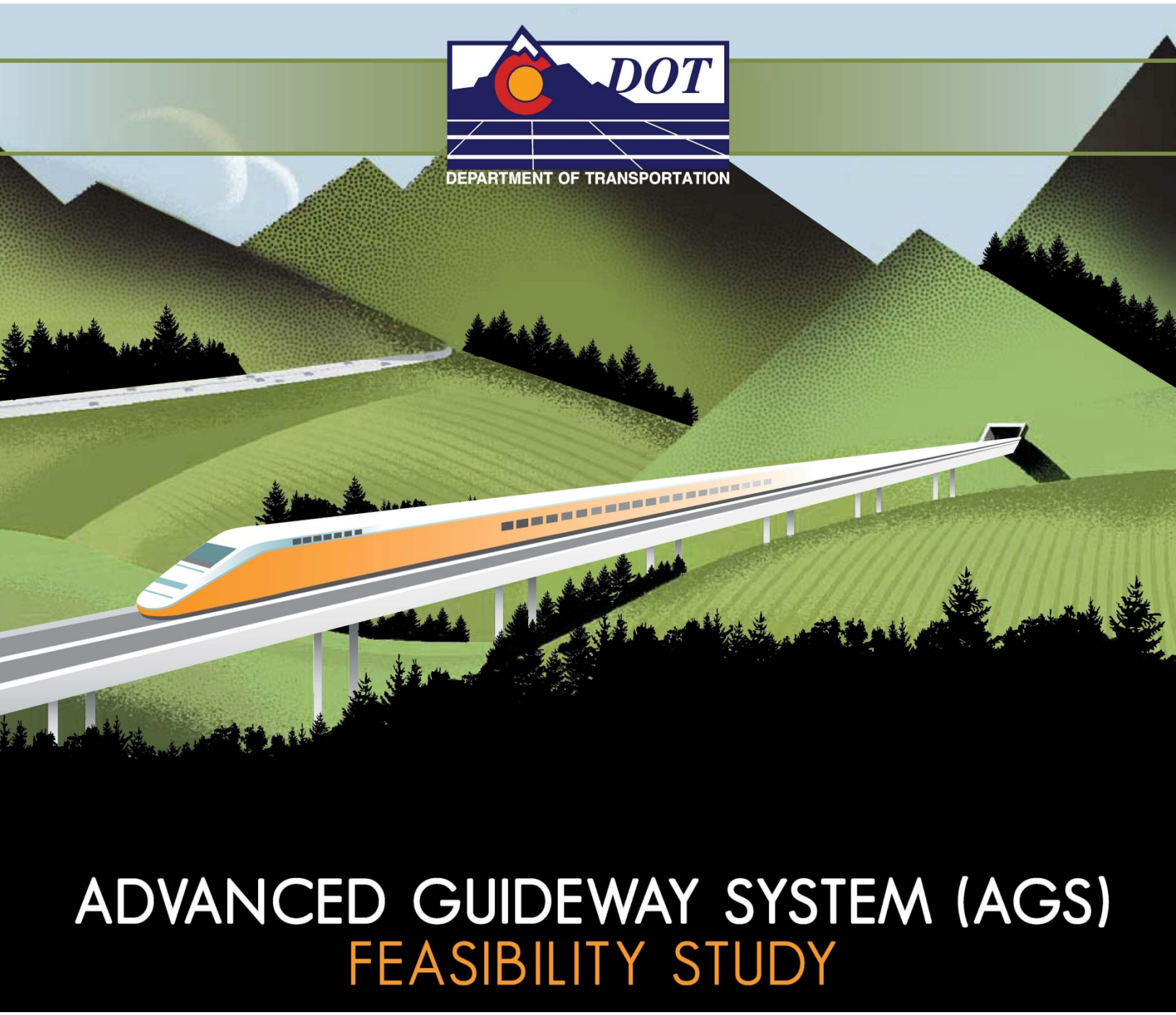
DRAFT



ADVANCED GUIDEWAY SYSTEM (AGS)
FEASIBILITY STUDY

APPENDIX H
AGS REVIEW OF ICS RIDERSHIP MODELING

Memorandum

TO: Mike Riggs, AZTEC Engineering

FROM: Smith Myung and Monique Urban, Cambridge Systematics

DATE: December 31, 2013

RE: Review of ICS Model, Documentation of Level of Service Sensitivity Tests and Analysis and Comparison of Forecasts (DRAFT)

The I-70 Advanced Guideway System (AGS) Feasibility Study evaluated AGS and high-speed rail (HSR) investments in the I-70 Mountain Corridor from the Denver metropolitan area to west of the Continental Divide near the ski resorts.. This study built on past efforts such as CDOT's I-70 Mountain Corridor Final Environmental Impact Statement (FEIS) 2011 and the Rocky Mountain Rail Authority's (RMRA) High Speed Rail Feasibility Study, March 2010. The intention of the I-70 AGS Study was to refine the recommendations from those previous studies and select a final alignment, rail technology, and station locations. A model system developed by the SDG team for both this study and CDOT's parallel effort, the Interregional Connectivity Study (ICS), was used to develop ridership and revenue forecasts to support both projects

As part of model development, the SDG team collected new stated preference (SP) survey data, estimated resident mode choice models from the SP survey, and developed intercity auto trip tables from the cellular phone data. While SDG performed the modeling of the main alternatives for the I-70 AGS Study, Cambridge Systematics (CS) provided support to the AGS project team. CS' primary role was to provide an independent review the model system and determine whether the ridership forecasts were reasonable. This memo documents our efforts and is organized as follows:

1. Review of the ICS Travel Forecasting Procedures,
2. Level-of-Service Sensitivity Tests,
3. Additional Model Runs, and
4. Analysis of Ridership Forecasts.

Review of ICS Travel Forecasting Procedures

Our initial review of SDG's travel forecasting procedures predates this memorandum and was documented in our April 6, 2013 memo. In that memo, we documented our review of the stated preference (SP) survey and mode choice model design. Overall, based on conference calls and review of the available documentation, we found the SDG team used sound modeling principles. However, we identified several potential issues with the model that may limit its flexibility in responding to policy questions or, possibly, could lead to unrealistically high or low ridership forecasts if input assumptions are more than one-half or twice the base conditions.

Review of Stated Preference Survey

Our main issue with the SP survey concerned the experiment design. Travelers were asked to make decisions regarding mode use based on AGS/Train fare, toll costs, and the cost per gallon of gasoline. Alternatively, the survey questions could have presented gasoline costs as the total gas cost incurred over the trip. The SDG team suggested that this the per-gallon cost alone was appropriate since travelers purchase gasoline on a periodic basis and don't really consider the actual cost per mile. However, we identified two concerns with this approach.

- Since the use of automated toll payment transponders is increasing, the same argument might be made for the cost of tolls. Travelers who need to "reload" their toll credits on a monthly basis are just as likely to disassociate toll costs with auto use as they are to disassociate gasoline costs. Presenting both types of costs (tolls and gasoline) in the survey using either the true cost of each or a proxy cost for each would have been more consistent.
- Since the SP survey used cost per gallon of gasoline rather than an actual auto cost specification, the use of an actual auto cost based on the specified cost per gallon of gasoline, an average fuel efficiency estimate, and a trip distance in the mode choice model estimation was contradictory to the survey design. Whether such a specification would produce credible model coefficients is unclear. We would have been more comfortable with SDG's recommended model if they had also tested an alternate specification that included auto distance and cost per gallon of gasoline as separate variables (rather than a single variable representing an estimated auto cost based on the cost per gallon of gasoline, fuel efficiency and distance).

Review of Mode Choice Model

The mode choice model includes a reasonable set of independent variables. However, it does not include variables that directly represent service frequency or reliability, which can be important in mode choice decisions. This section describes some potential implications of the model design.

Frequency

Scheduled service frequency is not directly accounted for in this model, although other models often include it as a stand-alone variable to reflect a traveler's sensitivity to changes in service levels. Such a variable can be represented as a departure frequency per hour or the actual headway between scheduled departures.

Frequency is an important determinant of wait time. As SDG has noted, the rail access time variable in the mode choice model is used as a proxy for all out-of-vehicle time including initial wait time (a function of service frequency) and transfer time. The initial wait time can occur at either the station or elsewhere. For example, when service is infrequent, a traveler will often linger at work or home before going to the station. This type of "initial wait" is different than waiting at a station or transfer wait. Thus, representing service frequency in initial wait time might misrepresent the variable's importance in choice of travel mode.

Reliability

There is no variable for reliability in the resident mode choice model estimated by SDG. It is argued that reliability would be captured through changes in auto travel times. Congestion in the corridor, for example, would make auto travel times longer and therefore make AGS a more attractive option. While this is true to a certain extent, the concept of reliability can be expanded to include the expectation of on-time performance. In the I-70 corridor, the issue of reliability is a serious concern. During peak weekend travel days, a trip that normally takes two hours during the week can take anywhere from 2.5 – 4.0 hours even without significant weather events.

Modeling such variation with an average congested travel time understates the impact of reliability. An AGS system in the corridor would be unaffected by the congestion and should be able to make the same trip according to its schedule with a high degree of reliability. Thus, having a reliability variable in the model would provide stakeholders the capability to test the impacts of reliability on travel demand. A travel option with high reliability in a corridor known for frequent, unplanned closures or delay could be an extremely attractive alternative.

Intercity Model Testing and Evaluation

CS obtained the ICS travel demand model from SDG and installed the model system on a CS computer. The ICS model system is made up several discrete choice models for long-distance intercity travel. Intracity travel, or travel that remains within the Denver metro area, is forecast using a modified version of the Denver Regional Council of Governments (DRCOG) Compass Trip-Based Travel Forecasting Model. CS attempted to obtain the adapted version of the DRCOG Compass Model for the I-70 AGS. Unfortunately, the Compass Model uses TransCAD 4.8, Build 475 which is no longer supported by the vendor, Caliper Corporation. The use of different build versions of the TransCAD software can produce different results and/or cause the model run to crash. For this reason, CS did not obtain and test the adapted version of the DRCOG Compass Model. Instead, SDG agreed to run the DRCOG model for various I-70 AGS alternatives under consideration.

CS installed the ICS model on our computers to become familiar with the model system. The first step involved reviewing the setup and output files. The next step was to verify that we were able to run the model on our computer system and match SDG's results for the preliminary forecasts that were produced for the ICS. While this step may seem trivial, it is actually very important since a computer's operating system or hardware can affect model results or cause the run to terminate.

CS installed and tested only the intercity auto diversion model since we determined that was the only model we would apply for alternatives testing that we performed. CS did not evaluate or run the intercity bus diversion model or connect air model. The intercity bus diversion model is applied to estimate the number of bus passengers that would be diverted to high speed rail or another advanced guideway system (HSR/AGS). Considering the size of the current market and even using aggressive growth assumptions for the future, the diversion of bus passengers to proposed HSR/AGS service would only contribute a small fraction of the total HSR/AGS ridership based on model runs performed by SDG for the ICS. The model accounts for only Greyhound and FLEX ridership in the model's base year. Similarly, the connect air model was not applied for the additional alternatives considered in the I-70 AGS since the model is only used when there are airports near proposed rail station. Second, the air market associated with the one airport in the I-70 corridor represents a very small percentage of the overall travel demand in the corridor. Therefore, the decision was made to focus on the auto diversion model where the major source of HSR/AGS ridership would originate (greater than 95 percent).

SDG provided the model inputs and output from eleven AGS alternatives that were evaluated in the Level 3 analysis of the ICS. CS staff set up the intercity auto diversion model and ran each of the alternatives to verify that we could match SDG's results. HSR/AGS inter-city ridership and revenue were compared at the following summary levels:

- Market to market, where each station was assigned to one of the following markets: I-70, I-25N, I-25S, and DEN, and

- Station level boardings.

Table 1 below shows a final summary of the results from CS' reproduction of the SDG alternatives. Initially, CS was able to reproduce results for only six alternatives but after investigation, the discrepancies in the remaining alternatives were traced to several sources including updated model scripts not originally provided, older model results in the SDG summary templates, and a level of service matrix file with incorrect values.

Table 1: Comparison of SDG Model Results with CS Model Results

Scenario		Ridership			
Name1	Name2	SDG Results	CS Results	Difference	Percent Difference
A1a	1a	12,171,190	12,171,190	0	0%
A1b	1b	13,162,834	13,162,834	0	0%
A5a	2a	12,987,085	12,987,085	0	0%
A5b	2b	13,137,458	13,137,458	0	0%
C1	5	10,844,306	10,945,458	-101,152	-0.93%
B2a	B2	13,848,747	13,848,747	0	0%
B4	B4	13,714,955	13,714,955	0	0%
A5aMag	2a Maglev	12,892,685	12,892,502	183	0%
A5aMagHMS	2a Maglev	12,458,847	12,458,847	0	0%
A5aMagHHS	2a Maglev	13,213,205	13,122,615	90,590	0.69%

Source: CS summary results

Level-of-Service Sensitivity Tests

Travel forecasting procedures should have reasonable sensitivity to changes in key input variables. Therefore, testing the model system to verify its reasonableness is a valuable part of model validation. As part of the model development effort, SDG did perform tests to evaluate the sensitivity of the mode choice model to different input variables. While most of the variables that were tested appeared to have reasonable sensitivity, CS did express some concern in our April 6, 2013 memo regarding the sensitivity of the mode choice model to HSR/AGS fares.

The concept of elasticity is commonly used in economics. Elasticity measures the impact of changes in one economic variable on demand. For example, elasticity is often used to estimate the impact of price changes on demand for a product. In transit planning, elasticities are often applied by planners to estimate the change in ridership that may result from a change in transit fares. In travel demand modeling, elasticities provide a measure of the sensitivity of the model and can be compared with elasticity values from other models, empirical experiments, and the research literature to determine reasonableness.

Elasticties can be either positive or negative. Negative elasticities indicate an inverse relationship between variables. For example, a negative sign indicates that as price increases, demand decreases while a positive sign means that demand changes in the same direction as price. When the absolute value of elasticity is less than one, the relationship between demand and the input variable is called "inelastic". Otherwise, the relationship is called "elastic."

CS prepared a set of sensitivity tests to determine how changing the main input variables affects the AGS ridership forecasts. The main purpose of this effort was to independently confirm the results from SDG's sensitivity analysis as well as perform some additional analyses not carried out by the ICS project team. The results from these operational sensitivity tests should help

reassure policy makers that the travel forecasting procedures used in both the I-70 AGS and ICS are reasonably sensitive and consistent with good modeling practice.

CS performed the sensitivity tests using the ICS A-1b scenario as the base run. Each input variable was tested separately by changing its original value by -90 percent, -70 percent, -30 percent, -10 percent, +10 percent, +30 percent, +60 percent, and +100 percent. For example, transit travel time was factored by 1.10 to represent a +10 percent increase. The intercity model was then rerun to determine the effect of the change on ridership. The input variables that were tested included the following:

- HSR/AGS in-vehicle travel time (IVTT),
- HSR/AGS out-of-vehicle time,
- Auto in-vehicle travel time (IVTT),
- Auto operating cost,
- The alternative-specific HSR/AGS constants, and
- HSR/AGS fare.

Based on the change in ridership, the log arc elasticity[1] was calculated using diverted ridership only and compared with SDG's elasticities for the same variables. This methodology was consistent with the calculation used by SDG. The initial comparison revealed the values were similar but not identical. In trying to identify the source of the differences, CS learned that all of SDG's sensitivity tests had been performed using an earlier version of the model and that the model provided to CS was their latest version. Hence, the elasticities were expected to be different considering the difference in model versions. **Tables 2** and **3** below show comparisons of the elasticities for the tested input variables.

HSR/AGS In-Vehicle Travel Time (IVTT) – Calculated elasticities for HSR/AGS IVTT from the sensitivity tests are all less than 1.0. This indicates that HSR/AGS ridership is inelastic with respect to HSR/AGS IVTT. Hence, HSR/AGS ridership is not very sensitive to changes in HSR/AGS IVTT. The negative sign is also logical as there should be an inverse relationship between HSR/AGS travel times and ridership: as HSR/AGS travel times increase, HSR/AGS ridership should decrease.

HSR/AGS Out-of-Vehicle Time – The calculated elasticities for HSR/AGS out-of-vehicle time are all less than 1.0 although the differences between CS' and SDG's values were fairly large at -70 percent and -90 percent. Wait time in the mode choice model is calculated as 1/4th the train headway and is capped at 30 minutes. The sensitivity test was also performed without constraining the wait time and the elasticities between CS and SDG were more similar. Overall, ridership is inelastic with respect to HSR/AGS out-of-vehicle time. This is reasonable and elasticity values are consistent with a view that intercity travel is less sensitive to service

[1] LogArc Elasticity = $[Ln(Quantity_2) - Ln(Quantity_1)] / [Ln(Price_2) - Ln(Price_1)]$

headways than urban travel. Improving headways, thereby reducing the out-of-vehicle time, has little impact on overall ridership.

Auto IVTT - The calculated elasticities reported for auto IVTT are cross-elasticities. Unlike the direct elasticity, a cross-elasticity measures the change in demand for a mode based on a change in an attribute belonging to a competing mode. The cross-elasticities for auto travel times are all less than 1.0 in cases where auto travel times were decreased. On the other hand, the cross elasticities were all greater than 1.0 when auto travel times were increased.

Auto Operating Costs – HSR/AGS ridership is relatively insensitive to changes in auto operating costs with calculated cross-elasticities all less than 0.39.

HSR/AGS Constant – HSR/AGS constants are used to account for variables that are not measured or explicitly included in mode choice models. These could include factors such as perceptions of safety, comfort, or other variables that are difficult to directly capture. For the testing process, the HSR/AGS constants for all four trip purposes (resident work, resident non-work, airport access, and visitor) were adjusted together in each test. Based on the calculated elasticities, HSR/AGS ridership with respect to the HSR/AGS constant is inelastic, with absolute values generally less than 1.0.

HSR/AGS Fare – The absolute elasticities calculated for HSR/AGS fares generally exceed 1.0 indicating that ridership is extremely sensitive to fares. As we noted in our April 13, 2013 memorandum[2], we expressed concern that the high elasticities might be the results of the methods used to present travel costs in the SP survey.

Overall, our test of the sensitivity of the intercity mode choice model confirms most of the elasticities reported by the SDG project team. Generally, the calculated elasticities are inelastic which is consistent with one Swiss study of long trips from 10 to 300 kilometers in length[3]. Exhibit 1 includes the elasticity values from that survey. However, as discussed earlier, our main concern is with the model's sensitivity to HSR/AGS fares.

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[2] Cambridge Systematics, Inc., *CS Comments on ICS_Model_Final_V2.docx*, April 2013.

[3] Vrtic, M. and Axhausen, K.W. (2003), Verifizierung von Prognosemethoden im Personen-verkehr: Ergebnisse einer Vorher-/Nachher Untersuchung auf der Grundlage eines netzbasierten Verkehrsmodells, Endbericht an die SBB - Division Personenverkehr und Bundesamtfür Raumentwicklung – Technischer Bericht, IVT, ETH Zürich, Zürich.

Exhibit 1: Reported Elasticities from Swiss Study

Table 2: Swiss elasticities for long distance travel (Source: Vrtic & Axhausen 2003)

Demand elasticities shown for distances greater than 10 kilometers
(SP parameters at the mean values of the underlying RP trips)

Parameter(s)	Mode	All	Commute	Business	Shopping	Leisure/ Vacation
Travel time car	Car	-0.425	-0.665	-0.68	-0.545	-0.53
	Train/transit	0.671	0.776	1.531	1.008	0.937
Cost car	Car	-0.121	-0.312	-0.076	-0.156	-0.174
	Train/transit	0.191	0.365	0.171	0.288	0.308
In-vehicle-time train/transit	Car	0.365	0.48	0.615	0.46	0.456
	Train/transit	-0.575	-0.56	-1.386	-0.85	-0.805
Fare train/transit	Car	0.157	0.435	0.092	0.223	0.217
	Train/transit	-0.247	-0.508	-0.206	-0.512	-0.373
Access/egress train/transit	Car	0.172	0.272	0.111	0.279	0.127
	Train/transit	-0.272	-0.318	-0.249	-0.515	-0.224
Headway	Car	0.144	0.32	0.154	0.121	0.116
	Train/transit	-0.277	-0.374	-0.346	-0.224	-0.205
Number of travelers	Car	0.115	0.133	0.151	0.101	0.134
	Train/transit	-0.181	-0.156	-0.339	-0.186	-0.237

Source: Vrtic and Axhausen, 2003.

Table 2: Elasticity Comparison

Percent Change	HSR/AGS Fare Elasticity			HSR/AGS IVTT Elasticity			HSR/AGS Out-of-Vehicle Time Elasticity			HSR/AGS Out- of-Vehicle Time Elasticity (Unconstrained)		
	CS	SDG	% Diff	CS	SDG	% Diff	CS	SDG	% Diff	CS	SDG	% Diff
-90	-0.53	-0.52	0.7%	-0.26	-0.33	-20.7%	0.05	0.36	-85.5%	0.28	0.36	-23.5%
-70	-0.80	-0.78	3.1%	-0.39	-0.48	-18.6%	0.10	0.21	-52.3%	0.15	0.21	-28.6%
-30	-1.17	-1.10	5.8%	-0.57	-0.65	-13.1%	0.08	0.14	-45.5%	0.08	0.14	-45.5%
-10	-1.31	-1.23	6.4%	-0.64	-0.71	-10.8%	0.07	0.12	-46.1%	0.07	0.12	-46.1%
0												
+10	-1.43	-1.34	6.7%	-0.70	-0.77	-8.9%	0.06	0.11	-46.5%	0.06	0.11	-46.5%
+30	-1.54	-1.44	6.8%	-0.75	-0.81	-7.5%	0.06	0.10	-46.8%	0.06	0.10	-46.8%
+60	-1.68	-1.58	6.6%	-0.82	-0.88	-6.2%	0.05	0.10	-47.0%	0.05	0.10	-47.0%
+100	-1.84	-1.74	6.1%	-0.90	-0.95	-5.2%	0.05	0.09	-47.3%	0.05	0.09	-47.3%

Table 3: Elasticity Comparison (Cross and Direct)

Percent Change	Auto IVTT Cross-Elasticity			Auto Operating Costs Cross-Elasticity			HSR/AGS Constant Elasticity		
	CS	SDG	% Diff	CS	SDG	% Diff	CS	SDG	% Diff
-90	0.36	0.33	11.1%	0.10	0.09	13.1%	-0.25	n/a	n/a
-70	0.55	0.49	12.2%	0.15	0.13	13.2%	-0.37	n/a	n/a
-30	0.85	0.74	14.5%	0.22	0.19	13.2%	-0.55	n/a	n/a
-10	0.99	0.86	15.2%	0.25	0.22	13.2%	-0.63	n/a	n/a
0									
+10	1.11	0.97	14.5%	0.28	0.24	13.0%	-0.70	n/a	n/a
+30	1.21	1.08	12.5%	0.30	0.27	12.9%	-0.77	n/a	n/a
+60	1.34	1.23	8.7%	0.34	0.30	12.5%	-0.88	n/a	n/a
+100	1.46	1.40	4.6%	0.38	0.34	11.8%	-1.01	n/a	n/a

Additional Model Runs

The I-70 AGS project team identified additional alternatives that needed to be evaluated for the horizon year (2035). Based on meetings with the Project Leadership Team (PLT) and results from the Level 2 screening, the project team identified several new minimum operating segment (MOS) options.

All MOS model runs assumed an operating plan of 24 trains per day. Service would be provided every 30 minutes for six peak period hours and every hour for 12 off-peak period hours. The first set of MOS runs also used the original distance-based fare assumption of $0.35 per mile. Depending on the alternative, the HSR/AGS lines were modeled as standalone lines or in conjunction with the full system. The full system reflected the Maglev HS Hybrid alignment and stations defined for the A-5a alternative in the ICS. This included Maglev HS Hybrid service in the Front Range corridor from Fort Collins to Pueblo following the I-25 alignment. A detailed definition of the A-5a alternative is described in the I-70 AGS Final Report. The first set of modeled alternatives include the following:

1. High Speed (HS) Maglev standalone – Golden to Breckenridge
2. HS Maglev with full ICS system - DIA to Breckenridge
3. HS Maglev standalone – DIA to Breckenridge
4. HS Maglev standalone – Golden to Breckenridge with El Rancho
5. Medium Speed (MS) Maglev standalone – Golden to Breckenridge
6. MS Maglev with full ICS system - DIA to Breckenridge

Travel time assumptions used as input in the MOS runs are included in **Tables 4** to **7** below.

Table 4: High Speed Maglev - Golden to Breckenridge

Station	Arrival Time (Minutes)	Milepost	Time between Stations	Distance between Stations (Miles)
Golden (Suburban West)	0	0.00		
dwell			*0*	
Idaho Springs	9	20.10	9	20.1
dwell			*2*	
Keystone	24	50.00	13	29.9
dwell			*4*	
Breckenridge	33	58.20	5	8.2

Source: Aztec Engineering

Table 5: Medium Speed Maglev – Golden to Breckenridge

Station	Arrival Time (Minutes)	Milepost	Time between Stations	Distance between Stations (Miles)
Golden (Suburban West)	0	0.00		
dwell			*0*	
Idaho Springs	16	20.10	16	20.2
dwell			*2*	
Keystone	37	48.20	19	28.1
dwell			*4*	
Breckenridge	48	57.90	7	9.7

Source: Aztec Engineering

Table 6: High Speed Maglev with El Rancho Station

Station	Arrival Time (Minutes)	Milepost	Time between Stations	Distance between Stations (Miles)
Golden (Suburban West)	0	0.00		
dwell			*0*	
El Rancho	5	8.90	5	8.9
dwell			*2*	
Idaho Springs	14	20.10	7	11.2
dwell			*2*	
Keystone	29	50.00	13	29.9
dwell			*4*	
Breckenridge	38	58.20	5	8.2

Source: Aztec Engineering

Table 7: High Speed Maglev – DIA to Breckenridge

Station	Arrival Time (Minutes)	Milepost	Time between Stations	Distance between Stations (Miles)
DIA	0	0.00		
dwell				
I-76/72nd Ave	9	17.70	9	17.7
dwell			*1*	
Golden (Suburban West)	20	35.80	10	18.1
dwell			*2*	
Idaho Springs	31	55.90	9	20.1
dwell			*2*	
Keystone	46	85.80	13	29.9
dwell			*4*	
Breckenridge	55	94.00	5	8.2

Source: Aztec Engineering

Results for MOS Runs Assuming $0.35 per Mile Fare

The intercity forecasts presented herein include the ridership and revenue summarized directly from SDG's auto diversion model for intercity travel, including both diverted and induced demand. For most alternatives**, intracity** ridership and revenue were estimated by taking a ratio of ridership from the $0.35 per mile fare and the $0.2625 per mile fare (2,632,745 at $0.35 cents/3,045,096 at $0.2625) and applying this factor to the scenarios where we had ridership and revenue results for the $0.2625 per mile but not $0.35 per mile. SDG ran the intracity model for most of the MOS runs assuming a fare of $0.2625 per mile – these estimates are presented in the table where available.

The ridership and revenue forecasts reflect only the trips with at least one trip end in the I-70 market. For the ICS, the study area was divided into the following markets: Denver, I-25N, I-25S, and I-70. In the standalone MOS alternatives, total ridership and revenue reflect only travel made to/from the I-70 market since there are no other HSR/AGS routes. In alternatives where the full ICS system is assumed, there would also be trips among the I-25N, I-25S, and Denver markets on the north-south HSR/AGS line that parallels I-25 from Fort Collins to Pueblo. For the full ICS system alternatives, **only** the ridership, revenue, VMT, and VHT statistics for those trips with at least one end in the I-70 market have been summarized.

Alternative 1 assumes HS Maglev from Golden to Breckenridge as a standalone service. Stations are assumed at Golden, Idaho Springs, Keystone, and Breckenridge. The intercity model forecasted annualized ridership and revenue at 1.21 million and $22.06 million, respectively.

In Alternative 2 with HS Maglev from DIA to Golden with the full ICS system, I-70 related ridership is forecasted to increase to 1.82 million. Annualized revenues are expected to rise to $52.97 million. While ridership increases by a factor of 1.5, revenue increases by a factor of 2.4 Revenue increases more rapidly in this Alternative due to longer trips on-board the vehicles. The full ICS system provides increased accessibility to travelers on the Front Range. For example, markets in Pueblo and Fort Collins are able to ride the proposed HS Maglev along I-25, transfer to the I-70 line and travel to/from any of the proposed stations.

Alternative 3 is identical to Alternative 1 except the I-70 line also includes stations in Denver and at DIA. Annualized ridership increased slightly from 1.21 to 1.24 million. Similarly, revenue increases from $22.06 to $27.15 million. The slight increase in ridership is explained by the fact that travelers in the metro Denver do not need to drive to Golden to board the HS Maglev line. They are able to access the line at stations at I-76/72nd Avenue and DIA. Although DIA is included, this alternative is not able to attract air passengers who may be traveling to the Eagle County Regional Airport (ECRA) since the western terminus at Breckenridge is a considerable distance away. Therefore the Connect Air model is not run for this alternative. Still, even if an airport were available near Breckenridge, the results of sensitivity model runs that include ECRA indicate that diversion from this market to AGS would only contribute a small fraction of total AGS ridership.

Alternative 4 is identical to Alternative 1 except it also includes a station at El Rancho. Ridership decreases by 4.6 percent to 1.16 million while revenues decrease by 5.1 percent to $20.94 million compared to Alternative 1. The increased accessibility to locations around El Rancho provided by the new station does not offset the longer travel times that are incurred on other interchanges due to the stop at this additional station.

Alternatives 5 and 6 are identical to Alternatives 1 and 2, except the technology assumed is Medium-Speed (MS) Maglev. Due to the significantly slower travel times of MS Maglev compared to HS Maglev, ridership decreases by 17 percent to 1.0 million for Alternative 5 and 12 percent to 1.60 million for Alternative 6. Revenue also decreases by 17 percent to $18.25 million for Alternative 5 and 11 percent to $47.08 million for Alternative 6.

Results for MOS Runs Assuming $0.2625 per Mile Fare

During the conduct of the study, the ICS project team evaluated different fare assumptions in order to maximize ridership and revenue. Their yield management analysis found that a $0.2625 per mile fare would satisfy the goals of maximizing ridership while generally maintaining or increasing revenues. While a lower fare of $0.19 per mile was tested and produced significantly higher ridership, the ICS project team felt the results from that scenario were reaching the limits of the reliability of the model with respect to the impact of fare changes. Therefore, a second round of MOS runs was tested using the fare assumption of $0.2625 per mile. The additional runs that were evaluated include the following:

7. MS Maglev standalone – Golden to Breckenridge

8. HS Maglev standalone – Golden to Breckenridge

9. HS Maglev with full ICS system – Golden to Eagle County Regional Airport

10. HS Maglev standalone – Golden to Keystone

11. HS Maglev standalone – DIA to Eagle County Regional Airport

12. HS Maglev with full ICS system - DIA to Breckenridge

13. HSR with full ICS system - DIA to Breckenridge

14. MS Maglev with full ICS system - DIA to Breckenridge

15. HS Maglev standalone – DIA to Breckenridge

Alternative 7 assumes a standalone MS Maglev from Golden to Breckenridge. Ridership increases by 25.5 percent to 1.26 million when compared to the same run using a $0.35 per mile fare (Alternative 5). Revenue, however, decreases by 5.5 percent to $17.24 million. The increase in ridership is not large enough to offset the loss in revenue resulting from the lower fare.

Alternative 8 assumes standalone HS Maglev from Golden to Breckenridge. This alternative is the same run as Alternative 1 except it uses the lower fare assumption. Compared to Alternative 1, ridership increases by 24.3 percent to 1.54 million while revenue decreases slightly by 5.5 percent to $20.85 million.

Alternative 9 assumes HS Maglev from DIA to ECRA with the full ICS system. Ridership is forecasted to be 4.64 million and total revenue is $113.91 million. Compared to the other MOS runs with the full ICS system, Alternative 9 has significantly higher ridership and revenues. While some of this related to the revised western terminus at ECRA, most of the increase is attributable to the lower $0.2625 per mile fare.

Alternative 10 assumes a standalone HS Maglev from Golden to Keystone. Ridership is forecasted to be 10 percent higher at 1.35 million than Alternative 1 which assumes the western terminus at Breckenridge and the higher fare of $0.35 per mile. The increase in ridership, however, is not large enough to offset the loss in revenue which drops by 22 percent to $17.14 million.

Alternative 11 assumes a standalone HS Maglev from DIA to ECRA. The most comparable run would be Alternative 3 which assumes HS Maglev service from DIA to Breckenridge. Compared to that run, ridership is forecasted to be 3.59 million, almost 200 percent higher than Alternative 3's results. Revenue is also significantly higher at $79.04 million compared to $27.15 million.

Alternative 12 assumes HS Maglev from DIA to Breckenridge with a full ICS system. It is identical to Alternative 2 except for the lower fare assumption. Compared to Alternative 2, ridership increases by 59.5 percent to 2.91 million while revenue increases by 26 percent to $66.94 million.

Alternative 13 assumes High Speed Rail (HSR) technology from DIA to Breckenridge with a full ICS system. It is identical to Alternative 12 except for the vehicle technology, alignment and the relocation of the Keystone station to Lake Hills. The Lake Hills station would be located just north of the exit for Breckenridge, south of I-70 and north of Dillon Dam Road. HSR has slower travel times when compared to HS Maglev. Compared to Alternative 12, ridership decreases by 8 percent to 2.68 million while revenue decreases by 13 percent to $58.28 million.

Alternative 14 assumes MS Maglev from DIA to Breckenridge with a full ICS system. This alternative is identical to Alternative 12 except for the train technology. The slower travel times with MS Maglev make this alternative slightly less attractive to riders than the higher speed, HS Maglev (Alternative 12). Compared to Alternative 12, ridership decreases by 14 percent to 2.51 million. Revenue also decreases by 15 percent to $56.78 million.

Alternative 15 was the final MOS option that was evaluated. It assumes HS Maglev from DIA to Breckenridge as a standalone line. This run is identical to Alternative 3 except it uses the lower fare assumption of $0.2625 per mile. Compared to Alternative 3, ridership is forecasted to increase by 44 percent to 1.78 million. Unlike some of the other alternatives, there is a large enough growth in ridership to offset the loss in revenue resulting from the lower fare. Revenue is forecasted to increase by 6 percent over the base run to $28.72 million.

Table 8 below includes the results for all fifteen alternatives that CS modeled in the study. Forecasted ridership, revenue, fare assumptions, vehicle technology, and VMT/VHT reductions are provided for each alternative. More detailed station level ridership is also included in **Tables 9** and **10**.

Table 8: 2035 Results from Minimum Operating Segment Alternatives – (I-70 Markets Only)

Alternative	Description	Fare (per mile)	Technology	Annualized Ridership (in millions)	Annualized Revenue ($ millions)	VMT Reduction (in millions)	VHT Reduction
1	Breckenridge to Golden - Standalone	$0.35	HS Maglev	1.21*	$22.06*	38.62	175,603
2	Breckenridge to DIA – Full System	$0.35	HS Maglev	1.82	$52.97	63.16	53,600
3	Breckenridge to DIA -Standalone	$0.35	HS Maglev	1.24*	$27.15*	44.76	188,129
4	Breckenridge to Golden with El Rancho Station - Standalone	$0.35	HS Maglev	1.16*	$20.94*	36.63	127,439
5	Breckenridge to Golden - Standalone	$0.35	MS Maglev	1.00*	$18.25*	31.87	56,846
6	Breckenridge to DIA – Full System	$0.35	MS Maglev	1.60	$47.08	54.65	-65,093
7	Breckenridge to Golden - Standalone	$0.2625	MS Maglev	1.26*	$17.24*	39.70	69,402
8	Breckenridge to Golden - Standalone	$0.2625	HS Maglev	1.54	$20.85	47.58	215,174
9	Eagle County Regional Airport to Golden – Full System	$0.2625	HS Maglev	4.64	$113.91	180.63	637,341
10	Keystone to Golden - Standalone	$0.2625	HS Maglev	1.35	$17.14	40.76	122,295
11	Eagle County Regional Airport to DIA - Standalone	$0.2625	HS Maglev	3.59	$79.04	152.23	852,987
12	Breckenridge to DIA – Full System	$0.2625	HS Maglev	2.91*	$66.94*	96.94	29,116
13	Breckenridge to DIA – Full System	$0.2625	High Speed Rail	2.68*	$58.28*	89.84	-28,874
14	Breckenridge to DIA – Full System	$0.2625	MS Maglev	2.51*	$56.78*	82.73	-148,742
15	Breckenridge to DIA - Standalone	$0.2625	HS Maglev	1.78*	$28.72*	57.50	210,468

* Indicates the intra-city ridership and revenue values estimated by taking ratio of ridership for 35 cents/26.25 cents runs. Otherwise, intra-city values were provided by SDG model runs.

Table 9: 2035 Ridership Summary by Station (Alternatives 1 to 7)

Stations	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7
Avon	0	0	0	0	0	0	0
Berthoud	0	346,084	0	0	0	344,087	0
Breckenridge	256,531	230,335	249,676	287,222	214,033	190,090	272,542
Castle Rock	0	257,727	0	0	0	255,907	0
Colorado Springs	0	1,107,730	0	0	0	1,105,828	0
Denver (I-76/72nd)	0	455,712	190,088	0	0	441,150	0
DIA	0	797,107	99,768	0	0	773,929	0
Eagle Airport	0	0	0	0	0	0	0
El Rancho	0	0	0	74,346	0	0	0
Fort Carson	0	400,663	0	0	0	400,336	0
Fort Collins	0	1,129,590	0	0	0	1,126,043	0
Idaho Springs	44,979	95,705	53,335	34,737	41,129	86,859	47,347
Keystone	349,900	345,318	360,769	291,244	288,715	279,529	358,637
Lake Hills	0	0	0	0	0	0	0
Lone Tree	0	868,914	0	0	0	863,845	0
Monument	0	618,124	0	0	0	616,737	0
North Suburban	0	413,983	0	0	0	409,909	0
Pueblo	0	711,238	0	0	0	711,050	0
West Suburban	561,452	555,839	281,422	469,383	461,619	507,060	583,832
Vail	0	0	0	0	0	0	0
Intercity Total	1,212,864	8,334,069	1,235,057	1,156,932	1,005,496	8,112,359	1,262,358
Intracity Total	23,310	117,958	125,052	20,979	20,676	104,690	22,555
I-70 Total	1,212,864	1,822,261	1,235,057	1,156,932	1,005,496	1,600,551	1,262,358

Table 10: 2035 Ridership Summary by Station (Alternatives 8 to 15)

Stations	Alt. 8	Alt. 9	Alt. 10	Alt. 11	Alt. 12	Alt. 13	Alt. 14	Alt. 15
Avon	0	357,444	0	377,508	0	0	0	0
Berthoud	0	515,202	0	0	505,918	465,319	482,394	0
Breckenridge	323,098	380,073	0	387,829	323,454	311,372	262,723	331,213
Castle Rock	0	354,997	0	0	350,895	328,511	346,234	0
Colorado Springs	0	1,515,148	0	0	1,509,880	1,398,122	1,478,443	0
Denver (I-76/72nd)	0	762,834	0	488,942	691,163	609,440	622,894	269,310
DIA	0	1,182,912	0	239,262	1,080,616	1,000,053	1,029,554	139,174
Eagle Airport	0	449,779	0	473,629	0	0	0	0
El Rancho	0	0	0	0	0	0	0	0
Fort Carson	0	562,525	0	0	561,151	519,489	548,921	0
Fort Collins	0	1,659,679	0	0	1,646,982	1,429,240	1,579,393	0
Idaho Springs	51,611	245,042	36,404	171,412	135,847	97,147	117,214	62,172
Keystone	430,944	399,845	659,533	425,523	491,827	0	437,231	475,408
Lake Hills	0	0	0	0	0	501,293	0	0
Lone Tree	0	1,149,960	0	0	1,140,639	1,066,238	1,127,720	0
Monument	0	839,677	0	0	836,197	609,513	812,950	0
North Suburban	0	572,429	0	0	561,639	437,601	551,716	0
Pueblo	0	990,835	0	0	989,393	928,536	981,283	0
West Suburban	702,431	1,110,086	623,128	653,594	825,486	746,517	735,770	353,880
Vail	0	206,654	0	222,853	0	0	0	0
Intercity Total	1,508,083	13,255,121	1,319,065	3,440,551	11,651,088	10,448,390	11,114,438	1,631,157
Intracity Total	26,948	261,567	26,948	144,569	136,525	136,525	121,169	144,569
I-70 Total	1,535,031	4,635,464	1,346,013	3,585,120	2,906,471	2,676,462	2,508,416	1,775,726

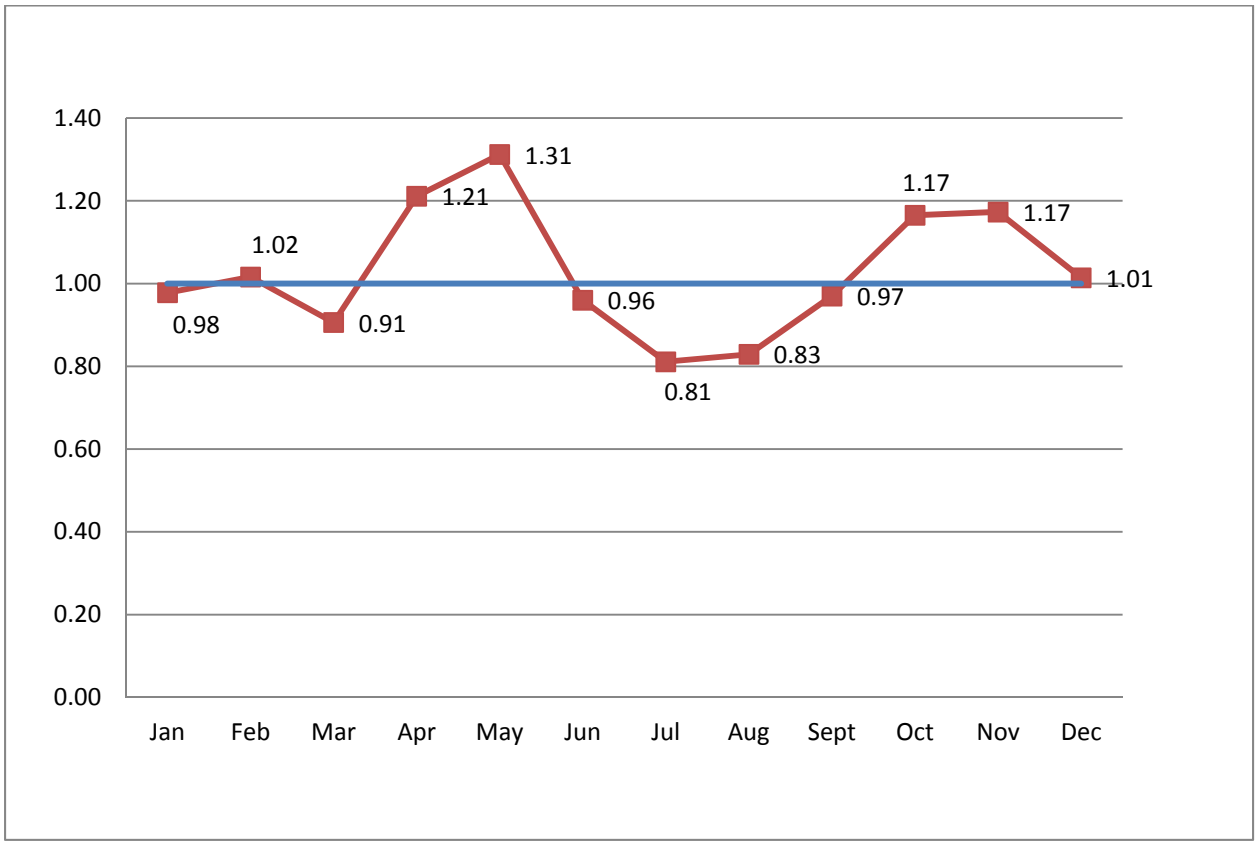
Analysis of Ridership Forecasts

The SDG intercity model produces annualized ridership and revenue forecasts. Annualized ridership forecasts can sometimes be difficult for non-transportation professionals to grasp since comparable statistics for highway volumes are often presented as an average weekday or daily figure. However, the travel patterns found on the I-70 corridor do not really lend themselves to being described by average weekday conditions. Unlike the work-oriented travel patterns found on most of Denver's urban roadways, the I-70 west traffic patterns show atypical characteristics with peak demand profiles on the weekends and during the winter and summer months.

CS reviewed CDOT's observed I-70 traffic count data including their derived monthly and daily factors. While data were provided for several I-70 sites, the most relevant location for this analysis was Site ID 106, located at I-70, northeast of SH 9, Blue River Parkway, at Eisenhower Tunnel. In 2011, the annual average daily traffic (AADT) was 29,000 at this location. All of the AGS alternatives have assumed a western terminus at locations west of the Eisenhower Tunnel. Therefore, the assumption was made that the traffic patterns at this location would reasonably reflect the ridership patterns on the HSR/AGS system.

Before applying the monthly or daily factors to the annualized ridership forecasts, CS graphed the AADT factors to confirm that the observed count data reflected the seasonal and daily peaking characteristics widely recognized in the corridor. Factors below 1.0 indicate traffic is higher than AADT and hence must be adjusted downward to transform the value into AADT. The monthly factors in **Figure 11** show that traffic in the summer months (June to August) is considerably higher than the annual average. Although the winter months of January to March are notorious for the skier-related traffic, they do not show the same above average values as the summer. In fact, only March is considerably above average at 0.91. However, once the daily factors (**Figure 12**) are applied to the monthly factors, the same above average trends are evident in the winter months

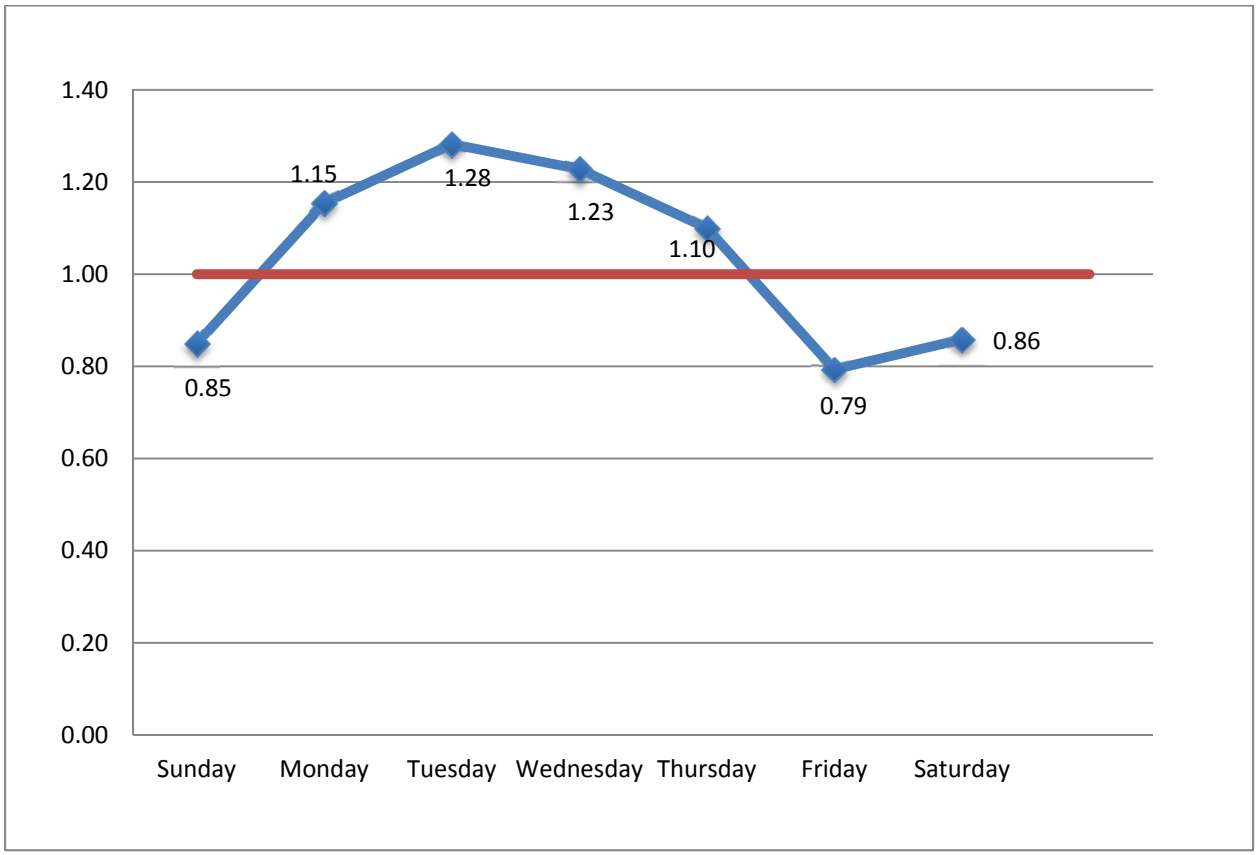
Figure 11: I-70 Average Monthly Variation of Traffic on I-70 at Eisenhower Tunnel



Source: 2011 CDOT I-70 Factors AADT

Figure 12 shows the variation in average daily traffic for 2011. As is evident from the graph, traffic on Friday, Saturday, and Sunday is significantly higher than the AADT which is represented by the data points below 1.0.

Figure 12: Average Daily Variation of Traffic on I-70 at Eisenhower Tunnel



Source: 2011 CDOT I-70 Factors AADT

CS used both the daily and monthly variation data to estimate "average days" for the peak winter, peak summer, and the off-peak seasons. Due to the variation in the monthly and daily data, average days were estimated for the following to illustrate this variation:

Peak Winter – Weekend and Weekday

Peak Summer - Weekend and Weekday

Off-peak - Weekend and Weekday

Peak winter was defined by using the average factor data for the months of January, February, and March. **Peak summer** was defined by the months of June, July, and August. The **Off-peak** was defined using the remaining six months of April, May, September, October, November, and December. The **weekend** was defined as Friday to Sunday while the **weekday** was defined as Monday to Thursday.

The annualized ridership forecasts were first converted to annual average daily ridership (which is analogous to roadway AADT) by dividing by 365 days. The annual average daily ridership was then divided by the appropriate factors for the season and day of the week. The seasonal factors reflect the average factors for the three winter months, three summer months, and remaining six spring and fall months.

Annualized ridership forecasts were converted to average seasonal days for three MOS alternatives, which were selected to show the range of the ridership estimates. **Table 13** below shows the ridership for "average weekend day" and "average weekday" for the peak winter, peak summer, and off-peak seasons for Alternative 1. Alternative 1 assumes HS Maglev from Golden to Breckenridge as a standalone line with $0.35 per mile fare. Forecasted ridership varies from about 2,650 for an average peak winter weekday to about 4,200 for an average peak winter weekend.

Table 13: Alternative 1 – 2035 Average Ridership by Season and Day

	Weekend	Weekday
Peak Winter	4,200	2,650
Peak Summer	3,950	2,800
Off-peak	3,900	2,850

Alternative 15 assumes HS Maglev from DIA to Breckenridge as a standalone line with $0.2625 per mile fare. Forecasted ridership would vary between roughly 3,900 during an average peak winter weekday up to 6,150 during an average peak winter weekend day. **Table 14** below has a summary of the estimated average ridership for Alternative 15.

Table 14: Alternative 15 – 2035 Average Ridership by Season and Day

	Weekend	Weekday
Peak Winter	6,150	3,900
Peak Summer	5,800	4,125
Off-peak	5,700	4,175

Alternative 9 assumes HS Maglev from Golden to the Eagle County Regional Airport with the full ICS system and $0.2625 per mile fare assumption. Average ridership is forecasted in the range of 10,100 for a peak winter weekday to 16,000 for a peak winter weekend. A summary of average ridership for Alternative 9 is provided in **Table 15** below.

Table 15: Alternative 9 – 2035 Average Ridership by Season and Day

	Weekend	Weekday
Peak Winter	16,000	10,100
Peak Summer	15,150	10,800
Off-peak	14,900	10,900

AGS Ridership Compared to Other Systems

The conversion of the annualized ridership values to typical "average days" for peak winter and peak summer seasons allow a basis of comparison to other transit projects in the Denver metro area. Although these examples serve different travel markets, they do provide a general benchmark on the AGS' performance relative to other existing and proposed systems.

The Regional Transportation District (RTD) as part of their multi-billion dollar FasTracks program developed ridership forecasts for each of their planned fixed-guideway projects. **Table 16** provides RTD's official forecasts on some of the corridors for opening year and the 2035 horizon year.

Table 16: Average Weekday Ridership Forecasts for Select FasTrack Corridors

Corridor	Project Description	Opening Year	Year 2035
East	22.8 mile commuter rail line from DUS to DIA	27,700	43,600
Gold	11.2 mile electric commuter Rail line from DUS to City of Wheatridge	10,000	13,900
I-225	10.5 mile light rail line within Aurora connecting East and Southeast Corridors	17,700	34,400
West	12.1 mile light rail line from DUS to Jefferson County Government Center	19,300	29,700

Source: RTD Planning & Development Committee Ridership Update, August 7, 2012

The I-70 AGS "average ridership" is in the range of 2,650 at the low end up to 16,000 depending on the fare assumptions, stations, and whether it operates as a standalone or part of the ICS system. The upper band of the AGS ridership forecast would put it above the Gold line which is planned to open in 2016.

It is difficult to find an HSR/AGS project that serves a market similar to that served by the I-70 HSR/AGS system. Most of the new HSR/AGS investments are occurring in regions that already have existing networks of HSR trains such as in France, Spain, and Germany. Furthermore, many of these HSR systems connect populous urban areas. This makes it difficult

to directly compare ridership forecasts for the I-70 HSR/AGS to existing or forecast ridership on systems in other areas. However, another way to compare the I-70 HSR/AGS with other HSR/AGS systems is to compare mode shares. The observed rail shares from the European systems, for example, can provide another check whether the ridership forecasts for the I-70 HSR/AGS system are reasonable.

- In France, rail's share of the overall transportation market is 9.6 percent which is one of the highest in Europe.[4]

- Spain's high speed rail network is called Alta Velocidad Espanola (AVE). Rail mode share, including conventional rail, is said to account for 4.8 percent of the total Spanish travel market. The new Barcelona-Madrid AVE increased mode share from 11 percent on conventional rail to 38 percent at the end of its first year in operating in 2008.[5]

- Great Britain has a relatively small high speed rail network. As of 2004, rail's travel market share in Great Britain was 6.4 percent (including conventional rail).

- Germany's HSR network is less extensive than in France. The ICE (inter-city express) is the main high speed rail provider. As of 2004, rail's travel market share in Germany was 8.4 percent (including conventional rail).

HSR/AGS mode shares from model results were calculated by dividing the HSR/AGS ridership by the input auto trip tables used in SDG's intercity model. Because diverted auto trips and induced trips comprise the ridership forecasts produced by the intercity model, the mode shares were calculated in two ways. In the first method, mode share was calculated by dividing the diverted auto trips by the input auto person trip table. In the second method, the sum of the diverted trips and induced trips was divided by the sum of the auto person trips and induced trips. Only the I-70 travel markets were used in the calculation. The calculated mode shares were in the range of approximately 5 percent to 20 percent. Lower mode shares are computed for alternatives where the full ICS system was assumed, in part because the travel market also includes travel between the I-25 and I-70 areas, for which a transfer would be required on the new transit service. The standalone MOS alternatives had the highest mode shares that ranged from about 15 percent to 25 percent depending on technology, fare assumption, and alignment. **Table 17** has a summary of the calculated mode shares for each model run.

Table 17: 2035 Model Mode Shares

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[4] Steer Davies Gleave. 2004. *High Speed Rail: International Comparisons.* Prepared for the Commission for Integrated Transport.

[5] Kingstone, Steve. 2009. "Trains in Spain Signal the Future." *BBC News.* September 22, 2009.

Alternative	Description	Technology	Fare (per mile)	Mode Share – Diverted Ridership	Mode Share – All Ridership
1	Breckenridge to Golden - Standalone	HS Maglev	$0.35	18.5%	20.1%
2	Breckenridge to DIA – Full System	HS Maglev	$0.35	5.9%	6.4%
3	Breckenridge to DIA - Standalone	HS Maglev	$0.35	13.9%	15.1%
4	Breckenridge to Golden with El Rancho Station - Standalone	HS Maglev	$0.35	17.4%	18.9%
5	Breckenridge to Golden - Standalone	MS Maglev	$0.35	15.7%	17.0%
6	Breckenridge to DIA – Full System	MS Maglev	$0.35	5.2%	5.7%
7	Breckenridge to Golden - Standalone	MS Maglev	$0.2625	19.5%	21.3%
8	Breckenridge to Golden - Standalone	HS Maglev	$0.2625	22.7%	24.8%
9	Eagle County Regional Airport to Golden – Full System	HS Maglev	$0.2625	10.9%	11.9%
10	Keystone to Golden - Standalone	HS Maglev	$0.2625	21.2%	23.1%
11	Eagle County Regional Airport to DIA - Standalone	HS Maglev	$0.2625	18.5%	20.3%
12	Breckenridge to DIA – Full System	HS Maglev	$0.2625	8.9%	9.8%
13	Breckenridge to DIA – Full System	High Speed Rail	$0.2625	8.8%	9.6%
14	Breckenridge to DIA – Full System	MS Maglev	$0.2625	7.7%	8.4%
15	Breckenridge to DIA - Standalone	HS Maglev	$0.2625	18.1%	19.8%

Conclusion

This section provides a brief summary of the main conclusions in this memorandum.

- The treatment of some variables in the stated preference survey and mode choice models could have been more consistent or improved in some other way.
    - In particular, automobile costs (toll and gasoline) could have been treated more consistently in the SP survey and between the survey and model procedures.

- Including scheduled service frequency as a stand-alone variable may have resulted in improved forecast accuracy.

- Likewise, including service reliability in the model may have resulted in improved forecast accuracy and greater flexibility in testing policy variables.

- A series of runs using the intercity model helped ensure consistency between the SDG forecasts and the subsequent CS forecasts. This process also verified that there were no hardware or other issues related to transferring the model across computing platforms.

- Sensitivity tests were conducted for all of the major model variables and alternative-specific constants. These tests revealed that the model may be overly sensitive to fares, indicating that results as they relate to fare assumptions should be interpreted in this context.

- Converting the annual forecasted ridership into estimated average daily value suggests that daily ridership would be on the order of about 2,600 on a peak winter weekday for a limited system priced at $0.35 per mile to roughly 16,000 for a peak winter weekend travel day given a more expansive HSR network and a reduced fare.

- A comparison of the model HSR/AGS ridership forecasts with ridership on existing or planned HSR systems is difficult because most new projects are in markets with a developed HSR network or connect very populous urban areas.

- Model mode shares are in the range of 5 percent to as high as 23 percent depending on the fare, station locations, mode, and background HSR/AGS network. Compared with observed HSR mode shares in Europe, the model mode shares fall within a reasonable range.