



Appendix E. Scenario Comparison: Qualitative and Quantitative Evaluations

Contents

	Page No
Qualitative Scenario Evaluation	2
Scenario Descriptions.....	2
Scenario 1: Business as Usual. Fiscally Constrained Regional Transportation Plan	2
Scenario 2: 2030 Gridlock. Current trends continue undirected.....	3
Scenario 3: 2030 Forward. Coordinated response to technology improves mobility and protects community.....	4
Scenario 4: 2030 Bold. Unified, proactive approach leverages technology to achieve a new mobility vision for the region.....	6
Mile High Travelers Daily Travel Diaries	11
Daily Travel Diary: Dan.....	12
Daily Travel Diary: Maria	13
Daily Travel Diary: Carl.....	14
Daily Travel Diary: Tonya	15
Daily Travel Diary: Jordan	16
Quantitative Scenario Evaluation	17
Travel Demand Modeling Analysis	17
Modeling Stakeholder Meetings	17
Factors/Trends Modeled.....	19
On-Demand Mobility	20
Intelligent Transportation System (ITS)	20
Non-motorized Modes/Active Transportation	20
Autonomous Vehicles	21
Transit.....	21
Mobility Choice Blueprint Scenarios	21
Results	23
Overall Results.....	24
Recommendations and Next Steps	25
Economic Analysis	26
Productive Travel Time (Metric #1)	29
Cost of Congestion (Metric #4 and #5).....	30
Person Trip Time (Metric #2).....	30
Active Transport (Metric #7)	31
Safety Benefits.....	31
USDOT BCA Guidance:	32
Total Crashes Denver County—CDOT (2017).....	32
Accessibility and Economic Opportunity (Metric #3 and #6).....	33
Overall Summary.....	34

Tables

	Page No
Table E-1. Future Trends.....	Error! Bookmark not defined.
Table E-2. Detailed Assumptions	21
Table E-3. Regional Model Summaries	23
Table E-4. Scenario Model Performance Summary	28
Table E-5. Personal Travel Value of Time.....	30

Qualitative Scenario Evaluation

Emerging mobility technologies will force the Denver region, like all metro areas, to adapt to dramatic changes in the way people move. The specific impact of these technologies depends on the institutional infrastructure of the region. The scenarios for the Mobility Choice Blueprint imagine several possible futures depending on how the region's public agencies, nonprofits, and private organizations choose to alter that institutional infrastructure (or not).

All scenarios use the 2030 horizon year. As a result, the 2040 Fiscally Constrained Regional Transportation Plan (FCRTP) as currently planned have been scaled to 2030 for the purposes of this planning exercise.

Scenario Descriptions

Scenario 1: Business as Usual. Fiscally Constrained Regional Transportation Plan

This scenario offers a baseline for comparison. It assumes the Denver metro area is able to implement about half of the projects associated with the 2040 FCRTP as currently planned through the year 2030

Transportation investments total approximately \$50 billion between 2016 and 2030 (half of the 2040 FCRTP) from DRCOG, CDOT, RTD, and local municipalities. Roughly half of that money goes to maintenance of the existing system. The other half is used to add new road lane miles and bolster existing multimodal services. (Reference maps detailing these improvements can be found on pages E-8 through E-10).

Consistent with the FCRTP, this scenario assumes limited public agency intervention to deal with emerging mobility technologies, other than implementation of additional TSMO strategies at the site-specific and active management levels. Information will remain within silos. Changes in vehicle technology will not reduce congestion or increase safety. Private entities and new technologies will continue to operate much as they do today, with minor regulation and little integration with the overall transportation network.



Scenario 2: 2030 Gridlock. Current trends continue undirected

This scenario assumes the Denver metro area continues to work toward implementation of the 2040 FCRTTP without any change in the effort or investment applied to preparing for emerging mobility systems and technologies. The private sector is left largely alone to implement new services and facilities, which continue to develop and be adopted at an exponential pace.

In this scenario, the impacts of emerging mobility technologies are:

On-Demand Mobility

Ridehailing, car sharing, and microtransit (such as scooters and e-bikes) are provided by the private sector, without a consistent regulatory framework to encourage or restrict their use. Many sectors of the population adopt these new services in a piecemeal fashion. Without coordination across services and with the public transit system, new safety concerns emerge, and deadhead travel results in increased vehicle miles traveled (VMT). Ridehailing and vehicle-sharing companies do not share data with travelers or the public agencies related to travel patterns, alternatives, or utilization, creating inefficiencies of roadway use and increasing congestion.

Traveler Information and Payment

Private sector mobility information apps improve substantially, but remain uncoordinated in the competitive marketplace. Similar information tools provided by CDOT, RTD, and DRCOG are limited in comparison and not widely used. Private companies enter the mobile payment market, but cannot integrate all forms of mobility.

Transportation Systems Optimization

Though many automobiles are equipped with “connected” technologies, traffic management centers are only able to manually monitor the transportation network through video cameras and traditional vehicle detection systems. Traffic management centers do not taking advantage of the potential safety and congestion relief opportunities that could be implemented with use of the V2X information. DRCOG continues converting 1 or 2 corridors per year to coordinated traffic signal timing.

Freight and Delivery

Technological improvements that save money and improve efficiency through use of “big data” to improve logistics for the private sector are implemented without regulatory encouragement or restriction. Increases in online shopping, rapid delivery and drone delivery services add to safety concerns, as well as congestion impacts on roads, sidewalks, and in the air.

Vehicle Technology

Electric, connected and automated vehicle technologies improve dramatically. Battery efficiencies improve and production costs drop making electric vehicles affordable for most of the population resulting in a sharp drop in gas tax revenues and high demand for charging stations.

OEMs meet their commitment for all new vehicles to have connected technologies by 2021, resulting in 25% market penetration by 2030. The introduction of CV technologies provides some vehicle to vehicle safety benefits but without a network of improved roadways or infrastructure, new operating systems create unpredictability and therefore contribute to more congestion in a system still dominated by traditional vehicles.

Fully autonomous vehicles are available to fleet operators by 2025 and to the consumer by 2030. They are moderately priced; RTD and TNCs convert their fleets, and the affluent and middle class purchase driverless vehicles. RTD, NGO, and other fleet operators and ridehailing fleets see dramatic cost savings and increased service. However, without coordination across these platforms, VMT greatly increases. These factors also lead to a spike in ridehailing and to longer trips, reduced demand for parking and increased demand for curb space.



Scenario 3: 2030 Forward. Coordinated response to technology improves mobility and protects community

Moving forward with innovative program development, interagency coordination, and pilot testing and implementation, the Denver region adapts to emerging mobility technologies, maintaining community visions and improving mobility for all.

This scenario assumes the Denver metro area’s transportation agencies establish collaborative coordination and communication methods to react to emerging mobility technologies and to implement solutions that are affordable and accessible to all. The private sector offers input in the development of necessary regulatory changes, and is invited to participate in pilot projects and infrastructure improvements.

These efforts allow investments by leveraging opportunities afforded by new technologies to maintain existing funding streams. The focus of the investments is on coordination of activities, building on existing programs, and implementation of new technologies through pilot projects. Policy changes and improvements within the existing transportation system bolster the region’s connectivity and livability.

In this scenario, the impacts of emerging mobility technologies are:

On-Demand Mobility

As in the previous scenario, ridehailing, car sharing, and microtransit are provided by the private sector. However, new regulations enable the equitable use of ridehailing and ridesharing services by all residents

across the metro area. Public agencies (including RTD) establish partnerships with private entities to conduct microtransit pilots (and selectively implement services) that integrate with the transit network to increase ridership and reduce travel times and VMT.

Traveler Information and Payment

CDOT, RTD, and DRCOG encourage private sector innovation and coordinate their systems to provide intuitive, simple access to services, better real-time information. An integrated payment system across modes for public and private sector services allows for seamless trip planning. Through these coordinated efforts, agencies empower all travelers by maintaining an accessible, empathetic interface across services.

Transportation Systems Optimization

Traffic management centers are integrated and enhanced to take advantage of V2X. Traffic signals on a few major corridors are upgraded to provide automated traffic signal performance measures (ATPSMs). DRCOG leads the steady coordination of traffic signals across jurisdictions. RTD bus service benefits from corridor management on key highway connections that prioritizes high-occupancy vehicles. Smart parking systems encourage more efficient use of park and rides.

Freight and Delivery

New regulations encourage technological improvements that improve transportation network efficiency and safety. Coordinated efforts across agencies and with private companies improves the efficiency of automated package delivery while containing impacts to public spaces. Delivery parking pilot projects demonstrate opportunities to minimize conflicts and improve roadway operations.

Vehicle Technology

The region is better prepared to integrate the dramatic improvements to electric, connected and automated vehicle technologies. The sharp drop in gas tax revenues resulting from the accessibility of electric vehicles poses a risk to funding streams, but the region is working to offset the loss of revenue through new mechanisms enabled by emerging technologies.

Connected vehicles (which achieve 25% market penetration by 2030) integrate with the region's strategic V2X upgrades to reduce crashes and improve operations on major corridors.

As driverless vehicles enter the region, regulatory incentives such as zero occupant vehicle fees work together with coordination across agencies and private fleets to incentive shared vehicle use. This helps minimize the impacts of increased number and length of trips enabled by the ease and cost-effectiveness of driverless travel.



Scenario 4: 2030 Bold. Unified, proactive approach leverages technology to achieve a new mobility vision for the region

By taking a chance on bold programs that work to break down traditional silos, build new partnerships, and prioritize impactful and innovative applications of emerging technologies, the Denver region begins to reshape its mobility systems.

This scenario assumes the Denver region’s transportation agencies aggressively and proactively engage in meaningful collaboration to assess, invest in, and implement those emerging mobility technologies that will have the greatest impact on mobility in the region. Through coordinated regulation and incentive programs, the private sector is given a clearly-defined role and is actively encouraged to work alongside public agencies and other organizations to develop all aspects of an equitable, safe, and efficient transportation network.

Funding streams are modernized and restructured to increase technology investments, and new partnerships increase available resources. Coordinated efforts across agencies allow for sustainable infrastructure investments that contribute to a cohesive transportation system that efficiently connects people across the region.

In this scenario, the impacts of emerging mobility technologies are:

On-Demand Mobility

The private sector works with a regional mobility manager/integrator (such as RTD) to introduce and integrate new ridehailing, car sharing, and microtransit services. Regulatory encouragement and public subsidy incentivize ridehailing fleets to provide equitable service to all residents across the region as well as address safety concerns and congestion impacts of deadhead travel. An empowered partnership between public agencies and the private sector leverages on-demand mobility options to seek significant service improvements in both frequency and reach of mass-transit.

Traveler Information and Payment

A partnership among RTD, CDOT, DRCOG and private sector providers creates simpler access, more universal trip information, and single-point fare payment system that responds to the needs of all travelers. Payment systems are interoperable within the Denver region. Service providers present travelers with a wide range of options across modes. Because of their integration across the range of mobility systems, public agencies can prioritize equitable, comprehensive travel information.

Transportation Systems Optimization

A regional data platform enables coordination and consistency while minimizing security vulnerabilities. Traffic management centers optimize the use of data from V2X communications to proactively manage the transportation system. Vehicles are dynamically routed to optimize the regional transportation system, as well as individual travel. All traffic signals on critical corridors are upgraded to provide adaptive, smart signal technology (ATPSMs). RTD bus service benefits from smart arterial management that recognizes high-occupancy vehicles.

Freight and Delivery

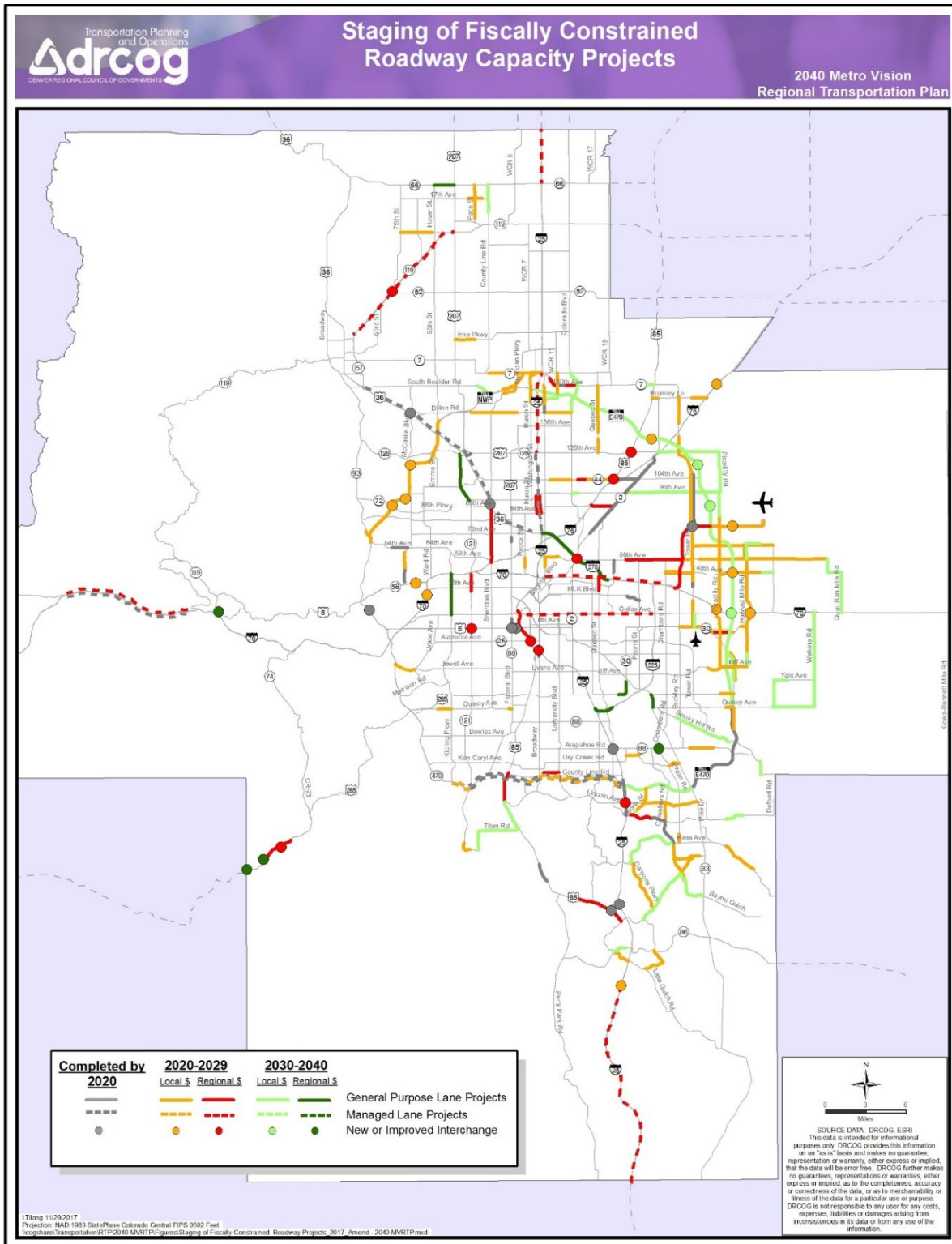
Private sector partners play an ongoing role in the creation of regulations to encourage and employ technological improvements that improve delivery efficiency and transportation network safety. Technological improvements and policies have enabled new modes and methods for personal package delivery that improve safety while reducing congestion.

Vehicle Technology

The region anticipates and adapts to the growth of electric, connected and automated vehicle technologies. A road usage charge program offsets lost revenues resulting from declining gas tax revenue.

The majority of all fleets (public and private) convert to electric vehicles, contributing to the goal of reducing emissions. Regional incentives speed up adoption of connected vehicles, and the significantly improved V2X capabilities of the region build on V2V systems to create a markedly safer roadway network in 2030.

Streamlined coordination with technology providers and a consistent regulatory environment enables the rapid adoption of driverless fleets across all sectors. Regulations and economics further encourage shared vehicle service membership and reduced private vehicle ownership.



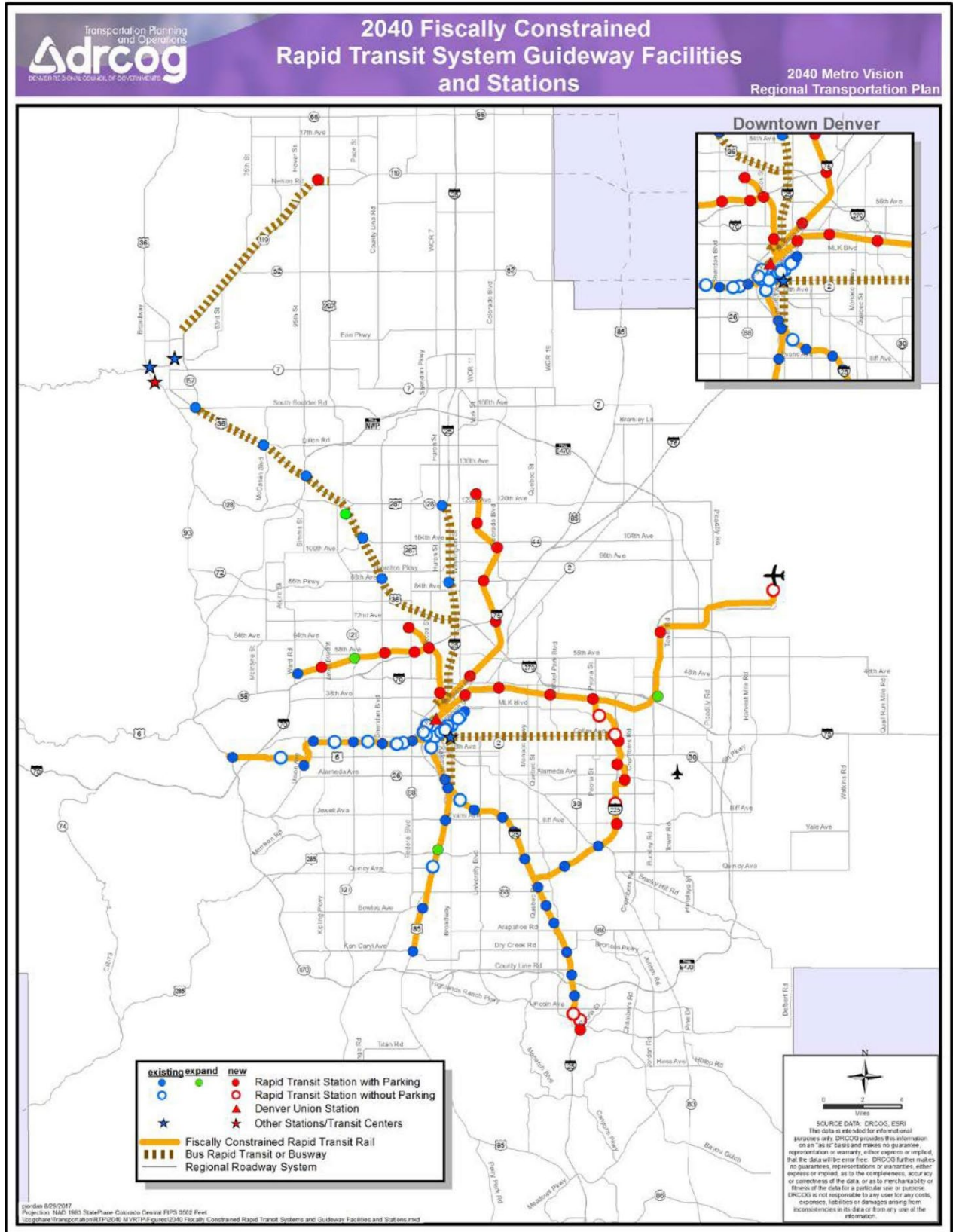


Table 6.1 2040 Fiscally Constrained RTP System Characteristics

SYSTEM CHARACTERISTIC	2015	2040 FISCALLY CONSTRAINED	2040 METRO VISION
REGIONAL ROADWAY LANE-MILES			
Freeways/Tollways	1,987	2,330	2,561
Major Regional Arterials	1,082	1,141	1,249
Principal Arterials	4,102	4,893	5,460
Total Regional Roadway System Lane Miles:	7,171	8,364	9,269
INTERCHANGES			
On Freeways/Tollways	223	236	245
On Major Regional Arterials, not Freeways	26	35	55
RAPID TRANSIT CENTERLINE MILES			
Light Rail	45	57	61
Commuter Rail	0	48	89
Intercity Passenger Rail	0	0	176
Bus Rapid Transit/Busway (exclusive right of way)	6	52	179
Total Rapid Transit System Miles:	51	157	505
TRANSIT SERVICE CHARACTERISTICS			
Fixed Route Fleet (including spares)	1,094	1,120	N/A
MallRide, MetroRide, and Call-n-Ride	103	106	N/A
ADA Paratransit	363	670	N/A
Light Rail Vehicles	172	201	N/A
Commuter Rail Vehicles	0	66	N/A
Bus Hours (millions in annual revenue service)	3.5	5.2	N/A
Light Rail Hours (millions in annual revenue service)	0.6	0.8	N/A
Commuter Rail Hours (millions in annual revenue service)	0	0.3	N/A
Total Revenue Hours	4.1	6.3	N/A
Bus Miles (millions in annual revenue service)	47	47	N/A
Light Rail Miles (millions in annual revenue service)	11	15	N/A
Commuter Rail Miles (millions in annual revenue service)	0	6	N/A
Total Revenue Miles	58	68	N/A
STATIONS: TRANSIT STATIONS AND PARK-N-RIDE LOTS (NUMBER OF PARKING SPACES)			
Rapid Transit Stations (with Parking)	25 (16,653)	48 (34,055)	N/A
Current Park-n-Rides that are Future Rapid Transit Stations with Parking	9 (5,970)	9 (8,110)	N/A
Rapid Transit Stations (without Parking)	22	27	N/A
Transit/Transfer Centers	4 (75)	4 (75)	N/A
RTD Park-n-Ride Lots	42 (8,362)	43 (7,114)	N/A
CDOT Carpool Lots	6 (926)	6 (926)	N/A
Total Parking Spaces	31,986	50,280	N/A

Mile High Travelers Daily Travel Diaries

Out of our community engagement process, five representative personas, labelled Mile High Travelers, emerged. These personas are not actual individuals, but they are inspired by real people. We use these personas to describe the mindsets and attitudes, behaviors, lifestyles, values, motivations, needs, and activities that relate to mobility in the Denver region.

These personas help us step into the diverse and multilayered daily lives of Denver region community members. They help us develop solutions to real everyday challenges based on current experiences with our transportation system and possible mobility choices in the future. The personas helped guide the Blueprint's scenario planning.

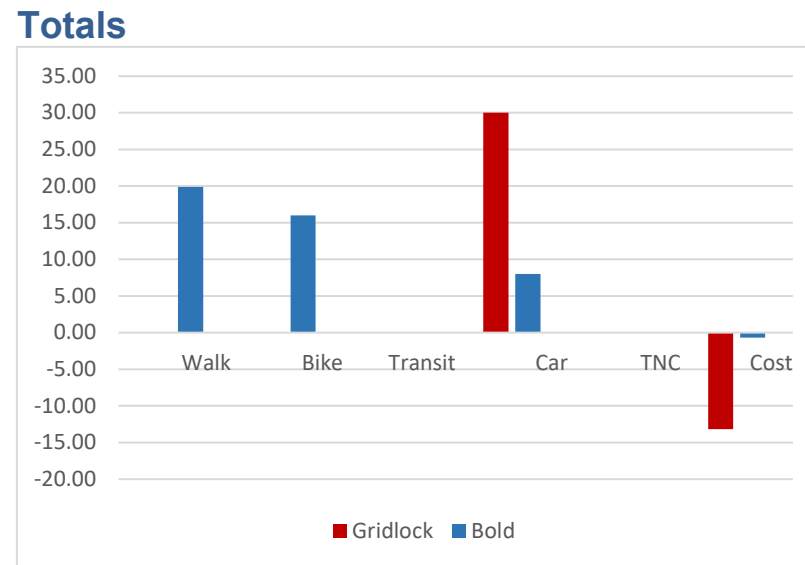
The following assumptions inform the daily trip calculations:

1. Travel Cost Assumptions
 - Cost of Driving, \$0.3715-\$0.5521/mile, "Your Driving Costs, 2017 Edition", AAA, (small sedan-SUV)
 - TNC Cost based on current fare for UBER, determined from App based on December 2018 non-surge rates.
 - MaaS costs modeled after Lyft 2018 Subscription Plan, 30 rides, \$199/month
 - Transit costs based on 2019 RTD fare schedule for 1-day Pass (Local 6.00, Regional 10.50)
 - RTD College pass is free (perceived) to the user
2. Walking benefit \$0.48/mile, VPTI "Evaluating Active Transport Benefits and Costs", Nov. 2018

Daily Travel Diary: Dan

Dan is a 75-year-old, semiretired professor who is married and lives in a south Denver neighborhood. Dan is a lifelong learner who loves to read about current affairs and technology. He is motivated to have a positive contribution to society, and prides himself on minimizing time in his car. It's important to him to stay socially and intellectually engaged with his community. He and his wife enjoy walking each day to stay fit and would like to bike more if the route were comfortable and safe.

Segment	To	Mode	Distance (miles)	Gridlock								Bold								Notes			
				Time (minutes)				Cost (\$)				Time (minutes)				Cost (\$)							
				Terminal 1	Journey	Terminal 2	Total	Parking Cost	Travel Cost*	Benefit	Net Cost	Terminal 1	Journey	Terminal 2	Total	Parking Cost	Travel Cost*	Benefit	Net Cost				
1	Home	Park/Coffee/Home	Walk										Walk	0.7				20			\$0.33		In Bold, adds a walk trip
2	Park	Coffee	Walk										Walk										
3	Coffee	Home	Walk										Walk										
4	Home	DU	Car	2.0		5	6	11	\$5.00	\$6.10			Bike	2.0		16		16					In Bold, shifts a car trip to bicycle ¹²
5	DU	Home	Car	2.0	6	5		11		\$1.10			Bike	2.0				0					
6	Home	Whole Foods	Car	0.9		4		4		\$0.50			Car	0.9		4		4		\$0.50			
7	Whole Foods	Home	Car	0.9		4		4		\$0.50			Car	0.9		4		4		\$0.50			
Totals				5.8				30	\$(5.00)	\$(8.19)			6.5					44		\$(0.99)	\$0.33	\$(0.66)	



	Gridlock	Bold
Walk	0.00	19.90
Bike	0.00	16.00
Transit	0.00	0.00
Car	30.00	8.00
TNC	0.00	0.00
Cost	\$(13.19)	\$(0.66)

Assumptions noted in daily travel diaries are described on page E-11. Daily travel breakdown values (time, cost) are presented and rounded in Chapter 3 (p. 29 to 33) of the Final Report.

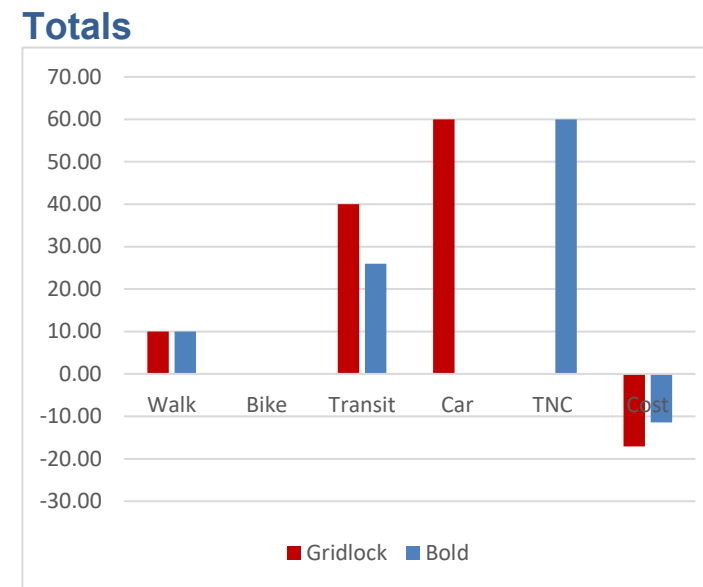
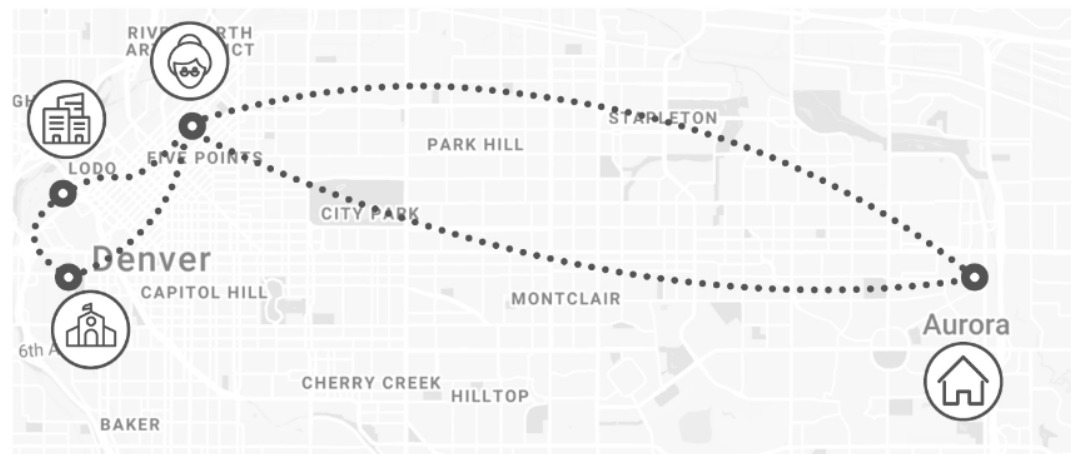
¹ DU Visitor Parking Cost, \$5.00

² Terminal times in Gridlock is the walk from DU parking to the campus building.

Daily Travel Diary: Maria

Maria is a 22-year-old mother who lives in Aurora. She is a student at Metro State University who also works part time at a restaurant in downtown Denver. Her pride and joy is her four-year old son Gabriel, who often stays with Maria’s mother at her home in the Five Points neighborhood. Maria bought a used car but struggles with payments and repairs. She typically uses her car to get to her mother’s house, but to avoid high parking costs in downtown Denver, she uses transit to get to school and work. She’s open to a Mobility as a Service program if it saves her time and money — her strongest mobility motivators.

Segment	From	To	Mode	Distance (miles)	Gridlock								Bold								Notes		
					Time (minutes)				Cost (\$)				Time (minutes)				Cost (\$)						
					Terminal 1	Journey	Terminal 2	Total	Parking Cost	Travel Cost*	Benefit	Net Cost	Terminal 1	Journey	Terminal 2	Total	Parking Cost	Travel Cost*	Benefit	Net Cost			
1																							
2	Home	Mother's Home	Car	13		30		30	\$8.00	\$4.81			TNC	13		30		30		\$6.00			In Bold, uses MaaS to ride in a TNC
3	Mother	School	Transit	2	4	16		20					Transit	2	1	12		13					Student pass for transit; AV shuttle faster than bus in Bold
4	School	Work	Walk	1.1		10		10		\$0.53			Walk	1.1		10		10		\$0.53			
5	Work	Mothers	Transit	2	4	16		20					Transit	2	1	12		13					AV shuttle faster than bus in Bold
6	Mothers	Home	Car	13		30		30		\$4.81			TNC	13		30		30		\$6.00			
Totals				31.1				110	\$(8.00)	\$(9.62)	\$0.53	\$(17.09)	31.1				96		96	\$(12.00)	\$0.53	\$(11.47)	



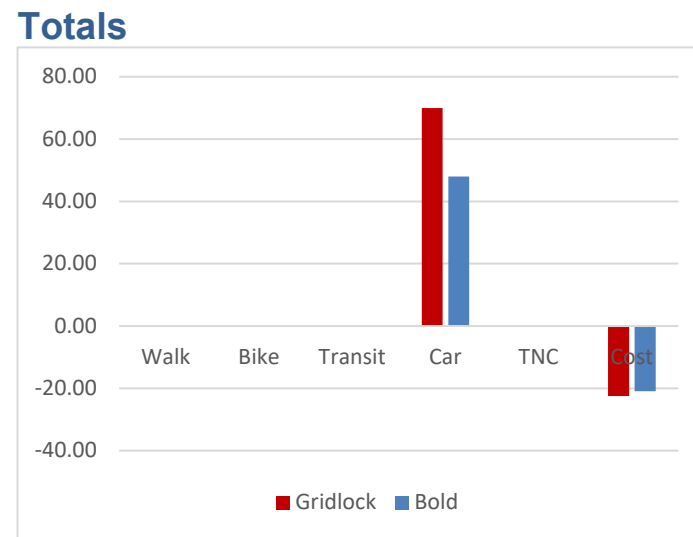
Mode	Gridlock	Bold
Walk	10.00	10.00
Bike	0.00	0.00
Transit	40.00	26.00
Car	60.00	0.00
TNC	0.00	60.00
Cost	\$(17.09)	\$(11.47)

Assumptions noted in daily travel diaries are described on page E-11. Daily travel breakdown values (time, cost) are presented and rounded in Chapter 3 (p. 29 to 33) of the Final Report.

Daily Travel Diary: Carl

Carl is middle-aged and married with a teenage son. His biggest concern is a recent health issue that is beginning to limit his mobility and forcing him to walk with a cane. He lives in Green Valley Ranch and works at Denver International Airport. His wife commutes from Green Valley Ranch to her job in Thornton. He has always had a car, ever since he got his license at age 16. He has never used public transportation. He "geeks out" on new technologies, such as autonomous vehicles, especially if they can provide him with new mobility opportunities as his physical capabilities deteriorate.

Segment	From	To	Mode	Distance (miles)	Gridlock								Bold								Notes		
					Time (minutes)				Cost (\$)				Time (minutes)				Cost (\$)						
					Terminal 1	Journey	Terminal 2	Total	Parking Cost	Travel Cost*	Benefit	Net Cost	Terminal 1	Journey	Terminal 2	Total	Parking Cost	Travel Cost*	Benefit	Net Cost			
1	Home	Work	Car	11.7		17	10	27	\$2.00	\$8.44	\$0.34		Car	11.7		17		17	\$1.00	\$7.44			Walks from Empl parking ³ . In Bold, Driverless drops him off at DEN and self-parks remotely
2	Work	Sports	Car	15.5	10	16		26		\$8.53	\$0.34		Car	11.7	3	18		21		\$6.44			In Gridlock, Walks to Empl parking
3	Sports	Restaurant	Car	4.2		8		8		\$2.31			TNC	4.2	0			0		\$5.00			In Bold, uses TNC ⁴ program to send kid to sports
4	Restaurant	Home	Car	3.4		9		9		\$1.87			Car	2		10		10		\$1.10			In Bold, drives between home & a restaurant
Totals				34.8				70	\$(2.00)	\$(21.14)	\$0.67	\$(22.47)		29.6				48	\$(1.00)	\$(19.97)		\$(20.97)	



	Gridlock	Bold
Walk	0.00	0.00
Bike	0.00	0.00
Transit	0.00	0.00
Car	70.00	48.00
TNC	0.00	0.00
Cost	\$(22.47)	\$(20.97)

Assumptions noted in daily travel diaries are described on page E-11. Daily travel breakdown values (time, cost) are presented and rounded in Chapter 3 (p. 29 to 33) of the Final Report.

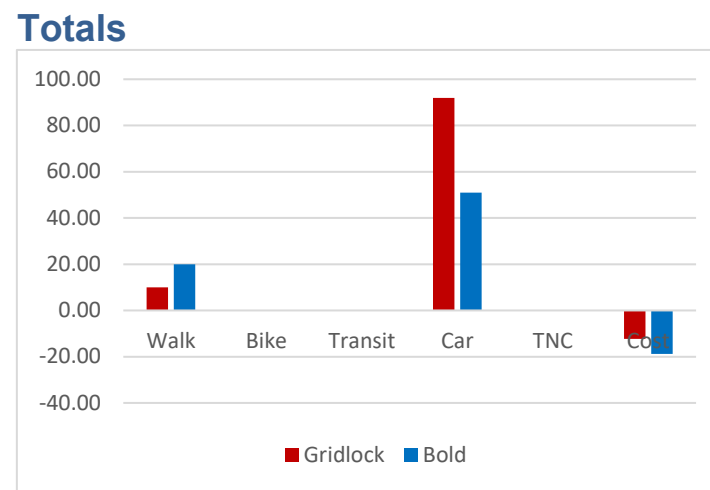
³ DIA Employee parking 2018 \$36/month. Assume 1/2 cost for remote parking by self-driving cars

⁴ TNC/MaaS subscription service for kids (HopSkipDrive in Denver used to estimate cost per family)

Daily Travel Diary: Tonya

Tonya is a 34-year-old Colorado native who lives in Boulder and is married with 3 young children. Her husband works at the Federal Center in Lakewood. Her week is packed with juggling errands, home chores, managing kids' schedules, and trying to find time to stay connected with friends. She has always loved the mountains and most enjoys the times when she and her family are skiing, hiking, and maximizing their weekends in the Rockies.

Segment	From	To	Mode	Distance (miles)	Gridlock								Bold								Notes		
					Time (minutes)				Cost (\$)				Time (minutes)				Cost (\$)						
					Terminal 1	Journey	Terminal 2	Total	Parking Cost	Travel Cost*	Benefit	Net Cost	Terminal 1	Journey	Terminal 2	Total	Parking Cost	Travel Cost*	Benefit	Net Cost			
1	Home	Mid School	Car	2		10		10		\$1.10			Car	2		10		10		\$1.10			
2	Mid School	Post Office	Car	0.5		5		5		\$0.28			Car	0.5		5		5		\$0.28			
3	Post Office	Home	Car	2		10		10		\$1.10			Car	2		10		10		\$1.10			
4	Home	Elementary	Car	0.5		2		2		\$0.28			Walk	1		10		10			\$0.48		In Bold, walks to/from Elementary school
5	Elementary	Pilates	Car	2		6		6		\$1.10			Car	2		6		6		\$1.10			
6	Pilates	Grocery	Car	2		6		6		\$1.10						0		0		\$2.00			In Bold, replaces car trip with drone delivery
7	Grocery	Home	Car	1.2		5		5		\$0.66						0		0					
8	Home	Mid School	Car	2		10		10		\$1.10			Car	2		10		10		\$1.10			
9	Mid School	Home	Car	2		10		10		\$1.10			Car	2		10		10		\$1.10			
10	Home	Elementary	Walk	0.5		5		5			\$0.24		Walk	0.5		5		5			\$0.24		
11	Elementary	Home	Walk	0.5		5		5			\$0.24		Walk	0.5		5		5			\$0.24		
12	Home	Gymnastics	Car	4.5		14		14		\$2.48			TNC	4.5				0		\$6.00			In Bold, uses TNC program to send kid to sports
13	Gymnastics	Home	Car	4.5		14		14		\$2.48			TNC	4.5				0		\$6.00			
Totals				24.2				102		\$(12.76)	\$0.48	\$(12.28)	21.5					71		\$(19.78)	\$0.96	\$(18.82)	



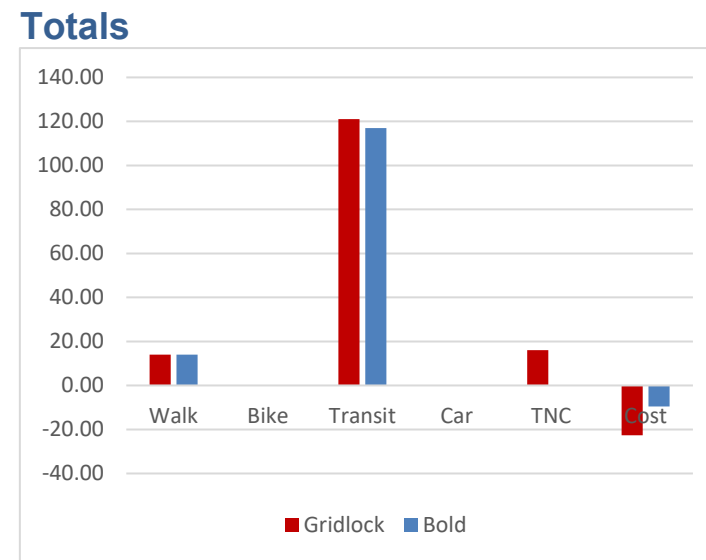
Mode	Gridlock	Bold
Walk	10.00	20.00
Bike	0.00	0.00
Transit	0.00	0.00
Car	92.00	51.00
TNC	0.00	0.00
Cost	\$(12.28)	\$(18.82)

Assumptions noted in daily travel diaries are described on page E-11. Daily travel breakdown values (time, cost) are presented and rounded in Chapter 3 (p. 29 to 33) of the Final Report.

Daily Travel Diary: Jordan

Jordan is a 29-year-old who recently moved to Denver from the Bay Area. He works for a tech company downtown, but really wanted to own his own home and have a yard. Central Denver is not affordable for him, so he bought a home in Parker He commutes four days a week and works from home on Fridays. He moved here for the renowned Colorado lifestyle, but he has plenty of job opportunities in whatever major metropolitan area he'd like to live. He's happy to take transit as long as it's comfortable and easy. He likes to head to the mountains for fun adventures on the weekend with friends, but doesn't plan to buy his own car.

Segment	From	To	Mode	Distance (miles)	Gridlock							Bold							Notes					
					Time (minutes)				Cost (\$)			Mode	Distance (miles)	Time (minutes)				Cost (\$)						
					Terminal 1	Journey	Terminal 2	Total	Parking Cost	Travel Cost*	Benefit			Net Cost	Terminal 1	Journey	Terminal 2	Total		Parking Cost	Travel Cost*	Benefit	Net Cost	
1	Home	Bus Stop	Walk	0.2		4		4			\$0.10		Walk	0.2		4		4			\$0.10			
2	Bus Stop	RTD Station	Transit	6.9	7	20		27					Transit	6.9	1	14		15						In Bold uses app to flag Microtransit, cost included in RTD Day pass
3	RTD Station	Downtown	Transit	20	4	39	2	45		\$10.00			Transit	20	4	37	2	43		\$10.00				LRT trip. In Bold, LRT benefits from TSP downtown
4	Office	Lunch Meeting	Walk	0.5		10		10			\$0.24		Walk	0.5		10		10			\$0.24			
5	Office	Restaurant	Transit	12	2	39	8	49		\$0.00			Transit	12	2	32	4	38						LRT trip, cost included in Day Pass
6	Restaurant	Home	TNC	8.7	2	14		16		\$13.00			Transit	2	3	3		6						In Bold, uses app to continue to station with Microtransit
7	RTD Station	Bus Stop											Transit	6.9	2	13		15						In Bold uses app to flag Microtransit
8	Bus Stop	Home											Walk	0.2		4					\$0.10			
Totals				48.3				151		\$ (23.00)	\$0.34	\$ (22.66)		48.7				131		\$ (10.00)	\$ 0.43	\$ (9.57)		



	Gridlock	Bold
Walk	14.00	14.00
Bike	0.00	0.00
Transit	121.00	117.00
Car	0.00	0.00
TNC	16.00	0.00
Cost	\$ (22.66)	\$ (9.57)

Assumptions noted in daily travel diaries are described on page E-11. Daily travel breakdown values (time, cost) are presented and rounded in Chapter 3 (p. 29 to 33) of the Final Report.

Quantitative Scenario Evaluation

Travel Demand Modeling Analysis

The Mobility Choice Blueprint used the Denver Regional Council of Government’s (DRCOG) Focus 2.1 Activity Based Model (ABM) system. Forecasts were developed using 2030 as the horizon year.

Modeling Stakeholder Meetings

The HDR team convened several meetings to discuss a proposed modeling methodology for the Mobility Blueprint project. Attendees included modelers and transportation planning professionals from the Regional Transportation District (RTD), Denver Regional Council of Governments (DRCOG), the Colorado Department of Transportation (CDOT), and the National Renewable Energy Laboratory (NREL). In the first meeting, the group discussed future trends that could influence travel behavior and how these factors could be addressed using a regional travel model. Table E-1 list the future trends that were discussed.

Trend	Change Type	How do we address using the Focus model?
Aging Population	Demographic	<ul style="list-style-type: none"> • UrbanSIM/PopGen already assume a higher percentage of 65+ year old in the future. • We may want to consider raising retirement age from 65 to 70.
Connected vehicles (CV)	Technology	<ul style="list-style-type: none"> • Increase capacity on freeways and major arterials. • Decrease auto operating costs. • Reduce or eliminate parking costs. • Reduce terminal times. • The model adjustments above are reasonable and can be considered singly or together to reflect increased adoption of connected vehicles. • We may want to consider waiting for CS to finish their CAV adjustments in the statewide model, if the schedule allows.
Automated vehicles (AV)	Technology	<ul style="list-style-type: none"> • Increase capacity on freeways and major arterials. • Decrease auto operating costs. • Reduce or eliminate parking costs. • Reduce terminal times. • The model adjustments above are reasonable and can be considered singly or together to reflect increased adoption of automated vehicles. • For modeling assumptions, it is best to keep adoption rates conservative • Millennials are expected to be early adopters • The trend needs to account for private ownership (by high income people) and fleet ownership

Appendix E. Scenario Comparison: Qualitative and Quantitative Evaluations

Trend	Change Type	How do we address using the Focus model?
Millennial behavior	Demographic	<ul style="list-style-type: none"> •
Workforce automation	Technology	<ul style="list-style-type: none"> • Some discussion about universal basic income and whether this would free up time for population to make more non-work trips; an input to Focus is the number of unemployed • The effect on transportation behavior isn't clear • If we wanted to represent the lower quality of jobs that have been created after the recession and want to indicate this trend continues, we could change the employment percentage mix from fewer basic/service jobs to more retail. • Multiple part time jobs aren't directly represented in Focus • This trend may not be as important as others to model
Urban living	Shifting user preference	<ul style="list-style-type: none"> • DRCOG already simulates more urban development in future land use scenarios, where multiple dense communities exist (free-standing cities); we may consider a future where development is more decentralized than the status quo; younger adults moving to the suburbs for more affordable living. • Since 2030 is the horizon year for this study, it is too soon to expect changes beyond DRCOGs' current assumptions
Fleet ownership	Shifting user preference	<ul style="list-style-type: none"> • In auto availability model, we could reduce the constant on a higher number of vehicles • MaaS model
TDM	Improved travel options	<ul style="list-style-type: none"> • DRCOG has tried addressing in Metrovision; population making few work tours
E-commerce	Shifting user preference	<ul style="list-style-type: none"> • This could have a significant impact (e.g. decrease) on shopping trips; but with a material increase in fleet/trucks used for delivery. • Current effect on VMT is relatively small, due to concentrated delivery areas • Drones could also deliver packages
Enhanced transit service	Improved travel options	<ul style="list-style-type: none"> • May want to consider free/reduced fares to make transit more attractive •
Enhanced active transportation facilities	Improved travel options	<ul style="list-style-type: none"> • Potentially increase bike speeds • Not easily discernible in model

Trend	Change Type	How do we address using the Focus model?
Shared mobility	Improved travel options	<ul style="list-style-type: none"> • Increase vehicle availability • Relationship with low auto ownership isn't clear • In urban areas may replace Walk/Bike/Transit trips; in Suburban may help with First/Last mile

Trying to adapt the DRCOG Focus model to account for these factors involved two categories of changes: changing model parameters or changing model inputs. It is important to note that for many of these trends, there were no model inputs that can be directly adjusted. Instead, using available literature and research on the potential impacts of these trends, procedures were developed to simulate the impacts of these factors on regional travel.

During the project, the project team reconvened the modeling group to share the initial results. The modeling group identified some issues and recommended alternative ways to model some of the future trends. A summary of comments is described

1. Why did HDR only decrease the coefficients (e.g. in the auto availability model) on households with elderly (75+) and driving age children? HDR wanted to provide mobility to households with limited mobility. However, one would also expect households with autos to also use ride-hailing services.
2. ITS improvements might be better simulated by increasing capacity versus free-flow speeds. This change may be easier to explain to non-modelers than increasing the speed limit.
3. DRCOG suggested model results should be presented using ranges, which would clearly illustrate the uncertainty with some of these factors.
4. The regional VMT and VHT change for ITS on Wadsworth seems high. Examine the convergence report. May need to run additional iterations of assignment to get more stable results.
5. For Level 5 AVs, one may want to consider changing the VOT instead of decreasing drive-along skim matrix IVTT.
6. For transit electronic fare payment, one may want to consider reducing the transit fare coefficient. This would be similar toll users who pay using EZ pass vs. cash.
7. For micro-transit (or first/last mile service), one may want to investigate having service coded directly from a zone centroid to the rail station.

Factors/Trends Modeled

The Mobility Choice Blueprint used the Denver Regional Council of Government's (DRCOG) Focus 2.1 Activity Based Model (ABM) system. Forecasts were developed using 2030 as the horizon year. In all regional models, there are inputs that can be varied. These inputs include zonal demographic data such as population and employment which generate the travel demand in a model. On the supply side, network assumptions may be altered such as number of lanes, lane capacity, and service frequencies or fares for public transit. Other inputs that may be changed include parking costs and terminal times which affect the attractiveness of a zone for travel. With many of the trends or emerging factors under consideration, there is no direct input that can be changed to assess their impacts on travel behavior.

Therefore, our approach is to adjust model parameters or constants is to approximate the impact of the trends. The actual effort involved changing the value of these model parameters incrementally and rerunning the full Focus model or parts of the model system to assess each factor's impact. The sections below describe each trend that was considered and our analytical approach using the Focus model.

On-Demand Mobility

Ride hailing companies, like Uber and Lyft, have transformed mobility options for the public. At least in urban areas, these services provide a new alternative to driving alone, car-pooling, public transportation, and even walking or riding a bicycle. Whether these types of service become omnipresent or they ultimately morph into something different, the project team assumed this type of mobility service would continue to capture market share in the future.

The ideal way to include ride-hailing or mobility as a service (MaaS) in a regional travel model and assess the impacts would be to include this travel choice in the mode choice model much like including public transportation or taxis. Given resource limitations, the project team decided to adjust model parameters that would provide greater mobility to certain households. The argument is that ride-hailing provides individual more mobility options, especially those households without automobiles (0-car households). This included 0-car households with elderly (75+ years) and with driving age children who we believe would be most impacted by ride-hailing. Therefore, we decreased the auto constant on 0-car households with elderly adults and with driving age children. This would permit these households to travel on other modes and not be restricted to using public transportation. After further discussions with the modeling group, it was decided that ride-hailing would provide greater accessibility to all households. This adjustment was made geographically by decreasing the 0-car auto constant by county. Ride-sharing was also incorporated in the Mobility Choice scenarios. There is an overlap with ride-hailing except the "ride" is shared with other passengers. Besides adjusting the zero-car household auto constant, 2 percent of the drive-alone vehicle trips were moved to shared-ride 2 and shared-ride 3+ vehicle trip matrices before the final traffic assignment.

After ride-hailing vehicles drop off their passengers, they often drive around until finding other passengers. This period of driving without passengers is referred to as a "deadheading". Current research suggests that ride-hailing in its current business model adds considerable vehicles miles traveled (VMT) to the roadway network. To account for this deadhead VMT, 3 percent of the drive-alone vehicle trips were transposed and added to matrix before the final traffic assignment.

Intelligent Transportation System (ITS)

ITS technology was assumed for multiple smart corridors throughout the Denver metro region. These corridors would have the latest ITS technology and would be able to communicate with connected vehicles to ensure smooth, optimized traffic flow. This adjustment in the ABM was made by changing the free-flow speeds in the corridors by 5 percent. Smart corridors were assumed on Arapahoe between I-25 and Parker Road; Colfax between Speer Boulevard and I-225; Federal between I-76 and 6th Avenue; Havana between E. 6th Avenue and Parker Road; Wadsworth between US 36 and C-470; and US 287.

Non-motorized Modes/Active Transportation

Non-motorized modes such as bike-sharing programs and enhanced facilities for non-motorized modes have made these modes increasingly attractive for travelers. The recent introduction of electric scooters has also been embraced. While the Focus ABM does account for walking and bicycling, it does not

explicitly account for travel made by scooters. Moreover, there are no direct model inputs that can be adjusted to reflect increasing bike-sharing opportunities and enhanced non-motorized facilities. By 2030, the project team contends that non-motorized modes use will increase. To make walking more attractive in the ABM, the tour mode choice walk constant was increased by 8 minutes. Similarly, bicycling was made more attractive in the tour mode choice by increasing the constant by 1 mile. Constants in mode choice models are used to represent unmeasured or unexplained factors that may affect a traveler’s choice. Increasing the value of a constant has the impact of making the mode more attractive.

Autonomous Vehicles

No recent trend or technology has captured the public’s imagination more than connected and autonomous vehicle (CAV) technology. For the Mobility Choice Blueprint scenarios, HDR assumed CAVs will be available to consumer as private vehicles. Initially, the cost of CAVs will be high with only higher income households becoming the first adopters of this technology and buying these vehicles. To simulate this trend, we have assumed more CAVs operating in the system will be able to exploit their inherent efficiencies such as faster speeds, shorter headways, and more predictable driving behavior. The net benefit on the transportation system will be higher capacities on roadways with the act of driving becoming perceived as less onerous as drivers are able to cede control and perform other tasks while traveling. Model adjustments to represent CAVs were made by increasing capacity by various percentages to represent greater adoption levels of CAVs. To make driving less onerous, the in-vehicle travel time weight (IVTT) was reduced in highway skimming and assignment process.

Transit

Several policies in transit were modeled to represents changes in technology and provision of service. Convenient fare payment was modeled by decreasing dwell time by 25 percent to represent the widespread use of electronic fare media and the benefits from this technology. One area that has been difficult for transit agencies is providing first and last mile service. Improvements in first and last mile service was modeled by changing the mode of feeder bus service (from end of line rail stations to destinations) to a mall shuttle. The mall shuttle mode (mode 4) is a free fare in the Focus ABM. Finally, active government policies representing increased transit funding was represented by doubling service levels on existing and planned feeder bus service. For example, a 30-minute peak period headway on a bus route was improved to 15-minutes.

Mobility Choice Blueprint Scenarios

Three scenarios were assumed for the Mobility Choice Blueprint. They include

- 2030 Gridlock (low)
- 2030 Forward (medium)
- 2030 Bold (high)

For modeling purposes, the scenarios represent low, medium, and high values for each of the trends. Table E-2 lists the detailed assumptions made for each of the factors/trends with each scenario

Table E-1. Detailed Assumptions

Scenario	Trend	Model Adjustment
2030 Baseline	Base condition	• No adjustments. DRCOG Focus model results as is.

Table E-1. Detailed Assumptions

Scenario	Trend	Model Adjustment
2030 Gridlock	Ride-hailing, Ride sharing, and ITS	<ul style="list-style-type: none"> • Denver zero auto constant -1, • 3% transposed VMT added in Denver AT 1-3 • 2% of DA trips shifted to SR2 • Wadsworth corridor (5% Cap Improvements)
2030 Forward	Ride-hailing, Ride sharing, ITS, Active Transportation, and Transit	<ul style="list-style-type: none"> • Decreased zero autos constants by 1 for Adams, Arapahoe, Boulder, Denver, Douglas, Jefferson counties • Added 6% of trips transposed for TAZ in area types 1-4 • Moved 5% of trips from drive alone to shared ride 2, factored for vehicle occupancy • Increased walk mode choice constants by 2.5 minutes • Increased bike mode constants by 3 miles, except for work-based-subtours increased by 0.5 miles because of high distance coefficient. • Increased capacity by 5% for Wadsworth, Federal, and Colfax corridors • Increased highway (facility type 1) capacity by 15% • Decreased drive alone IVTT skim matrix by 2% • Decreased dwell times by 25% for modes that collect fareSMpar901 • Changed routes 35,130,131,133,135,139 to mall shuttle mode serving LRT H
2030 Bold	Ride-hailing, Ride sharing, ITS, Active Transportation, and Transit	<ul style="list-style-type: none"> • Decreased zero autos constants by 1 for all counties • Added 10% of trips transposed for TAZ in all area types • Moved 10% of trips from drive alone to shared ride 2, factored for vehicle occupancy • Increased walk mode choice constants by 5 minutes • Increased bike mode constants by 5 miles, except for work-based-subtours increased by 0.5 miles because of high distance coefficient. • Increased capacity by 5% for Wadsworth, Federal, US-287, Havana, Arapahoe Rd, and Colfax corridors • Increased highway (facility type 1) capacity by 25% • Decreased drive alone IVTT skim matrix by 3% • Decreased dwell times by 25% for modes that collect fare • Changed routes 14,17,26,29,30,33,35,45,54,59,67,77,72f,80,89,112,128,130,131,133,135,139,401,403,410,411 to mall shuttle mode > Reduce headways by 50% on specified routes

Results

Before combining the trends in the modeling of Mobility Choice Blueprint scenarios, each trend was evaluated independently to assess the impact of a range of values and the resulting effect on the performance of the transportation system. While these results from the independent testing have not been included here, they are available for further analysis. In general, the values that were tested for each trend and the model results appeared reasonable. Thus, changes in capacity for a roadway, for example, resulted in greater travel demand that was generally proportional to the change in value.

It is worthwhile noting that when combining the trends in the scenario model runs, the impacts from each trend may be lost as the resulting changes may be offset or even diminish when testing them together. For example, while improving transit service normally attracts ridership, incorporating this change along with adjustments to the non-motorized constant may attract short-transit trips resulting in decreases in overall transit ridership.

Table E-3 provides regional model summaries for the scenarios that were evaluated. DRCOG's 2030 model results have been provided as a baseline to allow readers to see the impact made each evaluated scenario.

Table E-2. Regional Model Summaries

Model Metrics	2030 Baseline	2030 Gridlock	2030 Forward	2030 Bold
Mode Bike Trips	166,948	164,440	184,949	201,432
Mode Drive Alone Trips	6,595,244	6,633,308	6,602,269	6,490,940
Mode Drive to Transit Trips	105,382	103,681	104,325	105,867
Mode School Bus Trips	254,798	255,217	253,214	252,600
Mode Shared Ride 2 Trips	3,303,780	3,316,103	3,276,890	3,231,693
Mode Shared Ride 3+ Trips	2,443,865	2,454,067	2,433,544	2,404,776
Mode Walk to Transit Trips	269,480	251,219	232,677	236,259
Mode Walk Trips	1,313,670	1,292,533	1,396,491	1,566,467
Peak Average Vehicle Speed	30.1	30.1	30.5	31.1
Regional Household Autos	2,979,011	3,001,264	3,034,842	3,034,690
Severely Congested Lane Miles	2,310	2,435	2,410	2,350
Total Households	1,651,234	1,651,234	1,651,234	1,651,234
Total Person Tours	5,385,296	5,388,605	5,398,381	5,405,735
Total Person Trip Distance	83,619,353	83,832,753	83,679,047	82,701,246
Total Person Trip Time	177,895,823	179,322,842	174,660,567	171,981,259
Total Person Trips	14,453,167	14,470,568	14,484,359	14,490,034
Total Persons	3,952,209	3,952,209	3,952,209	3,952,209
Total Vehicle Trips	12,448,271	12,507,159	12,417,028	12,233,276
Total VHD	485,283	536,955	539,817	532,629
Total VHT	2,666,644	2,831,655	2,899,323	2,930,355
Total VMT	91,644,063	97,935,903	100,918,042	103,308,627
Work Person Trips	3,442,271	3,441,240	3,450,666	3,449,389

Table E-2. Regional Model Summaries

Model Metrics	2030 Baseline	2030 Gridlock	2030 Forward	2030 Bold
Zero Car Households	90,247	71,383	44,320	43,796
CBD Walk Trips	73,433	73,170	77,698	82,168
Fringe Walk Trips	115,683	113,933	124,427	137,430
Urban Walk Trips	263,886	253,394	275,439	309,721
CDB Bike Trips	7,419	7,566	8,528	9,292
Fringe Bike Trips	13,771	13,472	15,441	16,911
Urban Bike Trips	45,334	43,797	49,600	53,800
CBD Walk Trips Percent	27.0%	27.5%	29.1%	30.7%
Fringe Walk Trips Percent	18.8%	18.6%	20.2%	22.2%
Urban Walk Trips Percent	10.1%	9.6%	10.5%	11.8%
CDB Bike Trips Percent	2.7%	2.8%	3.2%	3.5%
Fringe Bike Trips Percent	2.2%	2.2%	2.5%	2.7%
Urban Bike Trips Percent	1.7%	1.7%	1.9%	2.0%
NW Mode Bike Tours	39,425	38,244	45,951	50,674
NW Mode Drive Alone Tours	879,728	889,366	878,124	851,411
NW Mode Drive to Transit Tours	30,893	30,620	30,916	31,034
NW Mode School Bus Tours	150,391	151,103	150,732	150,306
NW Mode Shared Ride 2 Tours	1,117,932	1,124,261	1,111,445	1,093,862
NW Mode Shared Ride 3+ Tours	1,107,354	1,111,074	1,102,945	1,088,753
NW Mode Walk Tours	371,510	365,071	405,179	467,449
NW Mode Walk to Transit Tours	83,736	75,113	64,951	64,060
All-day Average Vehicle Speed	34.4	34.6	34.8	35.255
Work Mode Bike Trips	49,175	48,803	56,138	63,104
Work Mode Drive Alone Trips	2,833,939	2,840,555	2,846,964	2,825,091
Work Mode Drive to Transit Trips	75,692	74,263	74,437	75,784
Work Mode School Bus Trips	5,864	5,606	5,163	5,344
Work Mode Shared Ride 2 Trips	123,939	124,012	120,447	120,798
Work Mode Shared Ride 3+ Trips	86,155	86,459	85,303	84,666
Work Mode Walk Trips	89,463	89,643	95,060	104,184
Work Mode Walk to Transit Trips	136,577	131,082	125,802	129,366
Off-peak Average Vehicle Speed	38.5	38.8	38.8	39.2

Overall Results

1. The change in zero car households regionwide represents increased mobility provided by ride-hailing and ridesharing services.
2. Overall, the impact of all the modeled trends, results in more VMT and higher VHT. However, the average speeds systemwide increases.

Appendix E. Scenario Comparison: Qualitative and Quantitative Evaluations

3. Travel demand increases on major corridors due to ITS operations improvements; average speeds on these corridors improve slightly, especially in the peak periods.
4. Effective micro-transit, represented as free shuttles and with improved headways, boosts overall transit system ridership.
5. Electronic fare media, represented as reduced dwell times, had no impact on transit ridership. Either the value used was too small an improvement over the base condition, or the dwell time makes up a relatively small percentage of the transit utility resulting in little impact on overall route ridership.
6. Ride-hailing and ride-sharing provides more mobility options to elderly, low-income, and teenagers; however, VMT increases as a result of deadheading, or vehicles searching for the next paying customer.
7. Enhanced non-motorized modes, via bike-sharing, improved bicycle/pedestrian facilities and other modal options, increase non-motorized mode share. In some cases, at the expense of short trips made using transit.

Recommendations and Next Steps

Based on our experience with this project, we have the following recommendations to DRCOG staff for consideration:

1. In the short-term, formalize or provide guidelines on how DRCOG staff account for testing emerging trends. The Mobility Choice Blueprint was not a modeling project. The model was applied to test how current configuration might forecast future operations. Model results were used to potentially illustrate how certain factors may influence travel in the region in the near term. Formal guidance would allow other studies and member governments interested in scenario planning to focus less on the modeling process and more on running various scenarios and analyzing the rich data that are available from model results.
2. Continue to discuss these topics in various venues such as ITS meetings or regular meetings of the DRCOG model user's group. It may be that the "hype" of technology falters as adoption is much slower than envisioned or new travel behavior patterns develop. Therefore, we would recommend future exchanges between DRCOG staff and the modeling community take into account all relevant trends and how they may be modeled for scenario testing, to focus beyond just current hot topics like CAVs. System optimization is one critical area where modeling results can identify issues and benefits to justify investments.
3. In the longer term, we suggest DRCOG incorporate some of the model improvements that CDOT is currently undertaking on the Statewide model to simulate CAVs and transportation network companies (TNC). Since the Statewide model shares the same code base as DRCOG's Focus ABM, incorporating CDOT's changes is probably easier than starting from a blank slate. The project team, however, recognizes that DRCOG staff have obligations of running the ABM for the Regional Transportation Plan, air quality conformity, and other long-range planning activities. It is likely that evolving model structure to account for emerging technologies would require a parallel process to other required modeling work. Thus, any of the structural changes to the Focus ABM probably need to be weighed against the resources available.

Economic Analysis

The MCB final report summary compares and contrasts the outcomes of two mobility scenarios—Mobility Gridlock and Mobility Bold. Mobility Gridlock (Trend) describes a Year 2030 horizon where technology and new mobility services are neither managed nor incentivized through policy or special infrastructure provisions. Mobility Bold represents an actively managed scenario where policies, pilot projects,

partnerships and regional coordination are leveraged to maximize the expected benefits of technology and new mobility services towards a more efficient and equitable transport system. The Baseline Scenario serves as a comparative benchmark for the Mobility Gridlock scenario.

The MCB team used the DRCOG regional travel demand model (FOCUS) to gain insights of the impacts that new mobility technology could have on travelers and the regional economy by presenting an economic “snapshot” that considers user benefits and changes in spending and spending power that may be generated. The model-derived output of regional performance metrics for the Baseline, Gridlock, and Bold scenarios were used to estimate travel time savings, productivity and safety benefits associated with autonomous vehicles, health benefits and potential increases in spending generated by improved accessibility. There are other benefits and impacts that could be measured, but were beyond the scope of this analysis. The structure of the comparisons are outlined as follows:

- Benefit of Mobility Gridlock = Mobility Gridlock vs. Mobility Baseline
- Benefit of Mobility Bold = Mobility Bold vs. Mobility Gridlock

The performance results of the model scenarios are provided in Table E-4. The modifications to the regional travel demand model for each of the scenarios are documented elsewhere in this Appendix.

Transportation investment can be valued in a number of different ways. One very common method involves the monetization of user benefits, which are typically generated by reductions in factors that can be influenced by transportation improvements. For example, changes in travel time can generate benefits that can be monetized based on a value of time. A second relatively common approach considers changes in spending or spending power. The metrics presented below represent a sample of the types of benefits and impacts that are expected to be generated by the technology and mobility improvements

Travel Time Productivity

University of Michigan Transportation Research Institute. Their report “Would Self-Driving Vehicles Increase Occupant Productivity?” found that for 62% of Americans, self-driving vehicles would likely not result in increased productivity. The reasons?

- 36% would be so apprehensive they would only watch the road
- 23% would not ride driverless vehicles
- 3% would frequently experience some level of motion sickness

For the remaining 38% who would take advantage of this free time:

- 11% would read
- 10% would text or talk with family and friends
- 7% would sleep
- 6% would watch movies or television
- 5% would work
- 2% would play games

Appendix E. Scenario Comparison: Qualitative and Quantitative Evaluations

being considered in the study. Note that these benefits should not be added together to estimate total benefits, because some double counting may occur.

Table E-3. Scenario Model Performance Summary

#	Metric	2030 Baseline	Gridlock	Bold	Gridlock	Bold
	Mode Drive Alone Trips	6,595,244	6,633,308	6,490,940		
1	Level 4 or 5 AV	-	99,500	649,094	\$ 55,147,558	\$ 380,634,641
	Avg. Hrs/Trip	0.214	0.226	0.240		
	Mode Drive to Transit Trips	105,382	103,681	105,867		
	Mode School Bus Trips	254,798	255,217	252,600		
	Mode Shared Ride 2 Trips	3,303,780	3,316,103	3,231,693		
	Mode Shared Ride 3+ Trips	2,443,865	2,454,067	2,404,776		
	AV Trips		186,052.17	1,212,740.90		
	Mode Walk to Transit Trips	269,480	251,219	236,259		
	Mode Walk Trips	1,313,670	1,292,533	1,566,467		
	Peak Average Vehicle Speed	30.10	30.10	31.08		
	Regional Household Autos	2,979,011	3,001,264	3,034,690		
	Severely Congested Lane Miles	2,310	2,435	2,350		
	Total Households	1,651,234	1,651,234	1,651,234		
	Total Person Tours	5,385,296	5,388,605	5,405,735		
	Total Person Trip Distance	83,619,353	83,832,753	82,701,246		
2	Total Person Trip Time	177,895,823	179,322,842	171,981,259	\$ (153,237,010)	\$ 788,358,271
3	Total Person Trips	14,453,167	14,470,568	14,490,034	\$ 93,450,240	\$ 57,377,190
	Avg. Travel Time per Trip	12.308	12.392	11.869		
	Total Persons	3,952,209	3,952,209	3,952,209		
	Total Vehicle Trips	12,448,271	12,507,159	12,233,276		
4	Total VHD	485,283	536,955	532,629		
5	10% Commercial VHD	48,528	53,696	53,263	(43,959,747)	\$ 3,680,489
	Total VHT	2,666,644	2,831,655	2,930,355		
	Total VMT	91,644,063	97,935,903	103,308,627		
6	Work Person Trips	3,442,271	3,441,240	3,449,389	\$ (28,435,805)	\$ 224,755,939
	Zero Car Households	90,247	71,383	43,796		
	CBD Walk Trips	73,433	73,170	82,168	(21,334.56)	729,917.76
	Fringe Walk Trips	115,683	113,933	137,430	(141,960.00)	1,906,076.64
	Urban Walk Trips	263,886	253,394	309,721	(851,111.04)	4,569,246
	CDB Bike Trips	7,419	7,566	9,292	\$ 441.00	\$ 5,178.00
	Fringe Bike Trips	13,771	13,472	16,911	\$ (897.00)	\$ 10,317.00
	Urban Bike Trips	45,334	43,797	53,800	\$ (4,611.00)	\$ 30,009.00
7					(1,019,473)	7,250,745
					BENEFITS	
	Personal travel time of the AV driver that is productive				Productivity	\$ 55,000,000 \$ 381,000,000
	Change in travel time, Commercial Delay, Health				Other Benefits	(198,000,000) 799,000,000
					Safety	90,650,800 645,569,851
					Total	\$ (52,000,000) \$ 1,825,000,000
					IMPACTS	
					Non-Work Spendi	\$ 93,000,000 \$ 57,000,000
					Work Spending	(28,000,000) 225,000,000
					Total	\$ 65,000,000 \$ 282,000,000

The key assumptions and sources used in the estimation of these “snapshot” public benefits and spending impacts are as follows:

Productive Travel Time (Metric #1)

Proponents of automated vehicles and self-driving technology highlight a potential benefit to the driver than may find new ways to be productive when not tasked with driving a personal vehicle. These are not new benefits to passengers of these vehicles nor do the potential benefits extend to passengers of other modes. The focus of this benefit estimate applies only to the driver of a self-driving automated vehicle. Conservatively, this benefit was not applied to the driver of multi-occupant autos. The 2030 model estimates that drive alone single occupant vehicle trips will increase under the Gridlock scenario from 6,595,244 daily trips to 6,633,308 daily trips. The Bold scenario reduces the number of single occupant trips to 6,490,940.

It is assumed for 2030 that Level 4 and Level 5 automated vehicles will have entered the Denver market. A wide range of forecasts are predicted as to when and to what extent self-driving technology will be deployed and adopted in the US.⁵ A report by S&P Global (May 14, 2018) estimates that the expected range of AV fleet in the US to be between <1% - 10% by 2030. The MCB study brackets these estimates. Under the 2030 Gridlock (Trend) scenario, the percentage of vehicles with self-driving features is assumed at 1.5% of all drive alone trips. For the Bold scenario, this assumption is expanded to 10% of drive alone trips. The model does not make this vehicle type distinction and therefore the expected impact of self-driving vehicles is adjusted in the model parameters.

As noted, the model forecasts provide a general estimate of total travel time for all drive alone trips. However, for the productivity calculation, it is assumed that only 38% of the drivers of a self-driving vehicle would find this time to be productive⁶—i.e., allowing the driver to safely divert attention away from the task of driving, which would likely vary depending on the highway facility type, weather conditions, and traffic conditions.

The “value” of this potentially productive time was estimated based on the average value of time for the Denver region. The value of time measure utilizes the Texas Transportation Institute (TTI) Cost of Congestion Report values referenced in the TTI Reports (2010 to 2014) and extrapolated (*in italics*) to 2018. The value of time for automobiles is based on the median hourly wage rate for all occupations as produced by the Bureau of Labor Statistics (BLS). The value of travel time for trucks is based on the American Transportation Research Institute (ATRI) annual survey modified by speed, type of vehicle, and vehicle occupancy. The value of time is typically used to estimate the cost of congestion by applying the personal or commercial value of time to the hours of congestion delay in the network. The commercial vehicle value of time is based on the Texas A&M Transportation Institute report “Value of Delay Time for Use in Mobility Monitoring Efforts”⁷ which identifies \$25.17 (2015) as the truck cost per hour. The extrapolation of value for personal travel value of time for the Denver region is summarized in Table E-5.

⁵ <https://home.kpmg/us/en/home/media/press-releases/2017/11/personal-sedan-sales-in-jeopardy-as-us-auto-market-transitions-to-islands-of-autonomous-mobility-kpmg-research.html> (50% reduction in private auto sales by 2030); <https://www.ibtta.org/sites/default/files/documents/SP%20Global%20Ratings%20-%20Road%20Ahead%20For%20Autonomous%20Vehicles-Enhanced%20May-14-2018.pdf> (Resultant AV fleet share of US car fleet by 2030, <1% low - <10%)

⁶ <http://umich.edu/~umtristw/PDF/SWT-2016-11.pdf>

⁷ <https://static.tti.tamu.edu/tti.tamu.edu/documents/TTI-2017-10.pdf>

Table E-4. Personal Travel Value of Time

Year	Personal Travel Value/Hr.
2010	16.3
2011	16.79
2012	17.14
2013	17.39
2014	17.67
2015	18.06
2016	18.394
2017	18.728
2018	19.062

The value of time benefit is applied only to 38% of AV drivers for the average trip time (Drive alone trips x % AV fleet x avg. hrs/trip x 38% x \$19.06 x 338 annualized).

# Metric	2030 Baseline	Gridlock	Bold	Gridlock	Bold
Mode Drive Alone Trips	6,595,244	6,633,308	6,490,940		
1 Level 4 or 5 AV	-	99,500	649,094	\$ 55,147,558	\$ 380,634,641
Avg. Hrs/Trip	0.214	0.226	0.240		

Cost of Congestion (Metric #4 and #5)

Similarly, commercial vehicle trips were estimated from the model and used to estimate Vehicle Hours of Delay (VHD) changes for freight and goods movement in the region. Congestion, delay and travel time volatility has a major impact on the freight industry, which results in higher costs for goods and services and impacts the economic competitiveness of the region to attract industries such as manufacturing, distribution centers and value added logistics. To estimate this benefit, it is assumed that 10% of the total VHD impacts commercial vehicles.

# Metric	2030 Baseline	Gridlock	Bold	Gridlock	Bold
4 Total VHD	485,283	536,955	532,629		
5 10% Commercial VHD	48,528	53,696	53,263	(43,959,747)	\$ 3,680,489

Person Trip Time (Metric #2)

Person trip time is a measure of time each person spends per day in travel. The tour based model generates person tours from which total person trips, trip distance and person trip time can be derived. The Gridlock scenario results in an increase in total person trips (from 14,453,167 to 14,470,568) and increase in person trip time (from 177,895,823 min. to 179,322,842 min.). The Bold scenario provides a further increase of total person trips (14,490,034) but with an overall decrease in person trip time (171,981,259 min.).

Appendix E. Scenario Comparison: Qualitative and Quantitative Evaluations

The reduction of time spent in travel results generates a user benefit based on the value of time. (Personal travel time (increase or decrease)/60 min/hr. x 19.06 x 338 (annualized)).

# Metric	2030 Baseline	Gridlock	Bold	Gridlock	Bold
2 Total Person Trip Time	177,895,823	179,322,842	171,981,259	\$ (153,237,010)	\$ 788,358,271

Active Transport (Metric #7)

Cycling and walking provide both environmental and personal health benefits along with other external benefits associated with a reduction in vehicle crashes, parking, and congestion. There is also the potential for increased land values with improved transportation facilities. The Victoria Transportation Policy Institute conducted an economic benefit study⁸ across 6 major cities in Canada to estimate the monetary benefits of walking. The study estimates an economic health benefit of 0.48 USD per mile walked (other factors or benefits were not considered for purposes of the MCB study). Similarly, biking provides a health benefit of 0.19 USD per mile biked.

The model generates estimates of trips by cycling and walking modes. For the calculations, an average walk trip length of 0.5 miles was applied (intra-zonal trips are not recognized as walk trips and therefore short walking trips are not included in this estimate). Average length of cycling trips was assumed at 3.0 miles. The results of the calculations are as follows:

# Metric	2030 Baseline	Gridlock	Bold	Gridlock	Bold
CBD Walk Trips	73,433	73,170	82,168	(21,334.56)	729,917.76
Fringe Walk Trips	115,683	113,933	137,430	(141,960.00)	1,906,076.64
Urban Walk Trips	263,886	253,394	309,721	(851,111.04)	4,569,246
CDB Bike Trips	7,419	7,566	9,292	\$ 441.00	\$ 5,178.00
Fringe Bike Trips	13,771	13,472	16,911	\$ (897.00)	\$ 10,317.00
Urban Bike Trips	45,334	43,797	53,800	\$ (4,611.00)	\$ 30,009.00
7				(1,019,473)	7,250,745

Safety Benefits

The DRCOG 2017 Annual Report on Roadway Traffic Congestion in Denver, 10/2017 provides crash statistics for the DRCOG metro study region. The 2017 data establishes a crash rate of 346/100M VMT:

⁸ <http://www.vtpi.org/walkability.pdf>

Appendix E. Scenario Comparison: Qualitative and Quantitative Evaluations

	2015	2017
VMT - avg. weekday		64,394,000
VMT annual		21,765,052,000
Crashes - avg. weekday	223	
Crashes annual	75,214	
DRCOG estimated Crashes/100 M VMT		346

USDOT BCA Guidance:

		2017
O - No Injury	\$ per injury	\$ 3,200
C - Possible Injury	\$ per injury	\$ 63,900
B - Non Incapacitating	\$ per injury	\$ 125,000
A - Incapacitating	\$ per injury	\$ 459,100
K - Killed	\$ per injury	\$ 9,600,000
Injured - Severity Unknown	\$ per injury	\$ 174,000
Unknown - If Injured	\$ per injury	\$ 132,200
Property Damage Only	\$ per injury	\$ 4,327

Total Crashes Denver County—CDOT (2017)

		Percent by Severity	DRCOG Calculated Crashes by Severity
PDO Crashes Denver County	22,405	78%	270.1
Injury Crashes Denver County	6,178	22%	74.5
Fatal Crashes Denver County	81	0.2826%	1.0
Total Crashes Denver County	28,664		

More than 90 percent of crashes are due primarily to, or influenced in a major way by driver behavior. (FHWA <https://highways.dot.gov/research-programs/safety/human-factors>). For purposes of estimating AV related safety benefits, the crash rate per 100M VMT by AV vehicles was reduced by 90%. By 2030, advanced safety features will be increasingly standard in most new vehicles, not limited to automated vehicles (lane keeping/lane departure, adaptive cruise control, automatic emergency braking, blind spot detection—are examples available in 2018 vehicles). For purposes of comparison the safety benefit was applied to the estimated market of AVs for Gridlock and Bold scenarios, 1.5% and 10% respectively.

Appendix E. Scenario Comparison: Qualitative and Quantitative Evaluations

Metric	2030 Base	Gridlock	Bold
AV Trips - annual		62,885,633	409,906,424
AV VMT - annual		428,548,129	3,051,906,350
AV Miles		6.815	7.445
AV crashes avoided - annual		1,333	9,492
PDO Crashes		1,042	7,419
Injury Crashes		287	2,046
Fatal Crashes		4	27
AV Crash Benefits			
PDO Crashes benefit		\$ 4,507,919	\$ 32,103,157
Injury Crashes benefit		\$ 49,985,201	\$ 355,969,711
Fatal Crashes benefit		\$ 36,157,679	\$ 257,496,983
TOTAL Safety benefit		\$ 90,650,800	\$ 645,569,851

The public benefits presented above are a sample of the types of benefits that could be generated by the improved mobility and technology investments envisioned for this program, but they are not all-inclusive. In addition, they represent only a single year “snapshot.” Nonetheless, the estimates offer some sense of how these potential investments are likely to positively affect the public.

In addition to public benefits, these improvements will result in additional spending. For example, construction spending, as well as the spending associated with operating and maintaining the new facilities, generates economic activity. While this spending and the multiplier effects of that direct spending are not included in this assessment, it is an unquantified attribute of technology investments. The measures below reflect other types of spending that are anticipated to be generated by these improvements.

Accessibility and Economic Opportunity (Metric #3 and #6)

The change in person trips was also monetized to estimate the value of new trips added by the scenarios. It should be noted that the population of the region remained constant for all scenarios. The adjustments to the model that increased auto accessibility, improved transit frequency or reduced the total cost of mobility cause the model to respond by creating more trips. For example, total non-work trips increased by more than 11,300 new trips. New non-work trips could include shopping, school, recreation, etc. The value of these new trips is highly speculative but would generally result in an economic exchange in terms of spending. To estimate the potential new spending generated by these new non-work trips, each new trip was assumed to result in \$15 in new spending.

# Metric	2030 Baseline	Gridlock	Bold	Gridlock	Bold
3 Total Person Trips	14,453,167	14,470,568	14,490,034	\$ 93,450,240	\$ 57,377,190
Avg. Travel Time per Trip	12.308	12.392	11.869		

Similarly, the relative economic impact of new work trips produced in the scenarios was estimated. The value of these new work trips varies, depending on what share of the trips is assumed to represent new jobs for people who are currently not working. If we assume 100% of these new trips are being made to access new jobs, a per-trip value of \$81.60, based on the 2018 Denver minimum wage of \$10.20/hr, and the change in trips presented below, we can calculate new direct spending power associated with these new wages. It should be noted that the 100% assumption may be generous. If we assume only 10% of

Appendix E. Scenario Comparison: Qualitative and Quantitative Evaluations

the trips are to access new jobs, the benefit of the Bold scenario would be roughly \$22.5 million in new potential spending power.

#	Metric	2030 Baseline	Gridlock	Bold	Gridlock	Bold
6	Work Person Trips	3,442,271	3,441,240	3,449,389	\$ (28,435,805)	\$ 224,755,939

Overall Summary

Overall, greater accessibility to transportation creates job opportunity, access to healthcare, education and promotes consumer spending. Safety and quality measures that promote biking and walking improve health, reduce congestion and provide benefits to air quality. These are all examples of system wide performance metrics that have been reviewed to measure some of the benefits of the Mobility Blueprint.

The programs, projects, and initiatives recommended by the Mobility Choice Blueprint are expected to provide an estimated net annual public benefit to the region of approximately \$1.9B annually (in 2018 dollars) above the 2030 Trend Scenario. The benefits of Mobility Bold offset the disbenefits of the Mobility Trend (-\$52 million) to yield a positive \$1.82 economic benefit to the region (\$1.877 billion net benefit). This total includes:

- \$380M Increased productivity for personal travel in shared and automated vehicles
- \$800M Personal and commercial travel time savings due to congestion reduction and service improvements
- \$7M Health benefits accrued to increased cycling and walking
- \$645 in safety related benefits due to crash reductions due to enhanced safety features of automated vehicles.

In addition, direct spending power will also be increased. The estimate below does not include the multiplier effects that are typically generated by additional rounds of spending beyond just the direct impact.

- \$280M Direct economic activity generated by improved transportation access to destinations, including employment centers

If the disruptive trends in mobility are not managed as examined in the Gridlock scenario, and given the assumptions presented above, the Denver region could experience \$52 M in costs associated with congestion. In addition, health benefits associated with active transportation would not be generated, and driverless vehicle productivity benefits would represent only 5% of the benefits that could be achieved when the Mobility Choice Blueprint investments are made. In addition, new work and non-work trips would be significantly less.

The modeling analysis anticipates that although vehicle trips in the region can be reduced, overall vehicle miles of travel will increase—and, if unmitigated can offset the economic benefits of the Blueprint. Empty vehicles, either automated or FHV without passengers, add unproductive trips to the network—as much as 5.5% across the entire region and significantly higher in dense travel destinations such as Downtown Denver. Policies that promote ridesharing and restrict single and zero occupant travel are necessary to realize the benefits of the Mobility Blueprint.