$980M
Phase 3: 2025–2030 Express Toll Lanes			
I-70	Add 2 express toll lanes per direction between the C-470 Interchange and I-76 and 1 express toll lane per direction between I-76 and I-25 (47 lane-miles)	No	$1,580M
I-76	Add 1 express toll lane per direction between I-70 and I-25 (11 lane-miles)	No	$160M
Phase 4: 2030–2035 Express Toll Lanes			
C-470	Add 2 express toll lanes per direction between I-25 and I-70 (104.8 lane-miles)	No	$514M
US-6	Add 1 express toll lane per direction between I-70 and I-25 (17.6 lane-miles)	No	$580M
Pena Blvd	Add 1 express toll lane per direction between I-70 and E-470 (12.6 lane-miles)	Different Solution	$150M
Phase 5: 2035–2040 Express Toll Lanes			
I-25	Add 2 express toll lanes per direction between Speer Blvd and C470/E470 (68.4 lane-miles)	No	$1,540M
I-225	Add 1 express toll lane per direction between I-70 and I-25 (24.4 lane-miles)	No	$292.8M
Total Cost Express Toll Lanes			**$8,126M**
Total Cost Toll Roads			**$2,580M**
Total Cost Express Toll Network			**$10,706M**

Note: All figures are sketch-level estimates, not investment-grade figures.

Figure 16: Map of Denver Express Lane Network Expansions



The express toll lanes network is a comprehensive system of new lanes. The phases are structured first to build lanes on the most congested parts of the network and then expand those lanes to the entire network. A system built in this order will provide the most benefits. For example, many drivers from Castle Rock travel north on I-25 in the morning and south in the afternoon to the Denver Tech Center. The worst of the congestion is between Castle Rock and E-470 so the section from Castle Rock to E-470 should be built first and the section from E-470 to the Tech Center should be built later. Some delays may remain on I-25 north of I-225. However, since the worst congestion is currently south of E-470, that is where the first express toll lanes on I-25 should be built.

The express toll lanes on each highway will function together as a network. And the network is only as strong as its weakest link. Some parts of the network have better cost-benefit ratios than others. Some will transport more commuters than others, but the value lies in creating this total network offering uncongested travel throughout almost any part of metro Denver. As a result, it is critical that the entire network be built.

B. New General Purpose Capacity

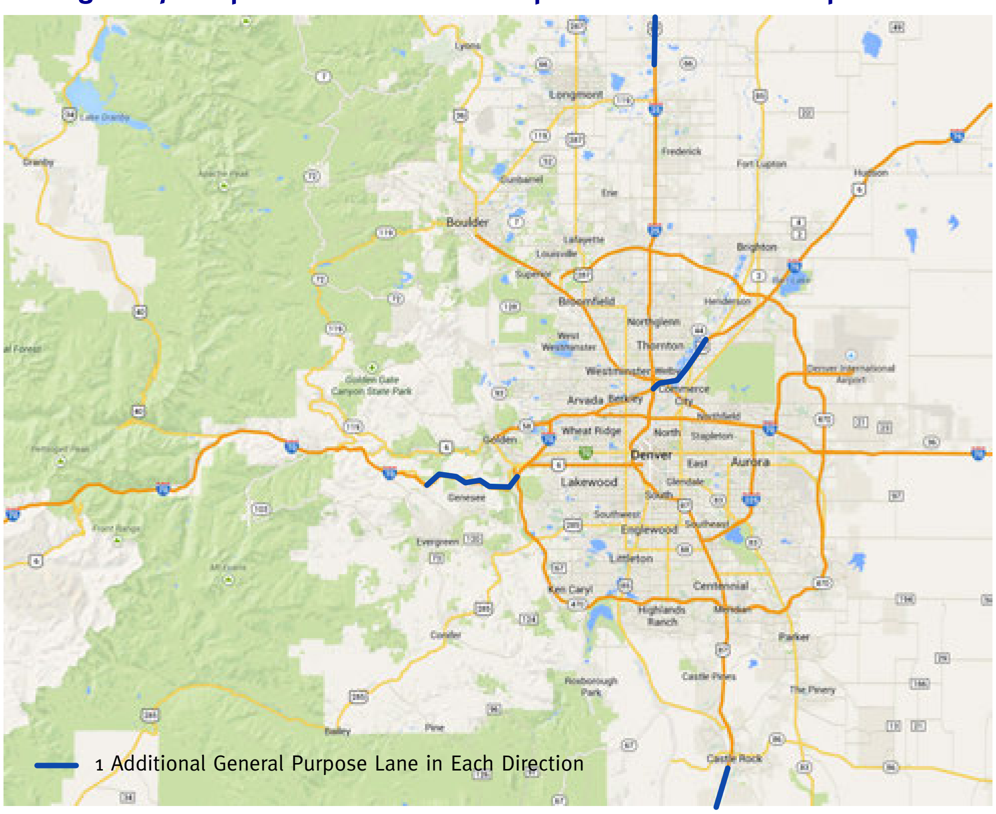
An express toll lane network is the most effective way to improve mobility in a growing metro area. However, some highways lack sufficient general purpose lanes, are so congested that additional general purpose lanes are needed, or are located in a rural corridor that cannot support express toll lanes. Certain parts of I-25, I-70 and I-76 need additional general purpose lane capacity. These sections are indicated in Table 14 below. Figure 17 shows the new general purpose sections.

Table 14: Proposed Denver General Purpose Network Expansions

Phase 2: 2020–2025		In LRP	Cost
I-70	Add 1 general purpose lane per direction between SR 74W (exit 252) and C-470 (exit 260) (16 lane-miles)	Yes	$416M
I-76	Add 1 general purpose lane per direction between I-25 and 88th St. (9.4 lane-miles)	No	$120M
Phase 3: 2025–2030			
I-25	Add 1 general purpose lane per direction between N of SR 66 to SR 14 (51 lane-miles in Weld County)	Part	$612M
I-25	Add 1 general purpose lane per direction between Exit 163 County Line Rd and 1.5 lane-miles south of Plum Creek Parkway (32.8 lane-miles)	No	$400M
Total Cost General Purpose Lanes			**$1,548M**

* Note: All figures are sketch-level estimates, not investment-grade figures.

Figure 17: Map of Denver General Purpose Lanes Network Expansions



C. Freeway Interchanges

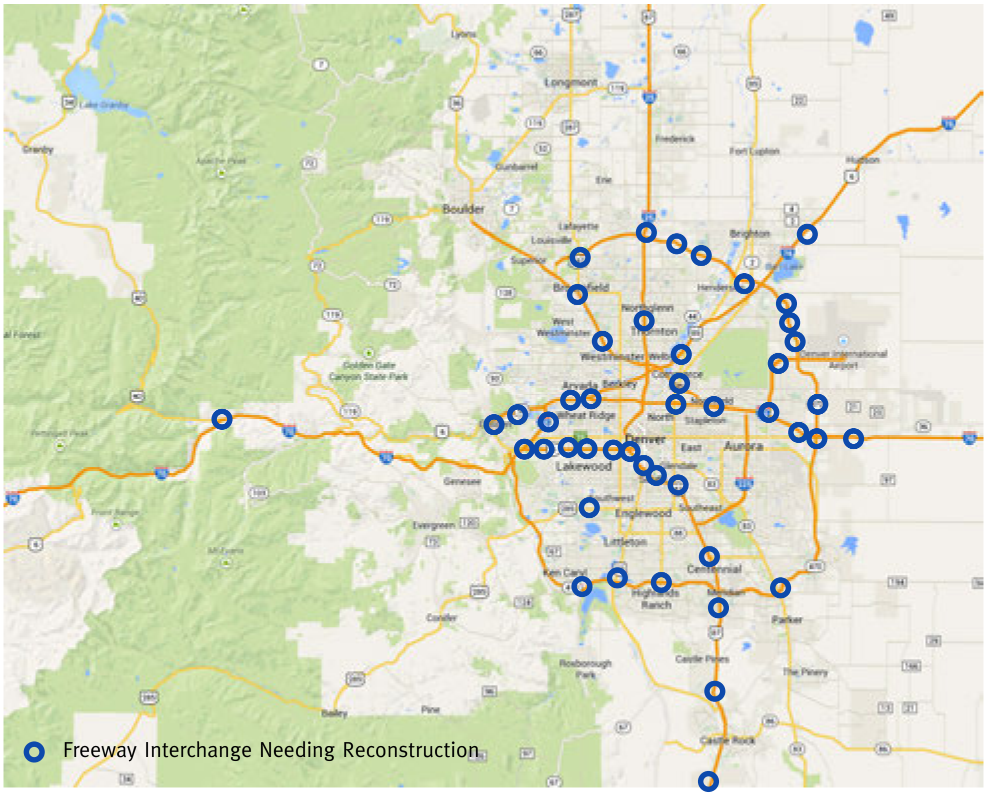
Some of Denver's freeway interchanges are functionally obsolete. Such interchanges feature outdated designs or carry far more traffic than the original design intended. Table 15 has a listing of interchanges that need to be modernized. Figure 18 displays the geographic location of these modernizations.

Table 15: New and Modified Freeway Interchanges

Interchange	In LRP	Cost*	Interchange	In LRP	Cost*
I-25 at Douglas Lane	Yes	$35M	I-25 at Baseline Rd.	No	$50M
I-25 at Castlegate Dr.	Yes	$12M	I-76 at 160th Ave.	No	$20M
I-70 at US 40, Empire Junction	No	$55.5M	I-70 at Colfax Ave.	Yes	$150M
US 6 Federal St. to Bryant St., Interchange Improvements	Yes	$31.2M	I-25 at Colfax Ave.	No	$50M
US 36 at Sheridan Blvd.	Yes	$49.2M	I-25 at Hampden Ave.	No	$150M
E-470, I-70, Gun Club Rd.	No	$145.7M	I-225 at Parker Rd.	No	$50M
I-25 at Broadway	No	$25.0M	E-470 at Hampden Ave.	No	$40M
I-70 at Central Park Blvd.	No	$50.6M	I-25 at Ridgegate Parkway	No	$50M
I-70 at Harvest Mile Rd.	Yes	$31.2M	C-470 at Wadsworth Blvd.	No	$100M
I-70 at Picadilly Rd.	Yes	$21.6M	Wadsworth Blvd at US 285	No	$100M
E-470 at 48th Ave.	Yes	$21.2M	Wadsworth Blvd at I-70/I-76	No	$50M
E-470 at 88th Ave.	Yes	$13.9M	Wadsworth Blvd at US 36	No	$140M
E-470 at 112th Ave.	Yes	$13.9M	US 287 at Northwest Parkway	No	$100M
E-470 at Potomac St.	Yes	$6.3M	C-470 at University Blvd.	No	$100M
E-470 at Quebec St.	Yes	$19.5M	I-25 at Colorado Blvd.	No	$75M
Jefferson Parkway at SH 72	Yes	$20M	I-70 at Colorado Blvd.	No	$25M
Jefferson Parkway at Candelas Parkway	Yes	$20M	I-270 at Vasquez Blvd.	No	$25M
Jefferson Parkway at Indiana St.	Yes	$20M	I-76 at Colorado Blvd.	No	$200M
I-25 at SH 7	Yes	$58M	E-470 at Colorado Blvd.	No	$100M
I-25 at Alameda Ave/Santa Fe Drive	Yes	$42.5M	E-470 at Parker Rd.	No	$50M
I-25 at Arapahoe Rd.	Yes	$83M	I-70/Pena Blvd at Airport Blvd.	Part	$100M
I-70 at 32nd Ave.	No	$22M	Pena Blvd. at Tower Rd. and Buckley Rd. Extension	No	$125M
I-70 at Kipling St.	No	$32.6M	6th Ave. at SR 58	No	$200M
I-70 at US 6	No	$25M	E-470 at 104th Ave.	No	$20M
I-70 at E-470	No	$145.7M	C-470 at Santa Fe Drive	Yes	$75M
US 6 at Simms St.	Yes	$35.4M	I-76 at Bridge St.	No	$20.0M
US 6 at Kipling St.	Yes	$29.2M	SR 58 at Cabela Dr.	Yes	$15.4M
US 6 at Wadsworth Blvd.	Yes	$95.5M	US 36 at Wadsworth Parkway	No	$60M
I-25 at 104th Ave.	No	$60M	New Alignment at I-76/74th St.	No	$50M
Estimated Total Cost					**$3,511M**

* Note: All figures are sketch-level estimates, not investment-grade figures.

Figure 18: Map of New and Modified Freeway Interchanges



Part 6

Arterial Highways and Managed Arterials

The next part of solving metro Denver's transportation challenges includes modernizing the existing arterial highway network and upgrading some arterials to managed arterials where appropriate. While Denver has a well-developed arterial system, it is crucial to continue to improve and expand this system. This report focuses on major arterials. Minor arterials, collectors and local roads are also important, but they are beyond the scope of this report.

To cost-effectively improve its existing primary arterials, we recommend that Denver develop a managed arterial network. Several metro areas across the country, including Miami and San Diego, are considering managed arterials. As discussed previously, managed arterials combine dynamic traffic management systems with pricing to offer drivers a premium travel option.

To cost-effectively improve its existing primary arterials, we recommend that Denver develop a managed arterial network.

A. Managed Arterials

The biggest component of any managed arterial is overpasses or underpasses at major intersections. Building grade-separated intersections improves traffic flow. Unlike a traffic light, which limits flow to the peak direction at least 50% of the time at major intersections, grade separation allows continuous flow. Traveling though these intersections and paying a small toll to bypass congestion will be optional. Vehicles will not be required to pay the toll to get across the intersection, only to use the bypass route that allows for a continuous "green time" for prevailing through traffic. Dynamic traffic management systems and access management are other important features of managed arterials.

All major arterial intersections in the Denver metro area were investigated to determine whether they would be suitable for grade-separated intersections. Tolled grade-separated interchanges require both sufficient space (right-of-way) to build a surface intersection and grade separation, and sufficient traffic volume. Tolled grade separation is considered only for highways which have a minimum of three lanes per directional travel (i.e., a six-lane width requirement) and large enough traffic volumes on side streets to necessitate a long red signal for the peak direction. Intersection site visits were used to check intersection right-of-way needs. Intersection traffic volume data were obtained from numerous sources, including DRCOG, CDOT and the city of Denver.

This report recommends that Denver implement five east-west managed arterials and four north-south managed arterials. Managed arterial costs include the cost to build the overpasses/underpasses, right-of-way acquisition costs at some intersections, minor street widenings in some areas and new alignments in some areas. These components are discussed below. The street widenings and associated right-of-way expenses are estimated at $1.1 billion. New grade-separated interchanges are estimated at $4.24 billion, but approximately half of this cost will be covered by toll revenue. New alignments are expected to cost approximately $224 million, while intelligent transportation systems (ITS) improvements are expected to cost $500 million. All projects not covered by toll revenue will be funded through gas taxes and/or mileage-based user fees.

All Denver-area managed arterials will offer access to all local business and residences. For safety reasons, left turns from the main highway and from businesses located along the highway will be limited to areas with traffic signals. Since these managed arterials have many traffic signals, major delays are not expected. In areas without a traffic light, special signals that allow u-turns only can be installed.

Some arterials will be widened to four or six lanes and converted to managed arterials. While managed arterials are typically used in place of road widening, some parts of Denver are growing so rapidly that both the widening and the conversion must occur.

While these arterial improvements are not cheap, arterials form the basis for Denver's street and transit network. While freeways transport more vehicles, major arterials transport commuters to and from the freeways and form the backbone of local travel. If the arterial system is ineffective, improving the freeway network will have limited results.

Further, improving arterial networks with managed arterials will also improve the transit system by providing reliable bus rapid transit service on congestion-free streets. One of the biggest reasons that choice bus riders (those who can commute to work by another mode) drive their cars is that many bus services take just as long as commuting by automobile since buses sit in the same congestion. Managed arterials would decrease bus travel times, likely increasing ridership and providing a robust transit network.

Improving arterial networks with managed arterials will also improve the transit system by providing reliable bus rapid transit service on congestion-free streets.

B. Proposed Arterial Projects

The following tables detail managed arterials components. Table 16 details the arterial sections that need to be widened. Tables 17 and 18 detail the new roadways and rail crossings needed to complete these arterials. Figure 19 displays the location of these arterials. Table 19 details the new grade separations. Figure 20 displays the location of the grade separations. All components of managed arterials are included in Appendix A.

Table 16: Arterial Widenings

Road	From	To	Scope	In LRP	Cost
100th Ave.	Simms St	Independence St.	Widen by 1 lane in each direction (2.4 lane-miles)	No	$7.2M
Church Ranch Blvd.	101st Ave.	103rd Ave.	Widen by 1 lane in each direction (2.8 lane-miles)	No	$8.4M
104th Ave.	Westminister Blvd.	Croke Dr.	Widen by 1 lane in each direction (7.2 lane-miles)	No	$22.2M
104th Ave.	Marion St.	1/4 mi W of SR 2	Add 1 lane in each direction (13.0 lane-miles)	No	$39M
Arapahoe Rd.	E of 55th St.	W of 75th St.	Widen by 1 lane in each direction (4.0 lane-miles)	No	$12M
Baseline Rd.	E of 75th St.	95th St.	Widen by 1 lane in each direction (3.2 lane-miles)	No	$9.6M
Baseline Rd.	¼ mi W of US 287	I-25	Widen by 1 lane in each direction (13.0 lane-miles)	No	$32.5M
Baseline Rd.	166th Ave.	I-76	Widen by 1 lane in each direction (25.4 lane-miles)	No	$63.5M
US 40	½ mi SW of US 6	Indiana St.	Add 1 lane in each direction (2.6 lane-miles)	No	$11.7M
US 40	Cole Blvd.	Wide Acres Rd.	Add 1 lane in each direction (2.2 lane-miles)	No	$9.9M
US 40	Sheridan Blvd.	Irving St.	Add 1 lane in each direction (2.4 lane-miles)	No	$10.8M
US 40	Park Ave.	Peoria St.	Add 1 lane in each direction (13.4 lane-miles)	No	$60.3M
US 40	Sable Blvd.	¼ mi E of Airport Blvd.	Add 1 lane in each direction (1.7 lane-miles)	No	$15.3M
Havana St.	½ mi SW of Galena St.	Dartmouth Ave.	Add 1 lane in SW direction (1 lane-mile)	No	$3M
Dartmouth Ave.	SR 30	Parker Rd.	Add 1 lane in each direction (1.2 lane-miles)	No	$3.6M
Hampden Ave.	Conservatory Parkway	Gun Club Rd.	Add 1 lane in each direction (2.2 lane-miles)	No	$4.4M
Titan Rd.	Rampart Range Rd.	US 285	Add 1 lane in each direction (6 lane-miles)	No	$12M
RidgeGate Parkway	I-25	Tomahawk Rd.	Add 1 lane in each direction (18.8 lane-miles)	No	$56.4M
SR 93	C-470	Table Mesa Rd.	Add 1 lane in each direction (40 lane-miles)	No	$240M
SR 93	¼ mi S of Baseline Rd.	¼ mi N of Canyon Blvd.	Add 1 lane in each direction (4.0 lane-miles)	No	$20M

Table 16: Arterial Widenings

Road	From	To	Scope	In LRP	Cost
Wadsworth Blvd.	C-470	Parkhill Ave.	Add 1 lane in each direction (7.4 lane-miles)	No	$33.3M
Wadsworth Blvd.	US 285	Ohio Ave.	Add 1 lane in each direction (7.0 lane-miles)	No	$31.5M
Wadsworth Blvd.	US 6	I-70/I-76	Add 2 lanes in each direction (16.4 lane-miles)	Part	$36.9M
Wadsworth Parkway	W 92nd Ave.	108th Ave.	Add 1 lane in each direction (4.4 lane-miles)	Yes	$20M
US 287	US 36	¼ mi N of Arapahoe Rd.	Add 1 lane in each direction (15.6 lane-miles)	No	$46.8M
University Blvd.	County Line Rd.	Quincy Ave.	Add 1 lane in each direction (10.0 lane-miles)	No	$45M
Quincy Ave.	University Blvd.	Colorado Blvd.	Add 2 lanes in each direction (4 lane-miles)	No	$18M
Colorado Blvd.	Quincy Ave.	Hampden Ave.	Add 2 lanes in each direction (4 lane-miles)	No	$18M
Colorado Blvd.	SR 2N	68th Ave.	Add 1 lane in each direction (1.0 lane-miles)	No	$3M
68th Ave.	Brighton Blvd.	Colorado Blvd.	Add 1 lane in each direction (0.8 lane-miles)	No	$2.4M
Colorado Blvd.	¼ mi S of 88th Ave	140th Ave.	Add 1 lane in each direction (13.2 lane-miles)	No	$39.6M
Colorado Blvd.	140th Ave.	¼ mi N of 144th Ave.	Add 2 lanes in each direction (2.8 lane-miles)	No	$5.6M
Colorado Blvd.	¼ mi N of 144th Ave.	168th Ave.	Add 1 lane in each direction (6.4 lane-miles)	No	$12.8M
SR 83	¼ mi S of SR 86	Bayou Gulch Rd.	Add 1 lane in each direction (6.6 lane-miles)	No	$13.2M
Arapahoe Rd.	Parker Rd.	Buckley Rd.	Add 1 lane in each direction (1.6 lane-miles)	No	$7.2M
Buckley Rd.	¼ mi S of Orchard Rd.	Mississippi Ave.	Add 1 lane in each direction (12.2 lane-miles)	No	$54.9M
Buckley Rd.	E 88th Ave.	Chambers Rd.	Add 1 lane in each direction (3.8 lane-miles)	No	$11.4M
Chambers Rd.	96th Ave.	¼ mi S of 104th Ave.	Add 1 lane in each direction (2.0 lane-miles)	No	$6M
Chambers Rd.	¼ mi S of 104th Ave.	¼ mi N of 104th Ave.	Add 1 lane in each direction (1.0 lane-mile)	No	$3M
Adams County Parkway N.	Bridge over I-76	Sable Blvd.	Add 1 lane in each direction (0.8 lane-miles)	No	$2.4M
Sable Blvd.	Adams County Parkway N.	¼ mi N of 144th St.	Add 1 lane in each direction (5.0 lane-miles)	No	$10M
US 85	Sable Blvd Connector	2 mi N of 168th Ave.	Add 1 lane in each direction (8.8 lane-miles)	No	$22.4M
Monaco Parkway	Yale Ave.	Jewell Ave.	Add 1 lane in northbound direction only (1.0 lane-mile)	No	$3M
US 85	¼ mi S of Mineral Ave.	Sumner St. northbound/Church Ave. southbound	Add 1 lane in each direction (4.0 lane-miles)	No	$13.2M
Total Cost					**$1101.4M**

*Note: All figures are sketch-level estimates, not investment-grade figures.

Table 17: New Roadway Sections

Road	From	To	In LRP	Cost*
Arapahoe-Baseline Rd. Connector (2.5 miles)	Arapahoe Ave. 2 mi W of 75th St	Baseline Rd. 1 mi E of 75th St.	No	$30M
Titan Rd. Extension (6.0 miles)	US 85 at Titan Rd.	Ridgegate Parkway just W of I-25	No	$72M
68th Ave Colorado Blvd. Connector (3.0 miles)	68th Ave. at Colorado Blvd.	86th Ave. at Colorado Blvd.	No	$72M
Pena Blvd.-Buckley Rd. Connector (1.5 miles)	Pena Blvd./ w of Tower Rd./ Buckley Extension	Buckley Rd. at E 88th Ave.	No	$18M
Chambers Rd. Adams County Parkway Connector (0.5 mile)	E 120th Ave. at Chambers Ave.	S Adams County Parkway S of Valente Dr.	No	$6M
Sable Blvd-US 85 Connector (0.5 mile)	Sable Blvd ¼ mi N of 144th Ave.	US 85 ½ mi N of US 85	No	$6M
Total Cost				**$204 M**

*Note: All figures are sketch-level estimates, not investment-grade figures.

Table 18: New Bridges

Action	Section	In LRP	Cost*
Railroad grade separation	Airport Blvd. just N of Smith Rd.	No	$20M
Total Cost			**$20M**

*Note: All figures are sketch-level estimates, not investment-grade figures.

Table 19: Arterial Grade-Separated Interchanges

Interchange	In LRP	Cost*	Interchange	In LRP	Cost*
Church Ranch Blvd. at Wadsworth Parkwy	No	$55M	Wadsworth Blvd. at 88th Ave.	No	$30M
W 104th Ave. at Sheridan Blvd.	No	$30M	Wadsworth Blvd. at Interlocken Loop	No	$30M
W 104th Ave. at Federal Blvd.	No	$36M	US 287 at South Boulder Rd.	No	$30M
W 104th Ave. at Huron St.	No	$30M	US 287 at Arapahoe Rd.	No	$30M
E 104th Ave. at Washington St.	No	$30M	University Blvd. at County Line Rd.	No	$30M
E. 104th Ave. at Colorado Blvd.	No	$55M	University Blvd. at Dry Creek Rd.	No	$30M
E 104th Ave. at US 85	No	$35M	University Blvd. at Arapahoe Rd.	No	$30M
104th Ave. at Chambers Blvd.	No	$45M	University Blvd. at Belleview Ave.	No	$30M
Arapahoe Ave. at US 36	No	$65M	Univerity Blvd. at Quincy Ave.	No	$18M
Arapahoe Ave. at 30th St.	No	$40M	Quincy Ave. at Colorado Blvd.	No	$18M
Arapahoe Ave. at Foothills Parkway	No	$40M	Colorado Blvd. at Evans Ave.	No	$30M
Baseline Rd. at US 287	No	$55M	Colorado Blvd. at Florida Ave.	No	$30M
Basline Rd. at Colorado Blvd.	No	$45M	Colorado Blvd. at Cherry Creek St.	No	$30M
Baseline Rd. at US 85	No	$45M	Colorado Blvd. at Alameda Ave.	No	$30M
Colfax Ave. at 6th Ave.	No	$35M	Colorado Blvd. at 1st Ave.	No	$30M
Colfax Ave. at Indiana St.	No	$30M	Colorado Blvd. at 17th Ave.	No	$30M
US 40 at Kipling St.	No	$30M	Colorado Blvd. at Martin Luther King Jr. Blvd.	No	$30M
US 40 at Wadsworth Blvd.	No	$55M	Vasquez Blvd. at 56th Ave.	No	$30M
US 40 at Sheridan Rd.	No	$30M	Canaan Highway at 60th Ave.	No	$30M
US 40 at Kalamath St. and N. Speer Blvd.	No	$50M	Canaan Highway at 68th Ave.	No	$40M
US 40 at York St. and Josephine St.	No	$45M	Colorado Blvd. at 88th Ave.	No	$30M
US 40 at Colorado Blvd.	No	$60M	Colorado Blvd. at Thornton Parkway	No	$30M
US 40 at Peoria St.	No	$30M	Colorado Blvd. at 120th Ave.	No	$55M
US 40 at Potomac St.	No	$30M	Colorado Blvd. at 128th Ave.	No	$30M
US 40 at Chambers Blvd.	No	$30M	Colorado Blvd. at 136th Ave.	No	$30M
US 40 at Airport Blvd.	No	$55M	Colorado Blvd. at 144th Ave.	No	$30M
Hampden Ave. at University Blvd.	No	$35M	Parker Rd. at SR 86	No	$20M
Hampen Ave. at Colorado Blvd.	No	$55M	Parker Rd. at Hess Rd.	No	$20M
Hampden Ave. at Monaco Parkway	No	$30M	Parker Rd. at Main St.	No	$30M
Hampden Ave. at Yosemite St.	No	$30M	Parker Rd. at Lincoln Ave.	No	$30M
East Dartmouth Ave. at Parker Rd.**	No	$20M	Parker Rd. at Pine Lane	No	$30M
Parker Rd. at Peoria St.	No	$30M	Parker Rd. at Cottonwood Dr.	No	$30M
Hampden Ave. at Chambers Rd.	No	$30M	Parker Rd. at Arapahoe Rd.**	No	$18M
Hampden Ave. at Buckley Rd.	No	$55M	Arapahoe Rd. at Buckley Rd.**	No	$18M
Hampden Ave. at Tower Rd.	No	$30M	Buckley Rd. at Orchard Rd.	No	$30M
Titan Rd. at US 85	No	$45M	Buckley Rd. at Smokey Hill Rd.	No	$30M
Titan Rd. Ext. at Monarch Blvd.	No	$95M	Buckley Rd. at Quincy Rd.	No	$30M
Ridgegate Parkway at Chambers Rd.	No	$25M	Buckley Rd. at E lliff Ave.	No	$30M
Ridgegate Parkway at Jordan Rd.	No	$30M	Buckley Rd. at Mississippi Ave.	No	$30M
Ridgegate Parkway at Twenty Mile Rd.	No	$30M	Airport Blvd. at Alameda Parkway	No	$30M
Ridgegate Parkway at Parker Rd.	No	$55M	Airport Blvd. at 6th Ave.	No	$30M
SR 93 at SR 58	No	$75M	Chambers Rd. at 120th Ave.	No	$55M
Broadway St. at Table Mesa Rd.	No	$30M	N. County Services Prkwy at Sable Blvd.	No	$12M
Broadway St. at Baseline Rd.	No	$35M	Canaan Highway at US 85-SR 2 Connector	No	$12M
Broadway St. at Boulder Canyon Dr.	No	$40M	Canaan Highway at 168th Ave.	No	$25M
U.S. 85 at 160th Ave.	No	$45M	120th Ave. at Sheridan Blvd.	No	$30M
Wadsworth Blvd. at Chatfield Ave.	No	$30M	120th Ave. at Washington St.	No	$30M
Wadsworth Blvd. at Ken Caryl Ave.	No	$35M	Federal Blvd. at 112th Ave.	No	$30M
Wadsworth Blvd. at Coal Mine Ave.	No	$35M	80th Ave. at Sheridan Blvd.	No	$30M
Wadsworth Ave. at Bowles Ave.	No	$30M	Alameda Ave. at Sheridan Blvd.	No	$30M
Wadsworth Ave. at Belleview Ave.	No	$30M	Alameda Ave. at Federal Blvd.	No	$35M

Table 19: Arterial Grade-Separated Interchanges

Interchange	In LRP	Cost*	Interchange	In LRP	Cost*
Wadsworth Blvd. at Quincy Ave.	No	$30M	Alameda Ave. at Monaco Parkway	No	$30M
Wadsworth Blvd. at Yale Ave.	No	$30M	Havana Parkway at Alameda Ave.	No	$30M
Wadsworth Blvd. at Jewell Ave.	No	$30M	Santa Fe Dr. at Mississippi Ave.	No	$40M
Wadsworth Blvd. at Mississippi Ave.	No	$30M	Monaco Parkway at Evans Ave.	No	$30M
Wadsworth Blvd. at Alameda Ave.	No	$30M	Havana St. at Mississippi Ave.	No	$30M
Wadsworth Blvd. at 32nd Ave.	No	$30M	Havana St. at Iliff Ave.	No	$30M
Wadsworth Blvd. at 44th Ave.	No	$30M	Havana St. at Parker Rd.	No	$30M
Wadsworth Bypass at 52nd Ave.	No	$30M	Broadway at Belleview Ave.	No	$30M
Wadsworth Bypass at Ralston Rd.	No	$30M	US 85 at Bowles Ave.	No	$30M
Wadsworth Bypass at 72nd Ave.	No	$30M	US 85 at Mineral Ave.	No	$30M
Wadsworth Bypass at 80th Ave.	No	$30M	Arapahoe Rd. at Havana St.	No	$20M
			Arapahoe Rd. at Revere Parkway	No	$23M
Total	**$4,235 M**				

*Note: All figures are sketch-level estimates, not investment-grade figures.

** Non-priced grade separation

Figure 19: Map of Denver-Area Managed Arterials

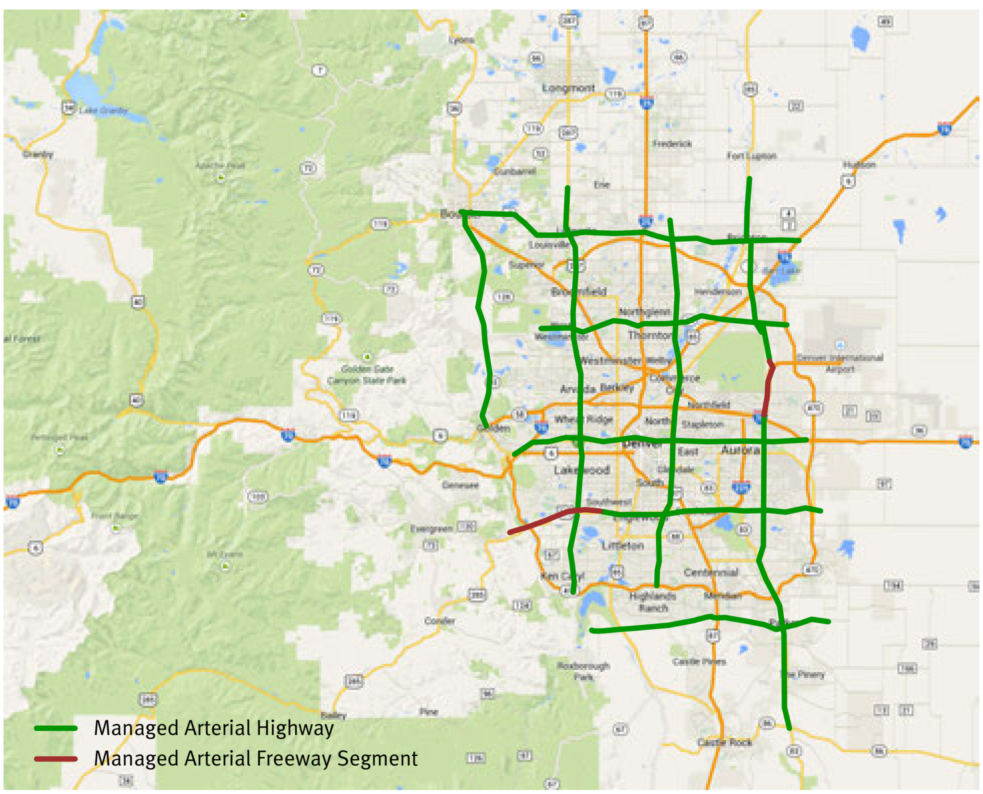
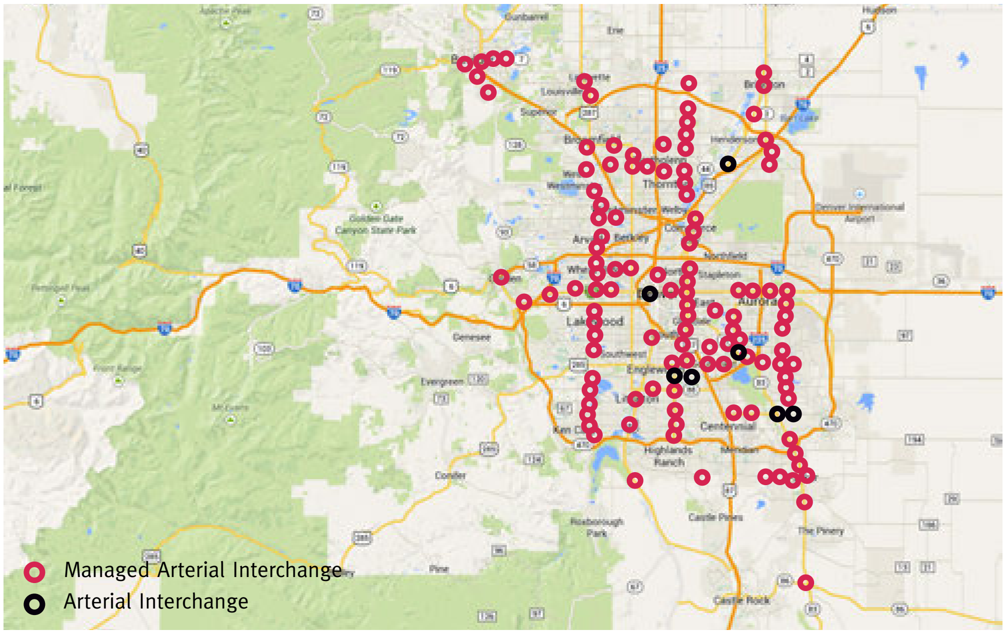
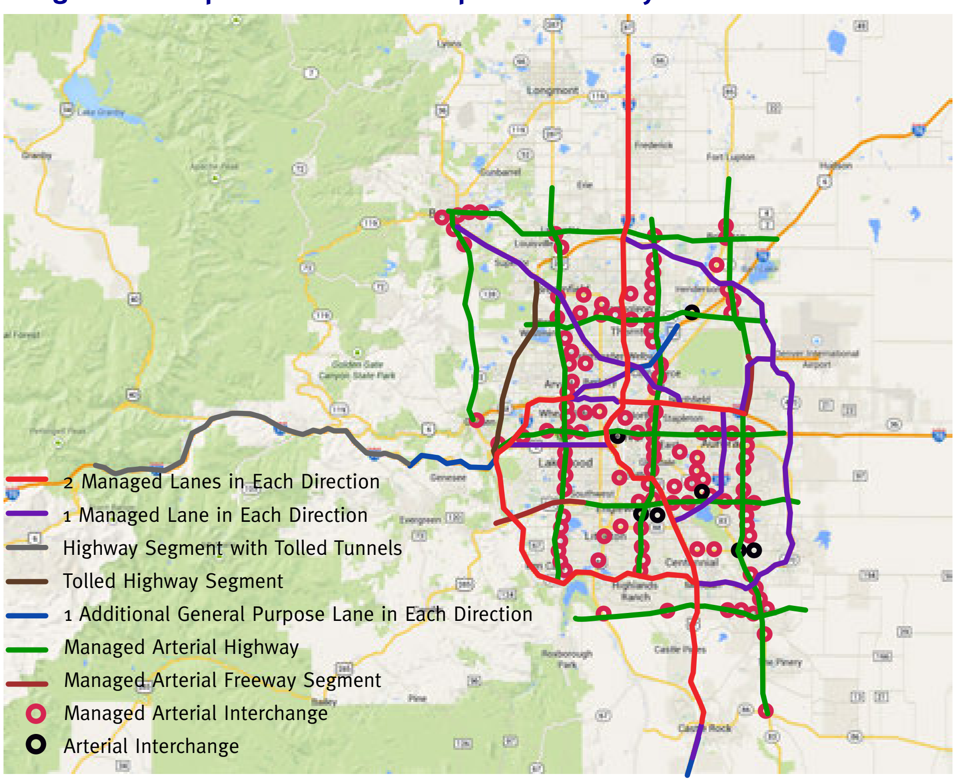


Figure 20: Map of Denver-Area Primary Arterial Grade Separations



Finally, Figure 21 shows all the proposed freeway and arterial improvements in one map.

Figure 21: Map of Denver-Area Improved Freeway and Arterial Network



Part 7

Transit

Quality transit service is an integral part of improving mobility. Denver already has a fairly robust transit network, with the Regional Transportation District (RTD) operating light rail and bus service in Denver, Boulder, Longmont and surrounding communities. Nevertheless, Denver's transit system can be improved. Reducing headways and increasing the amount of suburb-to-suburb bus service would better serve all residents.

A. Light Rail and Commuter Rail

Light and commuter rail are components of the transit network in Arapahoe, Denver, Douglas and Lincoln counties.

Current Service

Lines in operation include the C which connects Union Station and Littleton, the D which connects 30th Ave. and Littleton via downtown, the E which connects Union Station and Lincoln St. in Douglas County, the F which connects downtown and Lincoln in Douglas County, the H which connects downtown and the Tech Center, and the W which connects Union Station and Golden.

The C operates every 20–30 minutes between 4:45AM and 6:30 PM weekdays and approximately every hour early mornings on Saturday and Sunday.[96] The D operates every 10 minutes on weekdays between 6:00 AM and 8:30 AM and between 3:30 PM and 5:30 PM, and every 15 minutes at all other times. On Saturdays and Sundays the D operates every 15–30 minutes. The E operates weekdays every 15 minutes between 8:45 AM and 1:30 PM and between 6:15 PM and 8:45 PM, and every 30 minutes at all other times. On Saturdays and Sundays the E operates every 15 to 30 minutes. The F operates weekdays every 15 minutes between 4:20 AM and 8:45 AM and between 1:45 and 7:15 PM. The H operates every 30 minutes between 4:30 AM and 5:30 AM and between 9:00 PM and 1:15 AM, and every 15 minutes between 5:30 AM and 9:00 PM. On weekends the H operates every 15–30 minutes. The W operates weekdays every 15 minutes between 4:00 AM and 8:00 PM and every 30 minutes after 8:00 PM. The W operates weekends every 15–30 minutes.

At certain points the C and D lines, the E, F and H lines and the C, E and W lines travel together. In these instances trains operate every 5–15 minutes.

Expansion

The RTD is currently building the East Line, the Gold Line and the I-225 Line.[97] The East and the Gold will be completely new lines; the I-225 line will be an extension of the H line. While these lines have a questionable justification, construction has begun and it is unrealistic to stop building these lines.

The RTD is planning to start construction on the North and Northwest lines and to add extensions on to the Southeast (E and F) and Southwest (C and D) lines. This paper strongly recommends that the RTD does not construct the Northwest line or plan any additional rail lines. In addition to the cost to build, there are significant costs to operate and maintain these lines. Further, farebox revenue supports less than 50% of these operating and maintenance costs.

Instead, the RTD should expand its high-quality local, express and bus rapid transit service throughout the metro area. More details are available in sections B and C.

Operating Improvements

Currently, Denver’s rail lines feature dependable service with relatively short headways. Most lines feature rush hour headways of six to eight minutes. While a slight decrease in headways would be useful at the ends of the lines, such a change would cause service bunching in the middle of the lines, providing little overall benefit. No service changes are recommended at the present time.

B. Local Bus/Limited Stop Bus

Local bus service is the foundation for Denver’s transit network. Limited stop service skips some of the less popular stops on the route to provide faster service during high travel periods—typically rush hour.

Local bus service is the foundation for Denver's transit network.

Current Service

The Regional Transportation District operates 86 local bus routes in the Denver metro area seven days a week, including six local bus routes in Boulder.[98] RTD also operates 13 limited stop bus routes.

Expansion

This paper recommends that Denver add additional local and limited stop bus routes, but does not specify where to add the bus routes. Developing the network will require a comprehensive travel survey. However, as a general rule, Denver needs to expand its service for two types of areas. First, the RTD should add routes that serve non-downtown employment centers. For example, while the Denver Tech Center is a major employer, most bus routes end in downtown Denver or at Union Station. Adding routes to serve the Tech Center would limit bus transfers, likely increasing ridership. Second, there are very few suburb-to-suburb routes. Some commuters travel between Aurora and Centennial. Currently, these customers have to transfer in downtown Denver. A lack of direct service reduces transit customers.

Currently, the RTD directly operates more than 50% of its bus service. While the agency made a wise investment to contract out some of its service, it should periodically examine contracting out other bus lines to see if it can provide quality service at a cost savings.

C. BRT, Express Bus and Regional Bus

Express bus and BRT are two premium transit services that quickly move people long and intermediate distances respectively. They are typically a more cost-effective alternative to rail.

Current Service

The RTD operates 16 express routes that feature no stops on the part of the route on freeways or primary arterials, and multiple stops when the bus operates on local streets.[99] Such service operates as a combination local/express bus service and operates mainly during rush hour between the suburbs and downtown Denver.

The RTD also operates 17 regional bus routes that feature no stops on the freeway/primary arterial part of their route and several stops when the bus operates on local streets.[100] These buses differ from express routes in that they connect different cities throughout the region such as Denver, Boulder, Longmont and Nederland. Express buses connect different areas within Denver and its immediate suburbs.

Under Construction

The RTD is currently building a bus rapid transit line between Denver and Boulder along US 36 that is scheduled to open in 2016. This is the first BRT line for the region.

Expansion

This paper recommends adding 20 new express bus and/or BRT lines to the existing network. This addition would provide extensive BRT and express service across the metro area. Figure 22 displays a potential new express bus and BRT network. Figure 23 displays this proposed new network with Denver's existing express bus and regional bus network. However, before new routes are added a full study should be conducted to determine the exact routings.

Figure 22: Map of Potential New Express Bus and BRT Routes

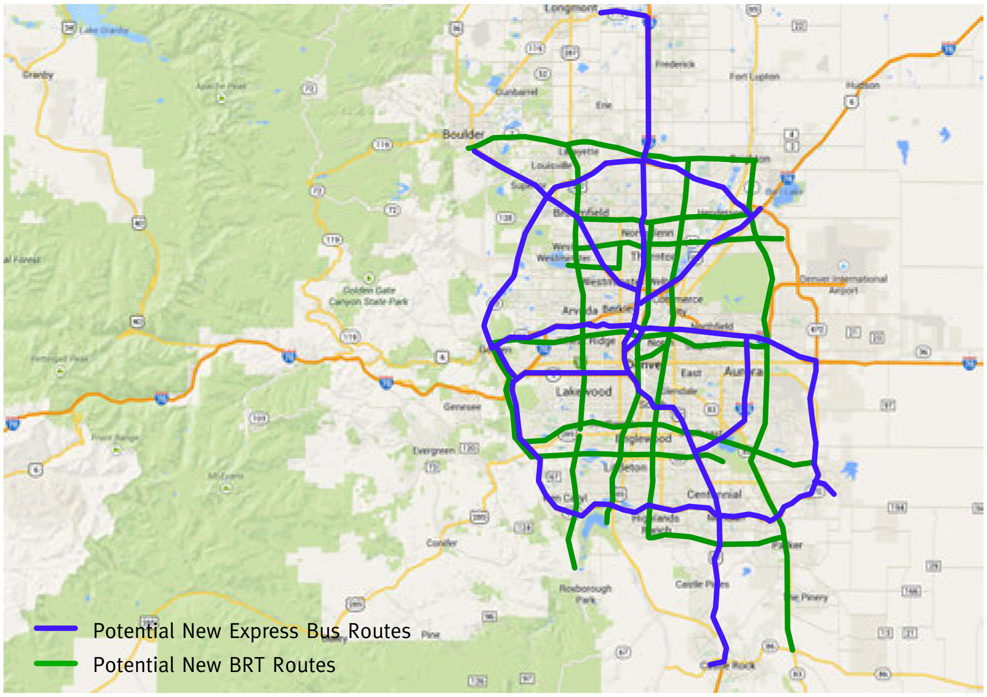
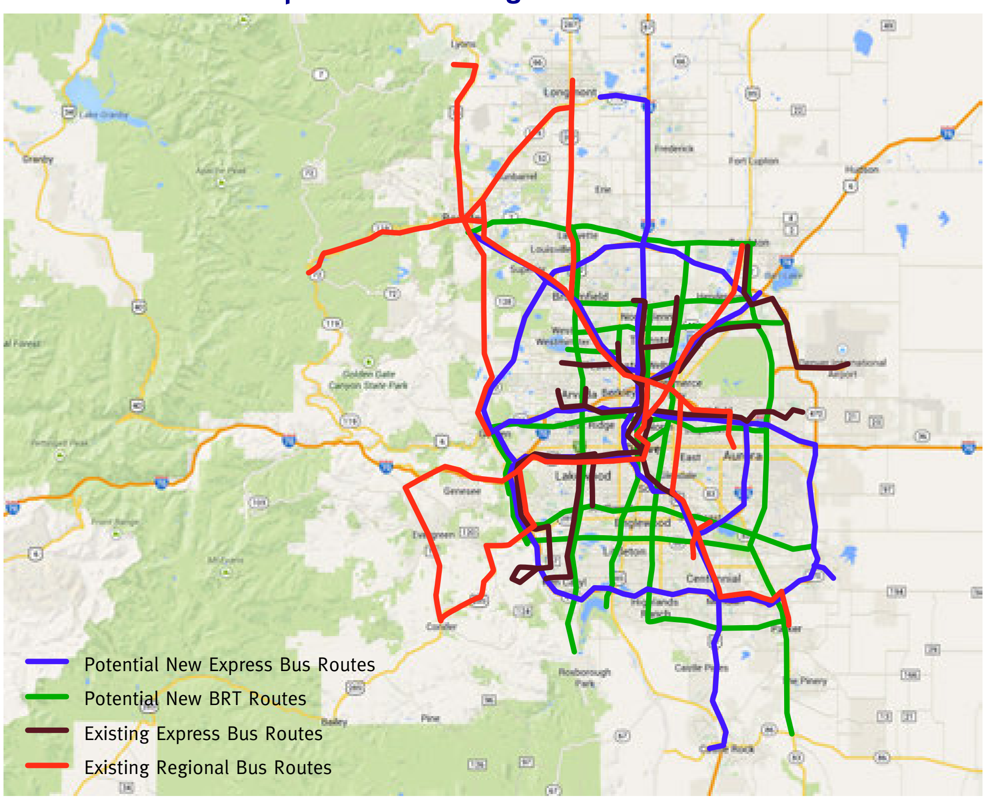


Figure 23: Map of Potential New Express Bus and BRT Routes and Existing Express Bus and Regional Bus Routes



D. Vanpools

A vanpool consists of a commercial van and a group of seven to 15 people who ride to and from work together. Most vanpools require a small monthly charge to pay for gasoline and insurance. Since seven to 15 people share the costs, however, commuting by vanpool is substantially less expensive and less time-consuming than commuting alone, because vanpools can use the express toll lanes for free. The driver and substitute driver for most vanpools either do not have to pay or receive a significantly discounted price.

Since seven to 15 people share the costs, however, commuting by vanpool is substantially less expensive and less time-consuming than commuting alone, because vanpools can use the express toll lanes for free.

Current Service

The DRCOG "waytogo" program coordinates vanpools in the Denver area.[101] CDOT coordinates vanpools between Denver, Fort Collins and Colorado Springs. There are more than 100 vanpools operating in the greater Denver area.[102]

Expansion

Vanpools are a cost-effective transportation service. The express toll lanes network and managed arterials will offer enhanced vanpooling opportunities on metro Denver's Interstates and arterial highways. Vanpool riders cover nearly 100% of the vanpool's operating and capital costs. Some employers will pay part of the costs for their employees to form and operate a vanpool. State and metro transportation agencies may also be able to provide discounted insurance for vanpool members who use a much smaller per capita amount of the region's infrastructure than other commuters.

E. Demand-Response Transit

With demand-response transit (DRT) service, individual passengers can request a ride from one specific location to another location at a certain time. Unlike local bus service, which offers a fixed-route service, the passenger must notify the transit operator of the need for service and the destination before he or she travels.

There are two types of DRT service. In suburban and rural areas with low populations, DRT service is offered in lieu of fixed-route transit service as a more cost-effective transit option. In denser areas, DRT service is for elderly and disabled residents who cannot use fixed-route transit services. The Americans with Disabilities Act requires transit providers who offer fixed-route service to offer DRT service as well. Buses, taxis, vans and cars are used as DRT vehicles.

As demand-response service typically has higher per capita costs than fixed-route service, most operators contract with the private sector to provide quality demand-response service at a lower cost. To its credit, the RTD contracts out DRT service.

Current Service

The RTD provides demand-response transit ("call-n-Ride") in several lower density areas where fixed-route service would be inefficient.[103] Brighton and Superior are two of the communities with such service. The RTD also provides DRT to seniors and people with disabilities.

Other smaller entities also provide service. For example, Adams County and Boulder County contract with Via Transit to provide DRT service.[104] A number of counties provide DRT to seniors and those with disabilities.

Expansion

The Denver region has several very rural areas where fixed-route transit will remain unfeasible. There is also a growing population of elderly and disabled residents who are unable to use fixed-route transit due to special medical conditions. As a result, substantial growth in demand-response transit is expected.

Part 8

Funding and Financing

Funding and financing are among the most challenging aspects of any major transportation improvement. Fortunately, there is existing statewide revenue currently being spent on other uses that can be devoted to transportation. Part 2 of this study detailed the economic losses caused by congestion, conservatively estimated at $200 billion annually by the U.S. Department of Transportation. In that context, dedicating $221 million per year that would have been spent on other programs to transportation is a minor investment.

Before considering any tax increases, Colorado needs to spend its existing transportation revenue more efficiently and on transportation purposes. The following sections detail current revenue streams and totals. After that, this section outlines which additional state revenue should be devoted to transportation. The end of this study discusses long-term funding solutions, including mileage-based user fees.

A. Current Revenues

In FY 2013, Colorado DOT had revenues of $1.2 billion.[105] Forty percent of this total, or $487 million, came from federal funds; 33%, or $400 million, came from the state highway trust fund supported by motor fuel taxes. Seventeen percent, or $198 million, came from the Funding Advancements for Surface Transportation and Economic Recovery Act of 2009 (FASTER) and 10% came from other federal, state and local funds.

CDOT can also receive transportation funds from two other sources.[106] Senate Bill 09-228 triggers funding once a 5% personal income tax growth rate is met. House Bill 95-1174 requires the transportation commission to submit to the Capital Development Committee (CDC) a list of state highway construction, repair and maintenance projects for potential funding. However, 09-228 relies on general funds (this limits the user-pay user-benefit system described below) and 95-1174 is limited by fiscal realities. More importantly, neither of these mechanisms has provided any funding for transportation since 2008.

State Highway Trust Fund

Most CDOT funding comes from the state highway trust fund. The highway trust fund is divided into two parts. The first stream is composed of the first seven cents of the excise tax on gasoline, license plate fees, traffic fines, driver's license/tag fees and passenger-miles fees. The second stream is composed of the remaining excise tax on gasoline and other fees and surcharges. Both funding streams support the account that pays for road construction formally known as the Colorado Highway Users Tax Fund, but a percentage of the first stream also funds the Colorado State Patrol and Ports of Entry. Both streams support the three main components of the Colorado Highway Users Tax Fund labeled the State Highway Fund, Counties (fund) and Local Governments (fund) but the exact funding percentages differ. The State Highway Fund receives 65% of the first stream and 60% of the second stream;[107] counties receive 26% of the first stream and 22% of the second stream; and local governments receive 9% of the first stream and 18% of the second stream.

B. Changes to Transportation Funding and Financing

As discussed at the beginning of this section, the best method of increasing transportation funding is to dedicate all transportation revenues (gas taxes, tolls, mileage-based user fees) to transportation and to spend those resources efficiently. Colorado needs to make the following changes:

Short-Term Specific Changes

First, the state should dedicate all state gasoline taxes to transportation. In FY 2013–2014 $108.1 million of gas tax revenue came "off the top" to support the State Patrol and Ports of Entry. The State Patrol, which operates Colorado's weigh stations, needs a certain amount of funding for safety purposes. However, $108.1 million per year is more money than is needed and comes in addition to the Colorado Department of Public Safety's $325+ million budget.[108] The agency could reprioritize funds or contract out its administration of benefits to save money. We recommend the state provide $48.1 million annually to the State Patrol to monitor and enforce safety, and dedicate the other $60 million annually to more pressing highway needs.

Second, local cities and counties should use some of their local and county funds to build and maintain regional roads. CDOT already provides significant funds (9% of the first stream and 18% of the second stream) to local governments. Particularly in the Denver area, the difference between a local road and a regional or state road can be murky, which calls for a teamwork-based solution. By developing partnerships to improve regional and state roads, CDOT and local communities can improve roads more effectively.

Third, Colorado legislators should consider reworking the complicated state funding formula. Prioritizing projects located in congested and quickly growing areas could target additional funds to where they are most needed. A similar reworking of the state formula in North Carolina increased funding for congested areas between 5% and 10%.[109]

Funding and Financing Solutions

While none of the preceding changes are a panacea on their own, together they can augment existing funding. Colorado needs $13.2 billion over 30 years ($439.9 million per year) to close the gap. A total of $60 million will come from funds currently redirected to the State Highway Patrol and Ports of Entry; local areas can use $149.2 million of the total $211 million they receive from CDOT on regional and state highways. CDOT's streamlined administrative procedures can provide $12 million per year. Table 20 details how Colorado can redirect more transportation funds toward improving the transportation system. Table 21 details what categories this redirected revenue will support.

Table 20: Annual Funding Categories

Funding Stream Diversion	Total	Percent of New Dedicated Funding
State Patrol	$60 M	27.1%
Local Funding	$149.2 M	67.4%
Administrative Changes	$12 M	5.4%
Total	**$221.2M**	**100.0%**

Source: Colorado Department of Transportation

Table 21: Annual Non-Toll Revenue		
CDOT Program	Current Expenditure	Proposed Expenditure
Maintenance	$620 M	$620 M
Debt Service	$187 M	$187 M
Funding of Local/Minor Roads*	$211 M	$61.8 M
Emergency/Contingency	$86 M	$86 M
Program Delivery	$41 M	$41 M
Maximize	$33 M	$33 M
Other Administration	$21 M	$9 M
State Highway Patrol/Ports of Entry	$108 M	$48 M
Capacity/Modernization	$4 M	$225.2M
Total	**$1,311 M**	**$1,311 M**

* Assumes local-state partnership

Source: Colorado Department of Transportation

Building and maintaining Colorado's roadway system is vital to the state's economic success. Our plan provides an implementable transportation plan that does not require a tax increase. However, there is still a $203.7 million annual funding deficit. A transition to a mileage-based user fee combined with continued population growth will eliminate this deficit over the long-term. The following section details mileage-based user fees.

Our plan provides an implementable transportation plan that does not require a tax increase.

Long Term Funding: Text Box: Mileage-Based User Fees

Over the long term Colorado should consider switching from a gas tax to a mileage-based user fee. There are several reasons to make this switch. Many Colorado residents are buying alternative fuel vehicles and conventional vehicles are becoming more fuel-efficient. The gasoline-electric hybrid Prius averages 46 miles per gallon, twice the 2014 new vehicle average of 23.[110] As a result, the Prius pays ½ the gasoline tax of an average new vehicle. The electric Nissan Leaf does not use gasoline so the Leaf pays no fuel tax at all. Conventional vehicles are also using less gasoline. Over the last 20 years, vehicle fleet fuel efficiency has increased by 25%, resulting in less gas purchased and thereby less gasoline tax incurred.[111] In this way, inflation has eroded the purchasing power of the gasoline tax. Colorado's state gas tax purchasing power has declined more than 40% since it was last increased.[112]

Over the last 20 years, vehicle fleet fuel efficiency has increased by 25%, resulting in less gas purchased and thereby less gasoline tax incurred.

Yet increasing the gas tax is not the best solution. Owners of hybrids and electric vehicles, who tend to be wealthier than the average vehicle owner, will continue to pay less than owners of traditional vehicles, introducing both economic and equity issues. As well, politicians will be tempted to use gas taxes for non-roadway expenses. Further, gas taxes are not the best proxy for roadway usage. Tractor-trailers and other heavy vehicles wear out the road 10 times faster than cars, yet they do not pay 10 times the gasoline taxes. Finally, even if gas taxes were increased, they would have to be increased every 10 to 15 years, a political impossibility.

With mileage-based user fees (MBUF), drivers pay a per-mile fee to use a certain section of road. The fee varies based on the type of road; Interstates and freeways have the highest rate per mile followed by arterials and then local streets. The fee varies by time of day. Driving during the height of rush hour is the most expensive, followed by driving during shoulder periods and then off-peak hours. The fee varies by type of vehicle. For example, passenger vehicles pay less than tractor-trailers.

MBUFs are not an additional tax. MBUFs will replace the fuel tax, although the two may co-exist during a transition period. MBUFs will also replace tolls on all highways where tolls are charged. In all situations MBUFs are a replacement of the existing revenue source, not an additional revenue source. Some have questioned whether MBUFs will increase the burden on the poor and elderly residents. Studies have found MBUFs are actually more equitable than gas taxes.[113]

Studies have found MBUFs are actually more equitable than gas taxes.

There are many types of MBUFs in operation.[114] They typically fall into one of three categories. The first is a plan that provides unlimited mileage for an annual fee. This option does not require an annual inspection or odometer reading. Vehicle owners pay a flat fee with their vehicle registration. The second is a more advanced system that uses wireless reporting to monitor miles driven on state roads. This system tracks mileage and uses variable pricing, which charges drivers a higher price during peak hours and a lower price during non-peak hours, but it does not track location. The third is a more advanced system that includes mileage data and vehicle location data. Since these plans have location data, they do not charge for out-of-state or off-road usage. These systems also enable safety warnings and road conditions to be communicated to drivers.

In Oregon, where an extensive pilot program was tested and a permanent MBUF program is being implemented, users are allowed to opt-in to the program.[115] This opt-in process has increased public acceptance, as the current MBUF option allows drivers to save by driving less and no participant pays more than he currently does in fuel taxes.

Colorado's transportation authorities initially began studying mileage-based user fees in 2008 and were expected to begin a pilot program in the near future. They ultimately decided against the pilot program after reviewing public feedback.[116] Colorado stakeholders wanted the state to be a "near follower" in adopting MBUFs—that is to say that they wanted other states to test and implement their own programs prior to continuing efforts in Colorado. In 2013 the Oregon state legislature passed the necessary legal framework for a permanent MBUF system.[117] Minnesota, Nevada and other states have successfully completed pilot programs.[118] Now that pioneering states have served as a laboratory, Colorado state transportation authorities should feel comfortable pushing forward with MBUFs. We recommend Colorado authorities take another look at MBUFs in 2015.

Part 9

Costs, Benefits and Structural Issues for Denver's Transportation Improvements

This report has detailed Denver's current approach to mobility, explained the difference between non-recurrent and recurrent congestion, and created a detailed plan for Denver's highway and transit network. This section will focus on the costs of such a plan.

A. Express Toll Lane and Toll Road Costs and Revenues

Since the express toll lane (ETL) network is the largest component of our plan, we discuss the costs and benefits in depth. While the $10.71 billion cost is significant, the benefits far outweigh the cost.

The below table provides an overview of the network's costs:

Appendices B, C and D provide details on how we estimated traffic on the ETL, drawing on the experience of other jurisdictions where similarly priced lanes have been in operation for more than a decade. All links in the freeway system were examined for projected congestion over the next several decades, using link-specific projections from DRCOG to determine which roads need additional capacity in a specific time frame, and whether that capacity should be one or more lanes in each direction or one or more reversible lanes. That analysis led to the network spelled out in Part 6, which we proposed building in five phases, with the first phase opening in 2020 and the final phase opening in 2040. New priced capacity, which is most of the total, is detailed in this section. New unpriced capacity is detailed below ("C. General Purpose Lanes Costs and Benefits").

Appendix B also explains how we estimated costs for each of the links making up the network, including improvements to I-70 west between east of the Twin Tunnels and the Eisenhower Tunnel, and a new toll road to complete the beltway (which we have named the Jefferson Parkway and included as part of the toll lane network). We used three sources for project numbers. Some of the project numbers come from Wilbur Smith Associates' study of potential toll lanes in 2004 under contract to CDOT's Colorado Tolling Enterprise. Some cost numbers are from the DRCOG 2035 long-range plan.[119] For the others, we used very recent cost estimates developed for a similar priced-lane network study in the Miami metro area, studied for the Florida DOT.[120] Costs from all sources were inflation-adjusted to 2014 dollars, and modified based on revised traffic count and land acquisition cost data. The network's cost in 2014 dollars is $10.7 billion.

The network's cost in 2014 dollars is $10.7 billion.

How much of that cost could be financed based on the toll revenues that the express lanes network would generate? To provide an approximation, we developed a 40-year projection of toll revenue for the proposed network, which is also explained in some detail in the Appendix D. Assuming that toll levels would be proportional to the intensity of congestion (higher with more congestion, lower with less), we compared Denver's 2014 congestion with that of the Atlanta, Los Angeles, Miami, San Diego and Washington, D.C. regions, drawing on their experience with priced lanes. The toll rates and congestion levels are shown below in Table 22. Since Denver is the smallest metro area and has the least congestion, we developed an average toll rate of $0.24 per mile. Since projections from DRCOG, CDOT and other sources show traffic growth in Denver continuing over the next four decades, the market-clearing toll rate for the ETL network will need to increase. We estimated this annual increase by adjusting the starting rate by an assumed 3.5% inflation rate. The 40-year spreadsheet then allowed us to project both the traffic volume using the ETL network and the toll rates charged each year.

Table 22: Average Weekday Express Lane Network Toll Rates for Selected Corridors (per mile)

Metro Area	Highway	Toll Rate per Weekday Mile	Toll Rate (peak direction)	Highway Travel Time Index
Atlanta	I-85	13 cents	25 cents	1.24
Los Angeles	I-10, I-110	54 cents	80 cents	1.37
Los Angeles	SR 91	48 cents	94 cents	1.37
Miami	I-95	14 cents	28 cents	1.25
San Diego	I-15	10 cents	20 cents	1.18

Source: Georgia State Road and Tollway Authority, Orange County Transportation Authority, 95Express, San Diego Association of Governments, Los Angeles Metro Express Lanes.

An initial way to estimate such a project's financial feasibility is to compare the net present value (NPV) of its cost with the net present value of its revenue (the amount of money available to build the highway). Future costs and revenues must be discounted to current dollar numbers in order to provide a valid comparison. For public infrastructure, a commonly used discount rate is 6%, which is the value we chose. The revenue spreadsheet uses standard 6% NPV factors to discount the value of each year's revenue to the net present value in the base year of 2020—the year the first phase of the network would open, according to our model. The NPV of revenue from this calculation is $10.7 billion.

For a valid comparison we compared the NPV of revenue to a cost figure in the same base year, in this case 2020. To obtain this figure, we used a two-step process. First, we adjusted the cost of each phase, given in 2014 dollars, to its value in year-constructed dollars, using a construction-cost inflation factor of 3.5% per year. That produced the construction-year figures for each of the five phases, as shown in Table 9-2. We then calculated the NPV of each of those figures as of 2020, the common year for comparing the NPV of costs and NPV of revenues. As the table reveals, the NPV of project cost, in 2020, is $11.0B.

The NPV of project cost, in 2020, is $11.0B.

Table 23: Major Project Costs (in thousands)

Project	Cost, 2014 $	Start Year	Future-Year Cost	NPV Factor	NPV of Cost
ETL Phase 1	$3,109M	2020	$3,822 M	1.0	$3,822M
ETL Phase 2	$2,780M	2025	$4,059M	.7473	$3,033M
ETL Phase 3	$1,740M	2030	$3,017M	.5584	$1,685M
ETL Phase 4	$1,244M	2035	$2,562M	.4173	$1,069M
ETL Phase 5	$1,833M	2040	$4,483M	.3118	$1,398M
Totals*	$10,706M		$17,943M		$11,007M

* Totals are rounded

Comparing the NPV of cost and the NPV of revenue shows that the two are approximately equal. And the values are equal using a relatively high inflation rate of 3.5%. If the historical 2.7% inflation rate is used, the NPV of cost is significantly lower than the NPV of revenue.

A second piece of good news is that developing the express lanes network using value-priced tolls would leverage limited public funds into a greatly improved transportation network. As toll revenues cover more than 60% of the cost of our express lane network (which also functions as a virtual exclusive busway), adding tolled lanes stretches limited state/federal dollars further than general purpose lanes while reducing congestion and improving transit service.

The 2035 RTP also notes the uncertainty of federal and state funding for even the fiscally constrained transportation plan. The partly self-financing nature of the express lane network that we are proposing reduces much of the financial uncertainty inherent in planning for a future that will rely largely on traditional governmental funding sources.

B. Time-Saving Benefits

The time savings are significant. We calculate the benefits from the freeways with express lanes only. But the toll roads, managed arterials, general purpose expansions and operational improvements also have extensive benefits. Using data from the traffic and revenue projection in Appendix D, together with recent projections of future congestion from DRCOG,[121] we can estimate the direct value of this congestion reduction to motorists.

First, we estimate the time-saving benefits for those using the express lanes. From the traffic and revenue spreadsheet in Appendix D, we find that in 2040 there will be 463 lane-miles in operation, averaging 1,280 vehicles/lane/hour for six peak hours per day. Daily vehicle-miles of travel in those lanes is thus 3,555,840. Assume the average one-way trip that uses the network travels 10 miles in those lanes, at an average of 60 mph in the express lanes (vs. an average of 34 mph if no express lanes are built (DRCOG predicts an average speed of 34 mph in the general purpose lanes). Simple math gives us a time saving of 0.15 hours per one-way trip, adding up to 53,338 hours saved/day. With 250 weekdays per year, that's 13.3 million hours per year saved. Using DRCOG's estimate of $26.50/vehicle hour as the average value of a driver's time, that totals $352 million per year for express toll lanes users.

Next, we estimate the savings in general purpose lanes. Since the express lanes capture 5% of total 2035 traffic, we are dealing with the remaining 95% that use the general purpose lanes on a given weekday. DRCOG estimates total vehicle-hours of delay in the status quo system (without adding the ETL network) at 999,800 per weekday. Taking 95% of that gives us 949,810 delay hours per weekday. Assuming that eliminating LOS F congestion reduced vehicle-hours of delay by 10%, that gives us 94,981 hours eliminated per day, or 23,745,520 per year. At $26.50 per vehicle-hour, that gives us $629 million per year in time savings for GP lane users.

Adding together the benefits to both categories of motorist gives us $981 million in annual time savings. Over the standard 20-year period used for benefit/cost analysis, that would be $19.6 billion. Comparing this with the $10.7 billion cost of the network, the benefit/cost ratio is nearly 2:1. This calculation includes only time and vehicle savings to motorists. And remember this calculation includes only the express toll lanes. Table 24 presents the total savings.

Adding together the benefits to both categories of motorist gives us $981 million in annual time savings.

Table 24: Electronic Toll Network Benefits

	Managed Lane Time Savings	General Purpose Lane Time Savings	Total
Time savings one-way trip	0.15 hours	Negligible	0.12 hours
Time savings per day	53,338 hours	94,981 hours	148,319 hours
Time savings per year	$13.3 million hours	$23.7 million hours	$37 million hours
Time savings in dollars	$352 million	$629 million	$981 million

C. General Purpose Lanes Costs and Benefits

There are only 122 lane-miles of additional general purpose lanes. We estimate these lanes will cost approximately $1,548 million dollars. Since most of these lanes can be constructed in existing right-of-way in flat rural areas of the metro area, they have relatively low costs. These general purpose lanes are suggested only in corridors where express lanes would be unfeasible. There are also several interchange improvements to both general purpose and managed freeways. Interstate interchange improvement projects are estimated to cost $3.32 billion.

D. Managed Arterial Improvements

Managed arterials are major surface streets with optional tolled overpasses or underpasses at signalized intersections. The cost to build overpasses and/or underpasses for the managed arterials network is estimated at $4.2 billion. Based on research of managed arterials in South Florida and Lee County, Florida, tolls are expected to cover half of the construction costs. Making roadway improvements associated with the managed arterials network is expected to cost $1.33 billion, bringing the total managed arterial network price tag to $5.57 billion.

While this cost is not cheap, it must be put in perspective compared to other costs. The $6 billion is approximately half of the resources DRCOG plans to spend on arterial highways; it is also less than the cost of the FasTrak expansions. Additionally, unlike arterial highways and rail expansions, users would pay about $2.3 billion in tolls of the costs to construct the managed arterial lanes. Table 25 displays the total cost, cost covered by toll revenue, cost covered by funding changes and any funding gaps.

Table 25: Roadway/Transit Construction Costs

Road/Transit Type	Total Cost	Total Cost Covered by Tolls	Covered by Funding Changes	Funding Gap
Electronic Toll Lanes/Toll Roads Freeway Network	$10,706M	$6,542M	$4,164M	$0M
General Purpose Freeway Additions	$1,548M	$0M	$357M	$1,191M
Freeway Interchanges	$3,511M	$0M	$0M	$3,511M
New Primary Arterials	$224M	$0M	$0M	$224M
Primary Arterial Widenings	$1,101M	$0M	$0M	$1,101M
Grade Separations	$4,235M	$2,120M	$2,115M	$0M
Intelligent Transportation Technology	$500M	$0M	$0M	$500M
Total	$21,825M	$8,662M	$6,636M	$6,527M

E. Summary of Costs

More than 60% of the construction costs of our $10.7 billion electronic toll lanes network are covered by toll revenue. Approximately half of the revenue needed to build the grade separations on our managed arterials network is also covered by toll revenue. As we discussed in Part 8, dedicating state transportation revenues currently used for other services to transportation will help reduce the remaining cost of the electronic toll lane/toll roads freeway network, the remaining cost of the managed arterials network and most of the general purpose freeway additions. The funds to build new primary arterials, arterial widenings and intelligent transportation technology and the remainder of the general purpose freeway network can be covered by local funds or the eventual transition to a mileage-based user fee. While our plan did not focus on purely local roads or study areas outside of the Denver-Boulder-Fort Collins greater metro area, Colorado's existing transportation budget of $1.2 billion per year ($39 billion over 30 years adjusted for inflation) combined with county and local funds is likely sufficient to pay for transportation needs in other areas of the state and local roads.

Our express lanes and managed arterials provide a free virtual guideway for express bus and bus rapid transit service and the associated ITS improvements guarantee fast, reliable transit service. Farebox revenue and, if needed, local funds can pay for the cost to buy, operate and maintain the buses.

More than 60% of the construction costs of our $10.7 billion electronic toll lanes network are covered by toll revenue.

Part 10

Conclusion

This report provides a detailed framework for Denver to increase its mobility. With significant growth projected over the next 25 years, Denver's productivity and quality of life are threatened by a lack of mobility.

Denver is at a crossroads in terms of transportation policy. Implementing the current *2035 Metro Vision Regional Transportation Plan* will lead to a future of dramatically worsening congestion, in which the average peak-period trip is projected to take 80% longer than at off-hours (compared with 40% longer, as of now). That approach would continue to spend substantial transportation resources on rail transit and non-motorized transportation. While both have benefits, they are not the key to reducing congestion.

By contrast, we have developed a comprehensive transportation system consisting of road and transit improvements that reduce congestion and increase mobility more effectively and more cheaply than the DRCOG 2035 plan. By including the congestion reduction components of the *2035 Metro Vision Regional Transportation Plan* and replacing the rail and non-motorized projects with additional projects to reduce congestion, our plan more effectively increases mobility.

We have developed a comprehensive transportation system consisting of road and transit improvements that reduce congestion and increase mobility more effectively and more cheaply than the DRCOG 2035 plan.

Our plan for the state and regional highway totals $22 billion (Table 25). Assuming DRCOG chooses to spend an additional $15 billion on local roads and an additional $15 billion to provide transit services, the 30-year total would be $52 billion. This $52 billion plan spends only 39% of the $133 billion (Table 1) in the DRCOG 2012 long-range plan and covers a longer time period of 30 years (from 2015–2044) compared to 24 years (2012–2035) for the DRCOG plan. More importantly, our plan has a realistic funding and financing source, filling a $6 billion hole with the transition to a mileage-based user fee, while the current DRCOG plan has a $40 billion hole that the entity has no realistic way of funding. Unlike the DRCOG's 2035 plan that hopes to spend $133 billion dollars and still results in worse congestion, our plan significantly reduces congestion and saves money.

Our plan includes the following components:

- Making major investments in dynamically priced express lane capacity
- Making minor investments in general purpose capacity
- Developing a network of managed arterials
- Improving the operation and management of the system through operational changes
- Creating an express bus network running on the ETL network
- Creating a bus rapid transit network running on managed arterials

Unlike the DRCOG's 2035 plan that hopes to spend $133 billion dollars and still results in worse congestion, our plan significantly reduces congestion and saves money.

Our plan also offers motorists a choice of paying tolls on express lanes and managed arterials in exchange for faster and more reliable trips or using free lanes that operate at lower traffic speeds. Our plan offers a transit option that provides quick, reliable service using ETLs, overpasses and underpasses, express lanes and managed arterials for commuters who choose to use transit at a cost-effective price. Our plan also offers continued free lanes on freeways and arterials for motorists who do not choose to take advantage of the express lanes in their car or as a transit rider. And our plan offers each of these three choices cost-effectively.

Congestion threatens to strangle Denver, destroying its viability as a place to live and work, as well as its position as a major economic center. But as former Transportation Secretary Norman Mineta said, "Congestion is not a scientific mystery, nor is it an uncontrollable force. Congestion results from poor policy choices and a failure to separate solutions that are effective from those that are not."[122] The policy choices recommended in this report would put Denver on the road to greatly increased mobility by 2040.

Appendix A: Major Primary Arterial Highways Components

Appendix A: Major Primary Arterial Highways Components			
Corridor	From	To	Scope
Boulder-Brighton Highway Arapahoe Ave/Baseline Rd.	US 36	I-76	Build N/S and E/W managed grade separations at US 36 and Arapahoe Ave.
			Build managed grade separation at 30th St.
			Build managed grade separation at Foothills Parkway
			Add 2 lanes from E of 55th St. to W of 75th St.
			Add new 4-lane alignment from Arapahoe Ave. W of 75th St. to Baseline Rd. E of 75th St.
			Add 2 lanes from E of 75th St. to 95th St.
			Build N/S and E/W managed grade separations at US 287
			Add 2 lanes to from ¼ mi W of US 287 to I-25
			Rebuild I-25 interchange
			Build N/S and E/W managed grade separations at Colorado Blvd.
			Add 2 lanes to from 166th Ave to I-76
			Rebuild US 85 interchange
			Rebuild I-76 interchange
Thornton Crossing 104th Ave./100th Ave./ Church Ranch Blvd.	Simms St.	E-470	Add 2 lanes between Simms St. and Independence St.
			Build grade-separated interchange at Church Ranch Rd.
			Add 2 lanes between 101st Ave. and 103th Ave.
			Rebuild Interchange at US 36
			Add 2 lanes between Westminster Blvd. and Crooke Dr. (3.6 miles)
			Build managed grade separation at Sheridan Parkway
			Build managed grade separation at Federal Blvd.
			Build managed grade separation at Huron St.
			Rebuild I-25 interchange
			Build managed grade separation at Washington St.
			Add 2 lanes between Marion St. and ¼ mi W of SR 2
			Build managed grade separation at Colorado Blvd.
			Build grade separation at US 85
			Rebuild E-470 interchange
Historic Denver Highway/US 40	C-470	I-70	Rebuild interchange at US 6
			Rebuild interchange at I-70
			Add 2 lanes from 1/2 mi SW of US 6 to Indiana St.
			Build managed grade separation at Indiana St.
			Add 2 lanes from Cole Blvd. to Wide Acres Rd.
			Build managed grade separation at Kipling St.
			Build managed grade separation at Wadsworth Blvd.
			Build managed grade separation at Sheridan Blvd.
			Add 2 lanes from Sheridan Blvd. to Irving St.
			Rebuild I-25 interchange
			Build grade separation at Kalamath St. and N. Speer Blvd.

Appendix A: Major Primary Arterial Highways Components			
Corridor	From	To	Scope
			Build managed grade separation at York St. and Josephine St.
			Build managed grade separation at Colorado Blvd.
			Add 2 lanes from Park Ave. to Peoria St.
			Build managed grade separation at Peoria St.
			Build managed grade separation at Potomac St.
			Build managed grade separation at Chambers Blvd.
			Add 2 lanes from Sable Blvd. to ¼ mi E of Airport Blvd.
			Build managed grade separation at Airport Blvd.
Englewood Crossing US 285/SR 30/SR 85/Hamden Ave.			Build managed grade separation at University Blvd.
			Build N/S and E/W managed grade separations at Colorado Blvd.
			Rebuild I-25 interchange
			Build managed grade separation at Monaco Parkway
			Build managed grade separation at Yosemite St.
			Add 1 lane in SW direction between Dartmouth Rd. and ½ mi SW of Galena St.
			Add 2 lanes from SR 30 to SR 83
			Build managed grade separation at Parker Rd.
			Build managed grade separation at Peoria St.
			Rebuild I-225 interchange
			Build managed grade separation at Chambers Rd.
			Build managed grade separation at Buckley Rd.
			Build managed grade separation at Tower Rd.
			Add 2 lanes between Conservatory Parkway and Gun Club Rd.
			Rebuild interchange at E-470
Southern Connector	Rampart Range Rd	Tomohawk Rd	Add 2 lanes to Titan Rd. between Rampart Range Rd. and US 85
			Build managed grade separation at US 85
			New 4-lane alignment between US 85 and Ridgegate Parkway
			Build full interchange at Monarch Blvd.
			Rebuild I-25 Interchange
			Add 2 lanes from I-25 to Tomahawk Rd.
			Build managed grade separation at Chambers Rd.
			Build managed grade separation at Jordan Rd.
			Build managed grade separation at Twenty Mile Rd.
			Build managed grade separation at Parker Rd.
Boulder-Golden Highway SR 93	C-470	SR 7 Canyon Blvd.	Add 2 lanes between C-470 and Table Mesa Rd.
			Rebuild interchange at SR 58
			Build managed grade separation at Table Mesa Dr.
			Build managed grade separation at Baseline Rd.
			Add 2 lanes between ¼ mi S. of Baseline Rd. to ¼ mi N of Canyon Blvd.
			Build managed grade separation at Canyon Blvd.
Old Western Highway Wadsworth Blvd., Wadsworth Parkway, US 287	C-470	Jasper Rd.	Rebuild interchange at C-470
			Add 2 lanes between C-470 and Parkhill Ave.
			Build managed grade separation at Chatfield Ave
			Build managed grade separation at Ken Caryl Ave.
			Build managed grade separation at Coal Mine Ave.
			Add 2 lanes between US 285 and Ohio Ave.
			Build managed grade separation at Bowles Ave.
			Build managed grade separation at Belleview Ave.
			Build managed grade separation at Quincy Ave.
			Rebuild interchange at US 285
			Build managed grade separation at Yale Ave.
			Build managed grade separation at Jewell Ave.

Appendix A: Major Primary Arterial Highways Components			
Corridor	From	To	Scope
			Build managed grade separation at Mississippi Ave.
			Build managed grade separation at Alameda Ave.
			Rebuild I-70/I-76 interchange
			Build N/S and E/W managed grade separations at US 40
			Add 2 lanes from US 6 to I-70/I-76
			Build managed grade separation at 32nd Ave.
			Build managed grade separation at 44th Ave.
			Build managed grade separation at 52nd Ave.
			Build managed grade separation at Ralston Rd.
			Build managed grade separation at 72nd Ave.
			Build managed grade separation at 80th Ave.
			Build managed grade separation at 88th Ave.
			Add 2 lanes between 92nd Ave. and 108th Ave.
			Build N/S and E/W managed grade separations at Church Ranch Blvd
			Build managed grade separation at Interlocken Loop
			Rebuild US 36 interchange
			Add 2 lanes between US 36 and ¼ mi N. of Arapahoe Rd.
			Rebuild Northwest Parkway interchange
			Build managed grade separation at W. South Boulder Rd.
			Build N/S and E/W managed grade separations at Baseline Rd.
			Build managed grade separation at Arapahoe Rd.
Capital Highway University Blvd.-Colorado Blvd.-Vasquez Blvd.	C-470	168th Ave.	Rebuild C-470 interchange
			Add 2 lanes between County Line Rd and Quincy Ave.
			Build managed grade separation at County Line Rd.
			Build managed grade separation at Dry Creek Rd.
			Build managed grade separation at Arapahoe Rd.
			Build managed grade separation at Belleview Ave.
			Build grade separation at Quincy Blvd.
			Build grade separation at Colorado Blvd.
			Add 4 lanes between University Blvd. and Colorado Blvd
			Add 4 lanes between Quincy Ave. and Hampden Ave.
			Build N/S and E/W managed grade separations at Hampden Ave.
			Build managed grade separation at Evans Ave.
			Rebuild I-25 interchange
			Build managed grade separation at Florida Ave.
			Build managed grade separation at Cherry Creek St.
			Build managed grade separation at Alameda Ave.
			Build managed grade separation at 1st Ave.
			Build N/S and E/W managed grade separations at US 40
			Build managed grade separation at 17th Ave.
			Build managed grade separation at Martin Luther King Jr. Blvd.
			Rebuild I-70 interchange
			Build managed grade separation at 56th Ave.
			Rebuild I-270 interchange
			Build managed grade separation at 60th Ave.
			Add 2 lanes between SR 2N and 68th Ave.
			Build overpass at US 85 and Brighton Blvd.
			Add 2 lanes between Brighton Blvd. and Colorado Blvd.
			New 4-lane alignment parallel to railroad tracks and W of reservior from 68th Ave W of Colorado Blvd. to 86th St at Colorado Blvd.
			Rebuild interchange at I-76/74th St.
			Add 2 lanes from ¼ mi S. of 88th Ave to 140th Ave.

Appendix A: Major Primary Arterial Highways Components			
Corridor	From	To	Scope
			Build managed grade separation at 88^{th} Ave.
			Build managed grade separation at Thornton Parkway
			Build N/S and E/W managed grade separations at 104^{th} Ave.
			Build managed grade separation at 120^{th} Ave.
			Build managed grade separation at 128^{th} Ave.
			Build managed grade separation at 136^{th} Ave.
			Add 4 lanes between 140^{th} Ave. and ¼ mi N of 144^{th} Ave.
			Build managed grade separation at 144^{th} Ave.
			Add 2 lanes between ¼ mi N of 144^{th} Ave. and E 168^{th} Ave.
			Rebuild E-470 intersection
			Build N/S and E/W grade separations at 160^{th} Ave.
Parker-Brighton Highway	SR 86	SR 52	Build grade separation at SR 86
			Add 2 lanes between ¼ mi S. of SR 86 and Bayou Gulch Rd. (3.3 miles)
			Build managed grade separation at Hess Rd.
			Build managed grade separation at Main St.
			Build managed grade separation at Lincoln Ave.
			Build managed grade separation at Pine Lane
			Rebuild E-470 interchange
			Build managed grade separation at Cottonwood Dr.
			Build managed grade separation at Arapahoe Rd.
			Add 2 lanes between Parker Rd. and Buckley Rd.
			Build managed grade separation at Buckley Rd.
			Build managed grade separation at Orchard Rd.
			Add 2 lanes between 1/4 mi S of Orchard Rd. and Mississippi Ave.
			Build managed grade separation at Quincy Rd.
			Build managed grade separation at E Iliff Ave.
			Build managed grade separation at Mississippi Ave.
			Build managed grade separation at Alameda Parkway
			Build managed grade separation at 6^{th} Ave.
			Build N/S and E/W managed grade separations at US 40
			Rebuild Pena Blvd/I-70/40^{th} Ave interchange
			Add 2 lanes from I-70/40^{th} Ave. interchange to Tower Rd/Buckley Rd. Interchange
			Add new 4-lane alignment from Tower Rd/Buckley Rd. interchange to 88^{th} Ave.
			Add 2 lanes between 88^{th} Ave. and Chambers Rd.
			Add 2 lanes between E 96^{th} St. and ¼ mi S of 104^{th} Ave.
			Add managed grade separation at 104^{th} Ave.
			Add 4 lanes between ¼ mi S of 104^{th} Ave. and ¼ mi N of 104^{th} Ave.
			Add grade separation at 120^{th} Ave.
			Add new 4-lane alignment between 120^{th} Ave. and S. Adams County Parkway ¼ mi S. of Valente Drive
			Add 2 lanes between new alignment and Sable Blvd.
			Add 2 lanes between Adams County Parkway and 1/4 mi N of 144^{th} St.
			Add new 4-lane alignment between ¼ mi N of 144^{th} Ave. and US 85 ½ mi S of Bromley Lane
			Add managed grade separation at Canaan Highway/US 85-SR 2 Connector
			Rebuild 160^{th} Ave. interchange
			Add managed grade separation at 168^{th} Ave.
			Add 2 lanes between new alignment and 2 mi N of 168^{th} Ave.

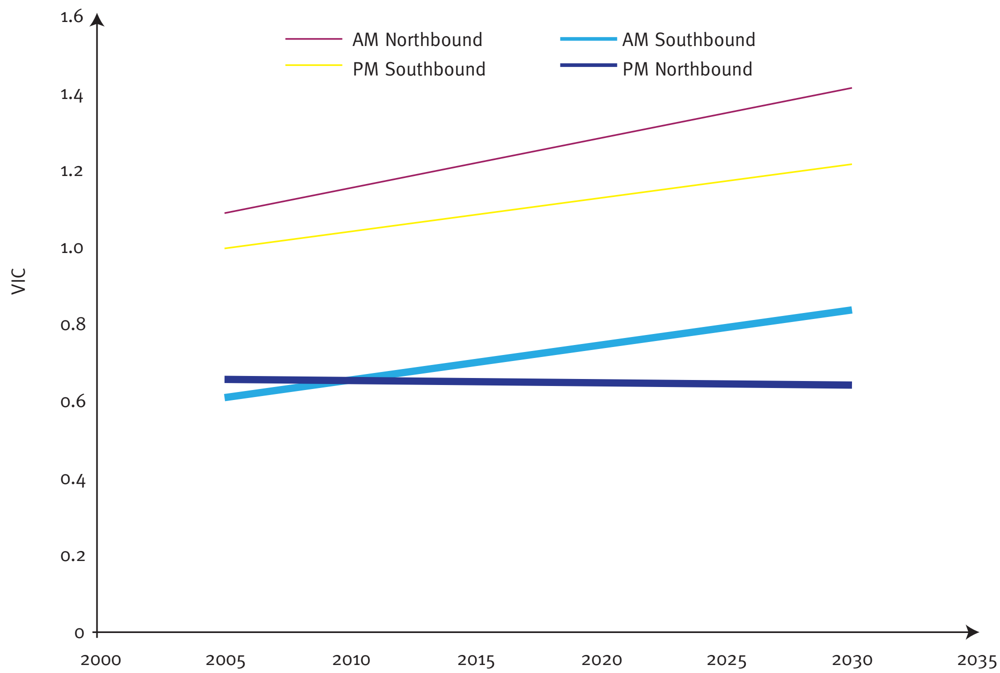
Appendix B: Analysis of Express Toll Lane Additions

In the body of this study, we made the case that additional freeway lane-miles are a key component in a serious effort to reduce congestion in the metro Denver area. This appendix explains how we determined where to put the freeway lane additions.

Using current traffic volume counts and DRCOG's Volume/Capacity maps of the Denver area projected to 2030, we were able to generate the Volume/Capacity graphs as illustrated below. Each graph provides data for both AM and PM peak directional volume and capacity for its corresponding segment. Any line extending above 1.0 on the chart depicts a road segment that is functioning above capacity in that direction during that time period. When this is the case, the building of new lane-miles is justified for that segment. Where (i.e., what year) the line crosses above 1.0 on the chart is also important and determines the phase into which the project falls. A line that begins above 1.0 implies a greater urgency to build new lane-miles. Some lines never reach 1.0, and in those cases adding new lanes is not justified. An example is shown in Figure B-1 (next page).

From these volume/capacity graphs, we were able to gain a better understanding of which freeway segments require additional lanes. Then, using DRCOG volume maps of the Denver metro area for 2005 and 2030, we examined traffic volumes on segments of freeway that showed potential for lane additions. We created spreadsheets to analyze what the addition of 1, 2 or 3 express toll lanes (ETLs) would do to traffic volumes in the general purpose (GP) lanes. The building of an *additional* ETL (beyond one) was only justified when conditions on the GP lanes are still somewhat congested with the initial ETL functioning at full capacity. From these spreadsheets, we were able to estimate both where ETLs were needed and how many to add. An example spreadsheet, titled Table B-1, is included at the end of this appendix.

Figure B-1: Typical Volume/Capacity Graph (I-25 C470/E470 to CastleRock)



The methodology underlying the spreadsheet is as follows:

- Column A represents the **Year**.
- Columns B and C represent directional Average Daily Traffic (**ADT**) (number of vehicles) as taken from the DRCOG Denver volume maps for 2005 and 2030. The ADT figures for years between 2005 and 2030 were interpolated, and those beyond 2030 reflect projections of continued growth of traffic volume.
- Columns D and E reflect **AM** and **PM Peak** hour traffic. More specifically, these figures reflect the number of vehicles that travel on each road segment per hour during peak hours. To calculate these figures, we must first look back at the Volume/Capacity graphs and determine which directional ADT coincides with which peak period (either AM or PM). Once this is determined, the **AM Peak** is calculated by taking 23% of the corresponding ADT figure and then dividing it by 2½. We use these calculations because according to the DRCOG model, about 46% of the average daily traffic occurs during peak hours, and Denver currently experiences about five hours of heavy peak traffic – from 6:30 to 9:00 AM in the morning and 3:30 to 6:00 PM in the afternoon. The same calculations were performed in order to determine the **PM Peak** by simply using the alternate ADT figure.

- The next three columns—F, G and H—represent projected traffic on the ETLs, depending on how many of them are added. Applying the dates from the proposed project staging chart enabled the analysis to project when the ETLs would go live and show how many new ETLs would be needed. In each case we assumed a 5-year "ramp-up" of ETL traffic, beginning with 480 vehicles per lane (in the peak direction) and increasing to the desired capacity of 1,600 vehicles per lane (in the peak direction). Thus, column F shows **Traffic with one ETL**, column G **Traffic with two ETLs**, and column H **Traffic with three ETLs**.
- Columns I, J and K correspond to the number of vehicles that will travel in the GP lanes per AM peak hour. These lanes are the existing freeway lanes and will continue to function as non-tolled lanes. As the ETLs are constructed and put into operation, some traffic will move onto the ETLs from the GP lanes. Column I shows the **AM GP Traffic/Lane if one ETL** is constructed; column J **AM GP Traffic/Lane with two ETLs,** and column K**, AM GP Traffic/Lane with construction of three ETLs**. ETL are not needed if traffic in the GP lanes does not exceed 2,000 vehicles per lane per peak hour. However, almost every freeway in metro Denver currently exceeds or is forecast to exceed 2,000 vehicles per hour during peak periods.
- Columns L, M and N are calculated the same way as columns I, J and K, but use the PM peak hour figures.

From these traffic projection charts we estimated the appropriate number of ETLs to be built on each freeway segment, as well as the project phasing. The resulting set of capacity expansions and proposed phasing are what appears in Table 13 in the body of the report.

There are no traffic projection charts for the I-70 Corridor, and the Jefferson Parkway, as neither project was included in the DRCOG modeling exercise. The I-70 Mountain Corridor project adds one lane in each direction to I-70 from the Twin Tunnels area to the Eisenhower Tunnel area. The Jefferson Parkway, which completes the beltway around Denver, is a new 4-lane tolled road. Once constructed, all capacity will be tolled and vehicles will not have the option of bypassing tolls by using GP lanes.

Table B-1: Traffic Projections on I-25 between the C-470/E-470 Interchange and Castle Rock

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Year	Northbound ADT	Southbound ADT	AM Peak (N)	PM Peak (S)	Traffic/ 1 ETL	Traffic/ 2 ETLs	Traffic/ 3 ETLs	AM GP traffic/lane 1 ETL	Am GP traffic/lane 2 ETLs	AM GP traffic/lane 3 ETLs	PM GP traffic/lane 1 ETL	PM GP traffic/lane 2 ETLS	PM GP traffic/lane 3 ETLs
2005	64,135	62,000	5,900	5,704	0	0	0	1,967	1,967	1,967	1,901	1,901	1,901
2006	65,407	63,202	6,017	5,815	0	0	0	2,006	2,006	2,006	1,938	1,938	1,938
2007	66,704	64,427	6,137	5,927	0	0	0	2,046	2,046	2,046	1,976	1,976	1,976
2008	68,027	65,676	6,259	6,042	0	0	0	2,086	2,086	2,086	2,014	2,014	2,014
2009	69,377	66,950	6,383	6,159	0	0	0	2,128	2,128	2,128	2,053	2,053	2,053
2010	70,753	68,248	6,509	6,279	0	0	0	2,170	2,170	2,170	2,093	2,093	2,093
2011	72,156	69,571	6,638	6,401	0	0	0	2,213	2,213	2,213	2,134	2,134	2,134
2012	73,587	70,920	6,770	6,525	0	0	0	2,257	2,257	2,257	2,175	2,175	2,175
2013	75,047	72,295	6,904	6,651	0	0	0	2,301	2,301	2,301	2,217	2,217	2,217
2014	76,535	73,696	7,041	6,780	0	0	0	2,347	2,347	2,347	2,260	2,260	2,260
2015	78,053	75,125	7,181	6,911	600	1,200	1,800	2,194	1,994	1,794	2,104	1,904	1,704
2016	79,601	76,581	7,323	7,045	700	1,400	2,100	2,208	1,974	1,741	2,115	1,882	1,648
2017	81,180	78,066	7,469	7,182	800	1,600	2,400	2,223	1,956	1,690	2,127	1,861	1,594
2018	82,790	79,580	7,617	7,321	900	1,800	2,700	2,239	1,939	1,639	2,140	1,840	1,540
2019	84,432	81,122	7,768	7,463	1,000	2,000	3,000	2,256	1,923	1,589	2,154	1,821	1,488
2020	86,107	82,695	7,922	7,608	1,100	2,200	3,300	2,274	1,907	1,541	2,169	1,803	1,436
2021	87,815	84,298	8,079	7,755	1,200	2,400	3,600	2,293	1,893	1,493	2,185	1,785	1,385
2022	89,556	85,933	8,239	7,906	1,300	2,600	3,900	2,313	1,880	1,446	2,202	1,769	1,335
2023	91,333	87,599	8,403	8,059	1,400	2,800	4,200	2,334	1,868	1,401	2,220	1,753	1,286
2024	93,144	89,297	8,569	8,215	1,500	3,000	4,500	2,356	1,856	1,356	2,238	1,738	1,238
2025	94,992	91,028	8,739	8,375	1,600	3,200	4,800	2,380	1,846	1,313	2,258	1,725	1,192
2026	96,876	92,793	8,913	8,537	1,600	3,200	4,800	2,438	1,904	1,371	2,312	1,779	1,246
2027	98,797	94,592	9,089	8,702	1,600	3,200	4,800	2,496	1,963	1,430	2,367	1,834	1,301
2028	100,757	96,426	9,270	8,871	1,600	3,200	4,800	2,557	2,023	1,490	2,424	1,890	1,357
2029	102,755	98,295	9,453	9,043	1,600	3,200	4,800	2,618	2,084	1,551	2,481	1,948	1,414
2030	104,793	100,201	9,641	9,218	1,600	3,200	4,800	2,680	2,147	1,614	2,539	2,006	1,473
2031	106,871	102,144	9,832	9,397	1,600	3,200	4,800	2,744	2,211	1,677	2,599	2,066	1,532
2032	108,991	104,124	10,027	9,579	1,600	3,200	4,800	2,809	2,276	1,742	2,660	2,126	1,593
2033	111,153	106,143	10,226	9,765	1,600	3,200	4,800	2,875	2,342	1,809	2,722	2,188	1,655
2034	113,357	108,200	10,429	9,954	1,600	3,200	4,800	2,943	2,410	1,876	2,785	2,251	1,718
2035	115,606	110,298	10,636	10,147	1,600	3,200	4,800	3,012	2,479	1,945	2,849	2,316	1,782
2036	117,899	112,437	10,847	10,344	1,600	3,200	4,800	3,082	2,549	2,016	2,915	2,381	1,848
2037	120,237	114,616	11,062	10,545	1,600	3,200	4,800	3,154	2,621	2,087	2,982	2,448	1,915
2038	122,622	116,838	11,281	10,749	1,600	3,200	4,800	3,227	2,694	2,160	3,050	2,516	1,983
2039	125,054	119,104	11,505	10,958	1,600	3,200	4,800	3,302	2,768	2,235	3,119	2,586	2,053
2040	127,534	121,413	11,733	11,170	1,600	3,200	4,800	3,378	2,844	2,311	3,190	2,657	2,123
2041	130,064	123,767	11,966	11,387	1,600	3,200	4,800	3,455	2,922	2,389	3,262	2,729	2,196
2042	132,644	126,166	12,203	11,607	1,600	3,200	4,800	3,534	3,001	2,468	3,336	2,802	2,269
2043	135,274	128,612	12,445	11,832	1,600	3,200	4,800	3,615	3,082	2,548	3,411	2,877	2,344
2044	137,957	131,106	12,692	12,062	1,600	3,200	4,800	3,697	3,164	2,631	3,487	2,954	2,421
2045	140,694	133,647	12,944	12,296	1,600	3,200	4,800	3,781	3,248	2,715	3,565	3,032	2,499

Appendix C: Project Cost Estimates

Cost estimates in this study are based on three sources. The first is a Wilbur Smith Associates Report, *CTE Preliminary Traffic and Revenue Study*, December 2004, pages 5–20 and 5–21. These figures were converted to 2014 dollars and traffic volumes were adjusted based on changes in growth patterns over the past 10 years. That study included several of the ETL projects included in our proposed network. Several other segments were not included in the Wilbur Smith study.[123] For those we used cost estimates from a 2009 Florida Department of Transportation study on a possible Express Lanes network for the greater Miami area.[124] That study used Federal Highway Administration freeway lane addition cost numbers from the agency's HERS system for at-grade lanes, and used cost estimates from the recent Tampa elevated express lanes project designer (Figg Bridge) for elevated lane costs. Those figures were converted to 2014 dollars. Finally, we used recent cost estimates in DRCOG 2035's Plan for appropriate freeway and arterial roads.[125]

The figures are shown in 2014 dollars. Cost estimates from the above studies were adjusted using historic construction cost indices to reflect construction cost inflation over the intervening years. The average construction cost index over 17 years is 2.79%. To err on the conservative side we assume annual construction cost inflation of 3.5%.

Table C-1: Annual Denver-Specific Construction Cost Indices (1989–2009)	
1990	1.3%
1991	1.3%
1992	3.2%
1993	4.7%
1994	-0.1%
1995	2.0%
1996	6.0%
1997	-0.1%
1998	3.3%
1999	0.6%
2000	6.0%
2001	-2.2%
2002	1.7%
2003	5.7%
2004	8.7%
2005	1.9%
2006	2.9%
2007	0.6%
2008	3.3%
2009	3.5%*
Average	**2.8%**

Source: ENR.com, cost index-Denver

*estimate

A p p e n d i x D

Appendix D: Project Revenue Estimates

The first step in estimating revenue for the proposed network of value-priced lanes (including the Jefferson Parkway) was to figure out the "market-clearing" price for such lanes in Denver operating at the desired LOS C during peak periods. We started with the assumption that this price level is proportional to the intensity of congestion. Variable-priced lane projects are operating in Atlanta, Los Angeles, Miami, San Diego and Washington D.C. (Denver's I-25 lanes feature fixed-time of day pricing; since we recommend variable pricing we have not included them.) The project, average toll rate and travel time index are listed in table D-1 below.

Table D-1: Average Weekday Express Lane Network Toll Rates for Selected Corridors

Metro Area	Highway	Toll Rate per Weekday Mile	Toll Rate (peak direction)	Highway Travel Time Index
Atlanta	I-85	13 cents	25 cents	1.24
Los Angeles	I-10, I-110	54 cents	80 cents	1.37
Los Angeles	SR 91	48 cents	94 cents	1.37
Miami	I-95	14 cents	28 cents	1.25
San Diego	I-15	10 cents	20 cents	1.18

Source: Georgia State Road and Tollway Authority, Orange County Transportation Authority, 95Express, SANDAG, Metro Express Lanes.

Denver is a smaller market than the above metro areas. However, its current traffic congestion is almost as severe as the larger metro areas and it is forecast to grow faster than the U.S. average. We therefore used 24.75 cents per mile as the peak period peak direction weekday (excluding holidays) toll price for the facility.

Assuming that traffic volume continues to increase as Denver grows over the next 40 years, the market-clearing toll rate will have to increase in order to remain effective as a tool to manage traffic demand in the lanes. To approximate this, we model it as increasing at the rate of inflation (the Consumer Price Index or CPI). We assume an average CPI of 3.5% over this time period. Because the first phase of the proposed ETL network would open to traffic in 2020, we must first adjust the starting toll rate from the 2014 value of 24.75 cents/mile to the 2020 toll rate. We calculated CPI by using 3.5% per year, yielding an inflation-adjusted 30.42 cents/mile as of 2020.

Our revenue estimation procedure makes use of a 40-year spreadsheet, covering years from 2015 through 2054. To calculate the total, we first estimate the weekday peak-period toll revenue and convert that to annual peak-period revenue. Then, we estimate the relatively small fraction of total revenue generated from weekends and non-peak times on weekdays and add it to the larger sum from peak periods.

Peak-period revenue consists of revenue generated from ETL travel in the peak direction plus revenue from trips taken in the non-peak direction (which is generally the case, since most of the proposed segments in the network have lanes in both directions). We make the general assumptions that the toll charged in the non-peak direction is 50% of what is charged in the peak direction. We also assume that traffic volume in the non-peak direction is 60% of volume in the peak direction. Simple algebra then tells us that the weighted average toll charged during peak periods is 81.25% of the peak-direction toll. That means our starting average peak-period toll in 2020 is 24.7 cents/mile, instead of the 30.42 cents/mile we calculated above for the peak direction toll. That number appears on the 2020 row in the spreadsheet in Table D-2.

Based on our capacity expansion project proposals and staging table, we determined how many ETL lane-miles would begin operation in each phase. In its opening year, the ETL network begins with 165 lane-miles (the Phase 1 projects plus the 35 miles of existing I-25 HOT lanes and US 36 HOT lanes). Five years later, the Phase 2 projects come on line, boosting the network total to 177 lane-miles. Subsequent phases increase the total to 235 lane-miles, then 370 and finally 463 lane-miles, as shown in the third column of the spreadsheet.

As each phase begins operating, we assume its lanes in the first year attract 480 vehicles/lane/hour in the peak direction and 160/lane/hour in the non-peak direction, for a first-year average of 640 vehicles per weekday peak hour per lane. Traffic continues to increase each year of the five-year ramp-up period, until that set of lanes reaches capacity (defined as 1,600/lane/hour in the peak direction and 960/lane/hour in the non-peak direction, for an average of 1,280). As each new phase begins operating, its lanes experience the same five-year ramp-up period, so the total network traffic during those five years is a weighted average of the traffic in the previously existing ETLs and the ramping-up traffic in the new ETLs of the added phase.

The final adjustment to be made is the definition of the peak period. DRCOG reports that the current peak period is defined as five hours per day, split between AM and PM peaks. We use that number for the first 10 years of network operation. However, Colorado DOT's 2008 annual report on Denver region congestion cites DRCOG projections indicating that by 2035 vehicle hours of delay in the region will be 361% greater than 2007 levels.[126] Thus, it is highly likely that the number of weekday hours defined as peak period hours will increase. We use 5.5 peak hours for 2025 to 2034, 6.0 peak hours for 2035 to 2044, and 6.5 peak hours for 2045 to 2054. This number directly affects the calculation of the weekday peak-period revenue, as shown in the spreadsheet's fifth column.

Annual peak-period revenue is simply 250 times the weekday figure, using the accepted measure of 250 net weekdays per year; that number appears in the sixth column.

The seventh column lists annual non-peak revenue, and is based on the experience of the 91 Express Lanes, whose annual non-peak revenue (non-peak periods on weekdays plus all weekend and holiday days) accounts for 29% of annual peak revenue. (Express toll lanes during non-peak hours are not operating at capacity and toll rates are reduced.) Adding annual peak and non-peak revenue gives us total annual gross revenue, in the next column. As is customary in toll revenue forecasts, we next deduct 10% of the gross revenue (to cover operating and maintenance costs), giving us (bondable) net annual revenue.

The final task accomplished via the spreadsheet is to compute the net present value of this 40-year revenue stream, as of the base year 2020. This is completed using a fairly standard 6% discount rate. The NPV of net revenue for these toll lanes is $4.0 billion.

Table D-2: Revenue Projection for ETL Network

Year	Lane-miles	Wkday peak vol/ETL	Average peak toll	Peak revenue/ wkday	Annual peak revenue	Annual non-peak revenue	Total gross revenue	Net revenue	NPV factor	NPV revenue
2020	165	640	0.247	$130,574	$32,643,600	$9,466,644	$42,110,244	$35,793,707	1.0000	$35,793,707
2021	165	800	0.256	$168,931	$42,232,658	$12,247,471	$54,480,128	$46,308,109	0.9434	$43,687,070
2022	165	960	0.265	$209,812	$52,452,961	$15,211,359	$67,664,319	$57,514,671	0.8900	$51,188,262
2023	165	1,120	0.274	$253,348	$63,336,950	$18,367,715	$81,704,665	$69,448,966	0.8396	$58,311,390
2024	165	1,280	0.284	$299,674	$74,918,564	$21,726,383	$96,644,947	$82,148,205	0.7921	$65,070,114
2025	177	1,005	0.294	$261,237	$65,309,327	$18,939,705	$84,249,031	$71,611,677	0.7473	$53,513,481
2026	177	1,074	0.304	$288,944	$72,236,014	$20,948,444	$93,184,459	$79,206,790	0.7050	$55,839,001
2027	177	1,143	0.315	$318,270	$79,567,566	$23,074,594	$102,642,161	$87,245,836	0.6651	$58,025,089
2028	177	1,212	0.326	$349,295	$87,323,838	$25,323,913	$112,647,751	$95,750,588	0.6274	$60,077,026
2029	177	1,280	0.337	$381,804	$95,451,007	$27,680,792	$123,131,799	$104,662,029	0.5919	$61,951,524
2030	235	1,203	0.349	$542,405	$135,601,284	$39,324,372	$174,925,656	$148,686,808	0.5584	$83,029,258
2031	235	1,222	0.361	$570,256	$142,563,953	$41,343,547	$183,907,500	$156,321,375	0.5268	$82,351,774
2032	235	1,241	0.374	$599,392	$149,847,898	$43,455,890	$193,303,789	$164,308,220	0.4970	$81,660,071
2033	235	1,260	0.387	$629,868	$157,467,078	$45,665,453	$203,132,531	$172,662,651	0.4689	$80,955,198
2034	235	1,280	0.400	$662,262	$165,565,385	$48,013,962	$213,579,347	$181,542,445	0.4423	$80,300,895
2035	370	1,139	0.414	$960,323	$240,080,844	$69,623,445	$309,704,289	$263,248,646	0.4173	$109,851,053
2036	370	1,174	0.429	$1,024,477	$256,119,256	$74,274,584	$330,393,841	$280,834,765	0.3937	$110,556,637
2037	370	1,209	0.444	$1,091,945	$272,986,258	$79,166,015	$352,152,273	$299,329,432	0.3714	$111,167,860
2038	370	1,244	0.459	$1,162,881	$290,720,204	$84,308,859	$375,029,064	$318,774,704	0.3504	$111,688,780
2039	370	1,280	0.475	$1,238,412	$309,602,996	$89,784,869	$399,387,865	$339,479,685	0.3305	$112,210,980
2040	463	1,139	0.492	$1,556,994	$389,248,624	$112,882,101	$502,130,725	$426,811,117	0.3118	$133,092,371
2041	463	1,174	0.509	$1,661,008	$415,252,073	$120,423,101	$535,675,174	$455,323,898	0.2942	$133,947,236
2042	463	1,209	0.527	$1,770,396	$442,598,933	$128,353,691	$570,952,624	$485,309,730	0.2775	$134,687,776
2043	463	1,244	0.546	$1,885,406	$471,351,390	$136,691,903	$608,043,293	$516,836,799	0.2618	$135,318,907
2044	463	1,280	0.565	$2,007,866	$501,966,496	$145,570,284	$647,536,780	$550,406,263	0.2470	$135,951,591
2045	463	1,280	0.584	$2,078,141	$519,535,324	$150,665,244	$670,200,567	$569,670,482	0.2330	$132,745,716
2046	463	1,280	0.605	$2,150,876	$537,719,060	$155,938,527	$693,657,587	$589,608,949	0.2198	$129,615,439
2047	463	1,280	0.626	$2,226,157	$556,539,227	$161,396,376	$717,935,603	$610,245,262	0.2074	$126,558,978
2048	463	1,280	0.648	$2,304,072	$576,018,100	$167,045,249	$743,063,349	$631,603,847	0.1957	$123,574,590
2049	463	1,280	0.671	$2,384,715	$596,178,733	$172,891,833	$769,070,566	$653,709,981	0.1846	$120,660,578
2050	463	1,280	0.694	$2,673,862	$668,465,405	$193,854,967	$862,320,372	$732,972,316	0.1741	$127,633,221
2051	463	1,280	0.718	$2,767,447	$691,861,694	$200,639,891	$892,501,585	$758,626,348	0.1643	$124,623,502
2052	463	1,280	0.744	$2,864,307	$716,076,853	$207,662,287	$923,739,141	$785,178,270	0.1550	$121,684,755
2053	463	1,280	0.770	$2,964,558	$741,139,543	$214,930,468	$956,070,011	$812,659,509	0.1462	$118,815,307
2054	463	1,280	0.797	$3,068,318	$767,079,427	$222,453,034	$989,532,461	$841,102,592	0.1379	$116,013,523
2055	463	1,280	0.824	$3,175,709	$793,927,207	$230,238,890	$1,024,166,097	$870,541,183	0.1301	$113,277,808
2056	463	1,280	0.853	$3,286,859	$821,714,659	$238,297,251	$1,060,011,911	$901,010,124	0.1228	$110,606,604
2057	463	1,280	0.883	$3,401,899	$850,474,673	$246,637,655	$1,097,112,328	$932,545,478	0.1158	$107,998,390
2058	463	1,280	0.914	$3,520,965	$880,241,286	$255,269,973	$1,135,511,259	$965,184,570	0.1093	$105,451,680
2059	463	1,280	0.946	$3,644,199	$911,049,731	$264,204,422	$1,175,254,153	$998,966,030	0.1031	$102,965,024
ETL Network Total NPV Revenue 2020–2059										$3,962,452,168

We included separate calculations for the I-70 mountain corridor and the Jefferson Parkway. These two facilities are toll roads where 100% of capacity is tolled. The Jefferson Parkway is the missing link in Denver's beltway and the I-70 mountain corridor project widens I-70 from four lanes to six lanes between the Twin Tunnels area and the Eisenhower Tunnel area.

Revenue Projections for I-70 West

For I-70 West, since much of the project cost includes the tunnel work, we believe it is appropriate to toll all lanes on the highway since all drivers will benefit from the tunnel expansion. We calculated the expected cost of the I-70 West project to be $1,540M. We assumed the tunnel would be paid off over 40 years. We took the current annual average daily traffic (AADT) and assumed a 1% annual average increase in traffic volumes. We assumed that the toll would increase at the construction inflation rate, which we estimated as 3.5%. Since we put this project in the second phase, we assumed a start date of 2025. To pay 100% of project costs we assumed a starting toll rate of $3.03. A $3.03 starting cost calculates to a $0.10 per mile toll, a remarkably low figure considering the mountainous terrain.

Table D-3: Revenue Projection For I-70 West								
Year	Toll Rate	Traffic Count	Revenue	Days of the Year	Gross Revenue	Net Revenue	NPV Factor	NPV Revenue
2020	2.550	65,000	$165,750	365.25	$60,540,188	$51,459,159	1.0000	$51,459,159
2021	2.639	65,650	$173,267	365.25	$63,285,685	$53,792,832	0.9434	$50,748,157
2022	2.731	66,307	$181,124	365.25	$66,155,691	$56,232,337	0.8900	$50,046,980
2023	2.827	66,970	$189,338	365.25	$69,155,851	$58,782,474	0.8396	$49,355,490
2024	2.926	67,639	$197,925	365.25	$72,292,069	$61,448,259	0.7921	$48,673,555
2025	3.028	68,316	$206,901	365.25	$75,570,515	$64,234,937	0.7473	$48,001,041
2026	3.134	68,999	$216,284	365.25	$78,997,637	$67,147,992	0.7050	$47,337,820
2027	3.244	69,689	$226,092	365.25	$82,580,180	$70,193,153	0.6651	$46,683,763
2028	3.357	70,386	$236,345	365.25	$86,325,191	$73,376,413	0.6274	$46,038,742
2029	3.475	71,090	$247,064	365.25	$90,240,039	$76,704,033	0.5919	$45,402,633
2030	3.597	71,800	$258,268	365.25	$94,332,425	$80,182,561	0.5584	$44,775,314
2031	3.722	72,518	$269,981	365.25	$98,610,400	$83,818,840	0.5268	$44,156,662
2032	3.853	73,244	$282,224	365.25	$103,082,382	$87,620,025	0.4970	$43,546,558
2033	3.988	73,976	$295,023	365.25	$107,757,168	$91,593,593	0.4689	$42,944,883
2034	4.127	74,716	$308,402	365.25	$112,643,955	$95,747,362	0.4423	$42,351,522
2035	4.272	75,463	$322,388	365.25	$117,752,359	$100,089,505	0.4173	$41,766,359
2036	4.421	76,218	$337,009	365.25	$123,092,428	$104,628,564	0.3937	$41,189,281
2037	4.576	76,980	$352,292	365.25	$128,674,670	$109,373,469	0.3714	$40,620,176
2038	4.736	77,750	$368,268	365.25	$134,510,066	$114,333,556	0.3504	$40,058,935
2039	4.902	78,527	$384,969	365.25	$140,610,098	$119,518,583	0.3305	$39,505,448
2040	5.073	79,312	$402,428	365.25	$146,986,766	$124,938,751	0.3118	$38,959,609
2041	5.251	80,105	$420,678	365.25	$153,652,615	$130,604,723	0.2942	$38,421,312
2042	5.435	80,907	$439,756	365.25	$160,620,761	$136,527,647	0.2775	$37,890,452
2043	5.625	81,716	$459,699	365.25	$167,904,913	$142,719,176	0.2618	$37,366,927
2044	5.822	82,533	$480,546	365.25	$175,519,401	$149,191,491	0.2470	$36,850,635
2045	6.026	83,358	$502,339	365.25	$183,479,206	$155,957,325	0.2330	$36,341,477
2046	6.237	84,192	$525,120	365.25	$191,799,988	$163,029,989	0.2198	$35,839,353
2047	6.455	85,034	$548,934	365.25	$200,498,117	$170,423,399	0.2074	$35,344,168
2048	6.681	85,884	$573,828	365.25	$209,590,707	$178,152,101	0.1957	$34,855,824
2049	6.915	86,743	$599,851	365.25	$219,095,645	$186,231,298	0.1846	$34,374,228
2050	7.157	87,610	$627,054	365.25	$229,031,633	$194,676,888	0.1741	$33,899,286
2051	7.407	88,486	$655,491	365.25	$239,418,217	$203,505,485	0.1643	$33,430,906
2052	7.667	89,371	$685,218	365.25	$250,275,833	$212,734,458	0.1550	$32,968,997
2053	7.935	90,265	$716,293	365.25	$261,625,842	$222,381,966	0.1462	$32,513,471
2054	8.213	91,168	$748,776	365.25	$273,490,574	$232,466,988	0.1379	$32,064,238
2055	8.500	92,079	$782,733	365.25	$285,893,372	$243,009,366	0.1301	$31,621,213
2056	8.798	93,000	$818,230	365.25	$298,858,636	$254,029,841	0.1228	$31,184,308
2057	9.106	93,930	$855,337	365.25	$312,411,875	$265,550,094	0.1158	$30,753,441
2058	9.424	94,869	$894,127	365.25	$326,579,754	$277,592,791	0.1093	$30,328,526
2059	9.754	95,818	$934,675	365.25	$341,390,146	$290,181,624	0.1031	$29,909,483
2060	10.096	96,776	$977,063	365.25	$356,872,189	$303,341,361	0.0972	$29,496,229
2061	10.449	97,744	$1,021,373	365.25	$373,056,343	$317,097,891	0.0917	$29,088,685
2062	10.815	98,721	$1,067,692	365.25	$389,974,448	$331,478,281	0.0865	$28,686,773
2063	11.193	99,709	$1,116,112	365.25	$407,659,789	$346,510,821	0.0816	$28,290,413
2064	11.585	100,706	$1,166,727	365.25	$426,147,161	$362,225,086	0.0770	$27,899,530
I–70 West Total NPV Revenue 2025–2064								$1,482,758,638

Revenue Projection for the Jefferson Parkway

The Jefferson Parkway is a new tolled 24-mile freeway with 96 lane-miles that completes the beltway. We determined the expected cost of the Jefferson Parkway to be $980 million. We assumed the road would be paid off over 40 years. We estimated the average annual traffic at a 2025 opening of 21,546 (AADT) and assumed a 1.5% average annual increase. We assumed the toll would increase at the construction inflation rate, which we estimated as 3.5%. Since we placed the project in the second phase, we assumed a start date of 2025. To pay 100% of the project costs, we assumed the toll rate to travel the 24-mile length of the corridor at $5.56. This averages to $0.23 cost per mile, which is a very low toll rate for a completely new road.

Table D-4: Revenue Projection for Jefferson Parkway

Year	Toll Rate	Traffic Count	Revenue	Days of the Year	Gross Revenue	Net Revenue	NPV Factor	NPV Revenue
2020	4.680	20,000	$93,600	365.25	$34,187,400	$29,059,290	1.0000	$29,059,290
2021	4.843	20,300	$98,329	365.25	$35,914,718	$30,527,511	0.9434	$28,799,654
2022	5.013	20,605	$103,297	365.25	$37,729,310	$32,069,913	0.8900	$28,542,337
2023	5.188	20,914	$108,516	365.25	$39,635,583	$33,690,245	0.8396	$28,287,319
2024	5.370	21,227	$113,999	365.25	$41,638,171	$35,392,445	0.7921	$28,034,580
2025	5.558	21,546	$119,759	365.25	$43,741,939	$37,180,648	0.7473	$27,784,099
2026	5.752	21,869	$125,810	365.25	$45,952,001	$39,059,201	0.7050	$27,535,856
2027	5.954	22,197	$132,166	365.25	$48,273,726	$41,032,667	0.6651	$27,289,831
2028	6.162	22,530	$138,844	365.25	$50,712,756	$43,105,842	0.6274	$27,046,004
2029	6.378	22,868	$145,859	365.25	$53,275,018	$45,283,765	0.5919	$26,804,356
2030	6.601	23,211	$153,229	365.25	$55,966,738	$47,571,727	0.5584	$26,564,867
2031	6.832	23,559	$160,970	365.25	$58,794,457	$49,975,289	0.5268	$26,327,517
2032	7.071	23,912	$169,103	365.25	$61,765,047	$52,500,290	0.4970	$26,092,288
2033	7.319	24,271	$177,647	365.25	$64,885,726	$55,152,867	0.4689	$25,859,161
2034	7.575	24,635	$186,623	365.25	$68,164,078	$57,939,466	0.4423	$25,628,117
2035	7.840	25,005	$196,052	365.25	$71,608,068	$60,866,857	0.4173	$25,399,137
2036	8.115	25,380	$205,958	365.25	$75,226,065	$63,942,155	0.3937	$25,172,203
2037	8.399	25,760	$216,364	365.25	$79,026,862	$67,172,833	0.3714	$24,947,297
2038	8.693	26,147	$227,296	365.25	$83,019,694	$70,566,740	0.3504	$24,724,399
2039	8.997	26,539	$238,780	365.25	$87,214,264	$74,132,125	0.3305	$24,503,494
2040	9.312	26,937	$250,844	365.25	$91,620,765	$77,877,650	0.3118	$24,284,562
2041	9.638	27,341	$263,518	365.25	$96,249,904	$81,812,419	0.2942	$24,067,587
2042	9.975	27,751	$276,832	365.25	$101,112,931	$85,945,991	0.2775	$23,852,550
2043	10.324	28,168	$290,819	365.25	$106,221,662	$90,288,412	0.2618	$23,639,434
2044	10.685	28,590	$305,513	365.25	$111,588,511	$94,850,234	0.2470	$23,428,222
2045	11.059	29,019	$320,949	365.25	$117,226,520	$99,642,542	0.2330	$23,218,898
2046	11.447	29,454	$337,165	365.25	$123,149,390	$104,676,982	0.2198	$23,011,443
2047	11.847	29,896	$354,200	365.25	$129,371,513	$109,965,786	0.2074	$22,805,843
2048	12.262	30,344	$372,096	365.25	$135,908,009	$115,521,808	0.1957	$22,602,079
2049	12.691	30,800	$390,896	365.25	$142,774,761	$121,358,547	0.1846	$22,400,136
2050	13.135	31,261	$410,646	365.25	$149,988,456	$127,490,188	0.1741	$22,199,997
2051	13.595	31,730	$431,394	365.25	$157,566,623	$133,931,629	0.1643	$22,001,647
2052	14.071	32,206.	$453,190	365.25	$165,527,676	$140,698,525	0.1550	$21,805,068
2053	14.563	32,689	$476,088	365.25	$173,890,962	$147,807,318	0.1462	$21,610,246
2054	15.073	33,178	$500,142	365.25	$182,676,803	$155,275,283	0.1379	$21,417,165
2055	15.601	33,678	$525,412	365.25	$191,906,549	$163,120,566	0.1301	$21,225,809
2056	16.147	34,183	$551,958	365.25	$201,602,627	$171,362,233	0.1228	$21,036,162
2057	16.712	34,696	$579,846	365.25	$211,788,600	$180,020,310	0.1158	$20,848,210
2058	17.297	35,216	$609,142	365.25	$222,489,219	$189,115,836	0.1093	$20,661,937
2059	17.902	35,744	$639,919	365.25	$233,730,486	$198,670,914	0.1031	$20,477,328
2060	18.529	36,280	$672,251	365.25	$245,539,719	$208,708,761	0.0972	$20,294,370
2061	19.177	36,825	$706,217	365.25	$257,945,614	$219,253,772	0.0917	$20,113,045
2062	19.849	37,377	$741,898	365.25	$270,978,316	$230,331,568	0.0865	$19,933,340
2063	20.543	37,938	$779,383	365.25	$284,669,495	$241,969,071	0.0816	$19,755,242
2064	21.262	38,507	$818,761	365.25	$299,052,421	$254,194,558	0.0770	$19,578,734
Total Jefferson Parkway Revenue 2025–2064								$1,080,670,860

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Endnotes

1 Texas A&M Transportation Institute, *2012 Annual Urban Mobility Report,* (College Station, TX, 2013), p. 7.

2 Ibid, p. 24.

3 Ibid.

4 "America's Fastest Growing Cities 2014," *Forbes Magazine*, July 2014 http://www.forbes.com/pictures/emeg45iikm/6-denver-colo/

5 Monte Whaley, "RTD Poll: FasTracks Image Untarnished by Delay in Northern Project," *Denver Post*, July 26, 2013.

6 Denver Regional Council of Governments, *Metro Vision Overview*, *Metro Vision 2035 Plan*, 2014, https://www.drcog.org/index.cfm?page=MetroVision, October 20, 2013.

7 Texas A&M Transportation Institute, *2012 Annual Urban Mobility Report.*

8 Hamilton County, OH, *Idling: Frequently Asked Questions*, http://www.hcdoes.org/airquality/anti-idling/idlefaq.htm

9 Spencer Hunt, "Central Ohio Businesses Emit Fewer Greenhouse Gases," *The Columbus Dispatch*, November 4, 2013, http://www.dispatch.com/content/stories/local/2013/11/04/central-ohio-businesses-emit-fewer-greenhouse-gases.html

10 "Cost of Living: How Far Will My Salary Go In Another City," *CNN Money*, http://money.cnn.com/calculator/pf/cost-of-living/, August 14, 2014.

11 Jeffrey Leib, "Denver-area Voters Won't See FasTracks Sales-tax Vote in November," *Denver Post*, April 27, 2011, http://www.denverpost.com/ci_17935951.

12 Eric Jaffe, "The End of Federal Transportation Funding as We Know It," *Atlantic City Lab*, March 11, 2013, http://www.citylab.com/cityfixer/2013/03/its-end-federal-transportation-funding-we-know-it/4931/

13 Texas A&M Transportation Institute, *2012 Annual Urban Mobility Report,* p. 3.

14 Ibid.

15 Ibid.

16 Ibid, p. 37.

17 Ibid, p. 40.

18 Texas A&M Transportation Institute, *2012 Annual Urban Mobility Report*.

19 Ibid, p. 5.

[20] Jack Wells, “The Role of Transportation in the U.S. Economy,” presentation to the National Surface Transportation Policy and Revenue Study Commission, June 26, 2006.

[21] U.S. Department of Transportation, Federal Highway Administration, NHCRP Report 463, *Economic Implications of Congestion* (Washington, D.C.: Federal Highway Administration, 2001).

[22] Remy Prud’homme and Chang-Woon Lee, “Size, Sprawl, Speed and the Efficiency of Cities,” *Urban Studies*, vol. 36, No. 11 (October 1999), pp. 1849–1858.

[23] Helena Oliviero, “Looking for love in all the close places,” *Atlanta Journal-Constitution*, October 15, 2002.

[24] Sperling’s Best Places, *Comparison Cost of Living Denver*, August 14, 2014, http://www.bestplaces.net/compare-cities/sacramento_ca/denver_co/costofliving.

[25] David Ellis et al., *Shaping the Competitive Advantage of Texas Metropolitan Regions*, (Austin, TX: Texas Business Leadership Council, 2006), August 4, 2014, http://www.txblc.org/reports/shaping-the-competitive-advantage-of-texas-metropolitan-regions/.

[26] U.S. Department of Transportation Federal Highway Administration Office of Operations, *Traffic Congestion and Reliability,* 2005, www.ops.fhwa.dot.gov/congestion_report/executive_summary.htm.

[27] The Texas Transportation Institute has defined both a Buffer Index and a Planning Time Index to measure these effects, http://mobility.tamu.edu/mmp.

[28] U.S. Department of Transportation, Federal Highway Administration, *Traffic Congestion and Reliability: Linking Solutions to Problems*, (Washington DC, 2004)

[29] U.S. Department of Transportation, National Cooperative Research Program, *The 21st Century Operations-Oriented State DOT*, (Washington D.C.: Transportation Research Board, April 2005), p. 18.

[30] ITS Decision, Services and Technologies, *Traffic Management –Dynamic Traffic Management Systems*, August 26, 2014. http://fresno.ts.odu.edu/newitsd/ITS_Serv_Tech/traff_manag/dyn_trafficmangmt_summary.html

[31] U.S. Department of Transportation Federal Highway Administration, *Safety Application of Intelligent Transportation Systems in Europe and Japan,* International Technology Scanning Program, http://international.fhwa.dot.gov/ipsafety/,2006.

[32] Intelligent Transportation Society of America, *Knowledge Center,* http://www.itsa.org/knowledgecenter/knowledge-center-20, 2013, January 8, 2014.

[33] U.S. Department of Transportation, Federal Highway Administration, *Safety Application of Intelligent Transportation Systems in Europe and Japan*, accessed from http://www.ops.fhwa.dot.gov/congestion_report/chapter2.htm, 2013, July 3, 2014.

[34] California Department of Transportation, Operations Division, *Frequently Asked Questions*, http://www.dot.ca.gov/hq/paffairs/faq/faq66.htm, June 4, 2014.

[35] Texas A&M Transportation Institute, *2012 Annual Urban Mobility Report*, p. 51.

[36] Texas A&M Transportation Institute, *2012 Urban Mobility Report*, pp. 35–36.

[37] Texas A&M Transportation Institute, *2012 Urban Mobility Report*, pp. 23–24.

38 Minnesota Department of Transportation, *FAQ—Freeway Incident Response Safety Team (FIRST)*, (St. Paul, MN: Minnesota DOT, May 2008).

39 Ibid, citing *ITE Journal*, March 1992.

40 Doug MacDonald, "Highway Congestion: What Is to Be Done?" Presentation before the Washington State Department of Transportation, Seattle, WA, November 2006.

41 Steve Hemminger, "Benefits of ITS," presentation at International Bridge, Tunnel, and Turnpike Association conference, Santa Monica, CA, March 2006.

42 U.S. Department of Transportation, National Cooperative Highway Research Program, *Safe and Quick Clearance of Traffic Incidents*, *Synthesis 318*, (Washington, DC: 2003), http://trb.org/publications/nchrp/nchrp_syn_318.pdf.

43 U.S. Department of Transportation, Federal Highway Administration, *Traffic Congestion and Reliability: Causes, How They Are Measured and Why They Matter*, (Washington D.C., 2005, pp. 2-1–2-26).

44 Texas A&M Transportation Institute, *2012 Urban Mobility Report*, pp. 35–36.

45 "National Traffic Signal Report Card," paper presented at Atlanta Regional Traffic Operations Task Force, presentation, Atlanta, GA, 2005.

46 Ibid.

47 U.S. Department of Transportation Federal Highway Administration, *Intersection Safety Issue Briefs: Access Management,* Issue Brief 13, http://safety.fhwa.dot.gov/intersection/resources/fhwasa10005/docs/brief_13.pdf, February 14, 2014.

48 Ibid.

49 U.S. Department of Transportation Federal Highway Administration, *Benefits of Access Management*, http://ops.fhwa.dot.gov/access_mgmt/docs/benefits_am_trifold.htm, updated 2013, February 14, 2014.

50 Iowa State University, *Driveway Density and Driveway Consolidation*, http://www.ctre.iastate.edu/research/access/toolkit/3.pdf, April 12, 2014.

51 U.S. Department of Transportation Federal Highway Administration, *Signalized Intersections: An Informational Guide*, *Chapter 2-2 Human Factors: Motorists*, http://safety.fhwa.dot.gov/intersection/signalized/13027/ch2.cfm, December 4, 2013.

52 Texas A&M Transportation Institute, *2009 Urban Mobility Report*, Exhibit 12.

53 David Hartgen, *Mobility Project—State by State Analysis of Future Congestion and Capacity Needs*, (Los Angeles, CA: Reason Foundation, August 2006), http://reason.org/news/show/mobility-project-state-by-stat-9

54 Cambridge Systematics, Inc., *Unclogging America's Arteries: Effective Relief for Highway Bottlenecks, 1999–2004*, (Washington, D.C.: American Highway Users Alliance, 2004).

55 U.S. Department of Transportation Federal Highway Administration, *Managed Lanes: A Primer*, http://ops.fhwa.dot.gov/publications/managelanes_primer/,September 28, 2013.

56 European Conference of Ministers of Transport, *Managing Urban Traffic Congestion*, (Brussels: International Transport Forum, 2007), http://www.internationaltransportforum.org/Pub/pdf/07Congestion.pdf, pp. 167–173.

[57] U.S. Department of Transportation Federal Highway Administration, Office of Innovative Program Delivery.

[58] Jeffrey Leib, "Tolling Gets Another Look on Congested Metro Denver Road Corridors," *Denver Post*, Jan. 29, 2010.

[59] Colorado Department of Transportation, *Value Express Lanes Feasibility Study, Final Report*, (Denver: CDOT, 2001).

[60] As of 2010, all toll facilities in metro Denver have eliminated cash tolling; see Peter Samuel, "Colorado's Third Toller Is All-Electronic," *Tollroadsnews.com*, Jan. 1, 2010 (www.tollroadsnews.com/node/4523).

[61] Baruch Feigenbaum, *Bus Rapid Transit and Managed Lanes*, Policy Study 432 (Los Angeles CA: Reason Foundation, January 2014), http://reason.org/files/bus_rapid_transit_and_managed_lanes.pdf, p. 24.

[62] Corona Research, *Tolled Express Lanes Public Opinion Survey*," 2006.

[63] Reason-Rupe Public Opinion Survey, *Poll Results Questions 27-32*, *Topline Results,* August, 2014*,* http://reason.com/assets/db/14084333327480.pdf.

[64] Wendell Cox and Alan Pizarski, *Blueprint 2030: Affordable Mobility and Access for All of Atlanta and Georgia*, (St. Louis, MO: Public Purpose, June 2004), http://www.publicpurpose.com/atl-blueprint2030.pdf

[65] Ibid, pp. 10–18.

[66] Kurtis Lee and Monte Whaley, "Hickenlooper Vetoes Bill Intended to Create Transparency in Road Deals," *Denver Post*, June 4, 2014, http://www.denverpost.com/news/ci_25898416/hickenlooper-vetoes-democratic-effort-creating-more-transparency-road

[67] Ibid, p 39.

[68] Bent Flyvbjerg, et al, *Megaprojects and Risk: An Anatomy of Ambition*, (Cambridge, U.K.: Cambridge University Press, 2003).

[69] Fitch Ratings, *Global Infrastructure and Project Finance*, http://ibtta.org/sites/default/files/documents/IBTTA%20Publications/Fitch%20Ratings%20Global%20PPP%20Lessons%20Learned%202013.pdf, October 2013.

[70] Federal Highway Administration, *P3 Toolkit*, http://www.fhwa.dot.gov/IPD/p3/toolkit/guidance_documents/index.htm, March 2014.

[71] Chris Swenson and Robert Poole, *Reducing Congestion in Lee County, Florida,* Policy Study No. 374 (Los Angeles, CA: Reason Foundation, February 2009), p. 18.

[72] CRSPE, Inc., et al., *Lee County Queue Jump Study, Final Report* (Lee County Department of Transportation, January 2003), pp. 4–8.

[73] Swenson and Poole, *Reducing Congestion in Lee County, Florida,* p. 18.

[74] Ibid., pp. 18–22.

[75] U.S. National Research Council, Transportation Research Board, *Transportation Research Record 2297*, (Washington, D.C.: U.S. National Research Council, 2011).

[76] Randal O'Toole, *Defining Success: The Case Against Rail Transit*, Policy Analysis No. 663 (Washington, D.C.: Cato Institute, March 2010), http://object.cato.org/sites/cato.org/files/pubs/pdf/pa663.pdf, p 6.

[77] Jeffrey Brown and Gregory Thompson, "Hub Spoke, the Grid, and the Future of Transit: The Importance of System Planning for Public Transit's Success," paper presented at the Future of Transportation Conference, Tallahassee, FL: September 15–17, 2012.

[78] Robert Cervero and Michael Duncan, "Which Reduces Vehicle Travel More," *Journal of the American Planning Association*, vol. 72, no. 4 (Autumn, 2006), pp. 475–490, http://www.uctc.net/papers/825.pdf

[79] Jeffrey Leib, "FasTracks Costs Running Into The Red," *Denver Post*, March 9, 2007.

[80] Brent Flyberg, Mette Skamri Holm and Soren Buhl, *Underestimating Costs in Public Works Projects*, *Journal of the American Planning Association*, vol. 68, no. 3 (Summer 2002), pp. 278-295.

[81] Colorado High Performance Transportation Enterprise, *I-25 HOV/Tolled Express Trends 2006–Present* (Denver: Colorado High Performance Transportation Enterprise, 2012), pp. 3–6.

[82] National Transit Database, *2012 Database, Service*, http://www.ntdprogram.gov/ntdprogram/datbase/2012_database/NTDdatabase.htm, August 14, 2014.

[83] Ibid.

[84] Baruch Feigenbaum, *Bus Rapid Transit and Managed Lanes*, Policy Study 432 (Los Angeles, CA: Reason Foundation, January 2014), http://reason.org/files/bus_rapid_transit_and_managed_lanes.pdf, p. 18.

[85] *What is Bus Rapid Transit?* (Tampa FL: Center for Urban Transit Research—National Bus Rapid Transit Institute, April 2014), http://www.nbrti.org.

[86] U.S. Department of Transportation, Federal Transit Administration, *Bus Rapid Transit,* (Washington, D.C.: U.S. DOT, 2014), http://www.fta.dot.gov/about/12351_4240.html

[87] U.S. Department of Transportation, Federal Transit Administration, *Characteristics of Bus Rapid Transit for Decision Makers 2009 Update*, (Washington. D.C.: U.S. DOT, 2009), http://www.fta.dot.gov/documents/CBRT_2009_Update.pdf

[88] CALSTART, *2008 Bus Rapid Transit Vehicle Demand & Systems Analysis," Report No. FTA-CA-26-7074-2008.1*, prepared for U.S. Department of Transportation, Federal Transit Administration, Washington, D.C., August 2008, pp. 5–8.

[89] Robert W. Poole, Jr. and Ted Balaker, *Virtual Exclusive Busways*, Policy Study 337 (Los Angeles, CA: Reason Foundation, September 2005), http://reason.org/files/9428e00f34f5a65fd35f5b6589f1a0dd.pdf, pp. 10–14.

[90] Ibid.

[91] Ginger Goodin et al., *KATY Freeway*: *An Evaluation of a Second Generation Managed Lanes Project*, (College Station, TX: Texas A&M Transportation Institute, September 2013), http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6688-1.pdf, pp. 141–147.

[92] U.S. Government Accountability Office, *Bus Rapid Transit: Projects Improve Transit Service and Can Contribute to Economic Development,* (Washington, D.C.: U.S. GAO, July 2012), http://www.gao.gov/assets/600/592973.pdf

93 Los Angeles Metro, *Metro Rapid*, http://www.metro.net/projects/rapid/, March 18, 2013.

94 Email from Rex Gephart of Los Angeles County Metropolitan Transportation Authority to Robert Poole, Aug. 25, 2008.

95 William Vincent and Lisa Callaghan, "A Preliminary Evaluation of the Metro Orange Line Bus Rapid Transit Project," paper presented at the 2007 Transportation Research Board Annual Meeting, Washington D.C., January 2007.

96 Regional Transit District-Denver, *Service—Light Rail Schedules*, http://www.rtd-denver.com/lightrail.shtml, March 4, 2014.

97 Regional Transit District-Denver, *What is FasTracks*, http://www.rtd-fastracks.com/main_26, March 4, 2014.

98 Regional Transit District-Denver, *Service—Schedules*, http://www.rtd-denver.com/Schedules.shtml, March 4, 2014.

99 Ibid.

100 Ibid.

101 Denver Region Council of Governments, waytogo, *Getting Around: Vanpool*, http://www.waytogo.org/getting-around/vanpool, June 12, 2014.

102 Colorado Department of Transportation, *Commuter Choices Vanpool*, http://www.coloradodot.info/programs/commuterchoices/vanpool-program.html, June 12, 2014.

103 Denver Regional Council of Governments, *Transit Element of the 2035 Metro Vision Regional Transportation Plan, Chapter 3 Inventory of Existing Services in the DRCOG Region*, (Denver, CO: June 2009), p. 31, http://www.drcog.org/agendas/ACTION%20DRAFT%202035%20Transit%20Element.pdf

104 Via Transit, *Paratransit,* http://viacolorado.org/services/paratransit/, March 4, 2014.

105 Colorado Department of Transportation, *Elected Officials Guide to The Colorado Department of Transportation*, 2013, p. 31.

106 Ibid, pp. 34–36.

107 Ibid.

108 State of Colorado, The Governor's Office of State Planning and Budgeting, *Public Safety: FY 2013–2014 Budget Request Reconciliation.*

109 David Hartgen, M. Gregory Fields, Baruch Feigenbaum, Robert Poole and Leonard Gilroy, *Transportation Priorities for North Carolina*, pp. 19–25 (Raleigh, North Carolina: John Locke Foundation, March 2013), http://reason.org/files/nc_transportation_full.pdf

110 U.S. Department of Energy, Energy Efficiency and Renewable Energy, *Compare Side by Side: Fuel Economy*, https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=33324

111 U.S. Department of Transportation Bureau of Transportation Statistics, Table 4-23: *Average Fuel Efficiency of U.S. Light Duty Vehicles*, (Washington, D.C.: USDOT, 2012), http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_23.html

[112] *Building a Better Gas Tax: How to Fix One of State Government's Least Sustainable Revenue Sources*, (Washington, D.C.: Institute on Taxation and Development Policy, 2011), http://www.itep.org/bettergastax/bettergastax.pdf

[113] Brian Weatherford, *Mileage-Based User Fees Winners and Losers: An Analysis of the Distributional Implications of Taxing Vehicle Miles Traveled, with Projections, 2010–2030*, (Santa Monica, CA: RAND Corporation, 2012), http://www.rand.org/pubs/rgs_dissertations/SD295.html

[114] Oregon Department of Transportation, *Oregon Mileage Fee Concept and Road User Fee Pilot Program Preliminary Findings February 2013*, http://www.oregon.gov/ODOT/HWY/RUFPP/docs/RUCPilotPrelimFind_Feb13.pdf

[115] Oregon Department of Transportation, *Oregon's Mileage Fee Concept and Road User Fee Pilot Program Final Report.*

[116] Colorado Department of Transportation, Applied Research and Innovation Branch, *Colorado Mileage-Based User Fee Study*, December 2013, http://www.coloradodot.info/programs/research/pdfs/2013/mbuf.pdf/at_download/file

[117] Oregon General Assembly, *Senate Bill 810*, 2013–2014 Session.

[118] Nevada Department of Transportation, Nevada *Vehicle Miles Travelled (VMT) Fee Study*, 2014, https://www.nevadadot.com/uploadedFiles/NDOT/Documents/VMT%20FEE%20STUDY%20Bk.pdf

[119] Wilbur Smith Associates, *Colorado Tolling Enterprise Preliminary Traffic and Revenue Study*, December 2004, pp. 5-1–5-19,
Denver Regional Council of Governments, *Metro Vision 2035 Appendix D*, 2011, https://www.drcog.org/documents/2035%20MVRTP%20-%20Appendix%202%20-%204%20-%20AdoptFeb11.pdf, pp. 1-9.

[120] Robert W. Poole, Jr., *A Managed Lanes Vision for Southeast Florida*, Policy Study 400, (Los Angeles, CA: Reason Foundation, March 2012), http://reason.org/files/mobility_southeast_florida.pdf.

[121] DRCOG, *2008 Annual Report on Traffic Congestion in the Denver Region*.

[122] Norman Mineta, "Importance of Reducing Congestion" speech before National Retail Federation, Washington, D.C., May 16, 2006.

[123] Wilbur Smith Associates, *Colorado Tolling Enterprise Preliminary Traffic and Revenue Study*.

[124] Robert W. Poole, Jr., "A Managed Lanes Vision for Southeast Florida," Miami: Florida Department of Transportation District 6, Contract No. C-8P07, January 2009.

[125] Denver Regional Council of Governments, *Metro Vision 2035 Appendix D.*

[126] Colorado Department of Transportation, *2008 Annual Report on Traffic Congestion in the Denver Region,* (Denver, CO 2009), p. 4.

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