Appendix A.

Benefit Cost Analysis and Methodology for SH 99 (Grand Parkway) – Segment 1-2

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Executive Summary

This memorandum summarizes the approach used for conducting a Benefit-Cost Analysis (BCA) for the Grand Parkway Segment I-2, in the Houston Metropolitan Area, Texas. Table 1 shows the project matrix, which describes baseline conditions, proposed improvements, types of impacts to all users/population affected, a summary of results, and the page reference in this memorandum. The cost effectiveness analysis shows that with a discount rate of 7 percent, the project is expected to generate $263 million in benefits, which leads to a net present value of $112 million. For that discount rate, the benefit-cost ratio equals 1.75. The largest share of benefits are travel time savings, a result that is driven by the significant increase in average speeds in the project area for: 1) users of road Segment I-2B in the baseline, and 2) users that divert from other routes due to faster speeds on Segment I-2B. The results also show sizable benefits in terms of avoided vehicle crashes due to the road redesigning, which changes from a two-lane and two-way road to a safer four-lane divided road. The project is expected to increase VMT and the average miles traveled per trip in the project area, which causes an increase in vehicle operating costs. The monetary value of additional vehicle operating costs per user, however, is small with respect to the total amount of travel time savings. A sensitivity analysis was performed in order to test whether assumptions in the cost effectiveness assessment could significantly change the direction and magnitude of results. It shows that all alternatives continue to lead to healthy benefit-cost ratios and that the project remains cost effective under those scenarios.

Table 1: Project Matrix

Current Status and Problem	Changes to Baseline	Types of Impacts	Population Affected	Economic Benefit	Summary of Results (7% Disc., 2015 Million Dollar)	Page Ref.
Lack of efficient connections between major radial roadways and suburban communities, local ports, and industries Existing conditions: SH 99 Segment I2B is a two-lane two-way road	Construction of: 1) four new tolled main lanes, 2) five bridged overpasses, 3) widening of existing bridge, 4) reconstruction of four lane frontage road, over a 6.1-mile segment (I-2B) Upgrading tolling equipment on existing 8.7-mile Segment I-2A	Increased capacity Increased travel speeds and improved travel time Improved Accessibility Change in Vehicle Operating Costs	Corridor users: trucks and autos	Monetized Value of Reduced Travel Time	$294.3	4
				Monetized Value of Reduced Vehicle Operating Costs	- $110.8	5
		Reduced costs of crashes due to safer road type	Local, state, and national population	Monetized Value of Reduced Crashes	$35.5	9
		Change in air emissions generated by motor vehicles	Local, state, region, and national population	Monetized Value of Reduced Carbon Emissions	-$6.1	7
				Monetized Value of Reduced Non-Carbon Emissions	-$2.0	8
		Reduced pavement maintenance costs	Government	Monetized Value of Reduced Pavement Maintenance Costs	$6.3	11

Project Background

The Texas Department of Transportation (TxDOT) State Highway (SH) 99 is seeking to add capacity to Segment I-2B and improve conditions in Segment I-2A. The project consists in the design and construction of four additional toll lanes (two each direction) from Farm-to-Market (FM) 1405 to SH 146, with five bridged overpasses, widening of existing bridges, retaining walls, drainage storm sewer and outfall structures, utility adjustments, removal of railroad bridge underpass and reconstruction of four-lane frontage road. The existing type of road in Segment I2-B is a two-lane two-way road.

The project is expected to: 1) improve the connectivity from SH146 to the Port of Houston Authority Container Terminal facilities, and 2) allow continuous non-stop movements from SH 146 to I-20 and to other segments of SH 99. The project is also expected to enhance mobility and reduce existing congestion, increasing capacity and improving the movement of goods to Port of Houston, Cedar Port, associated container terminals, petrochemical facilities, etc.

Cost Effectiveness Analysis

This section describes the methodology for estimating the benefits and costs of the Grand Parkway Segment I-2 project. In calculating the benefit-cost analysis, Cambridge Systematics Inc. (CS) followed Federal guidance regarding evaluation criteria, discount and monetization rates, and evaluation methods prescribed in the 2016 TIGER and FASTLANE guidance and supporting documents.

The BCA provides monetary benefits and costs, in present day dollars, associated with the project over the analysis period between 2022 and 2050. The estimated benefits have been categorized in four of the long-term outcomes listed in the BCA Resource Guide as follows: State of Good Repair, Economic Competitiveness, Environmental Sustainability, and Safety. An effort was made to comply with all BCA guidelines and a conservative approach has been used for all assumptions.

Travel Demand

The travel demand impact of the project was estimated using the Texas Statewide Analysis Model (SAM) with a build and a no-build scenarios in 2025 and 2040. The model was run in December 2016 by Cambridge Systematics, Inc. A variety of metrics were estimated for all trips in the four scenarios: number of trips, vehicle miles traveled (VMT), vehicle hours traveled (VHT), vehicle hours of delay (VHD) for auto commute, auto non-commute (leisure, henceforth), and trucks. The model output was calculated for Segment I2-B only and a broader project area, since it is also expected to affect trips that redirect from different routes.

The results in the larger project area show that the project will have a high impact on travel demand. Both in 2025 and 2040, the model reveals a reduction in total flow, a reduction in total vehicle hours and a reduction in total vehicle delay, however, the project also leads to an increase in total vehicle miles. This can be explained by the fact that new capacity on Segment I-2B does not only benefit current SH 99 users, but also reroutes other trips that did not go through the link in the no-build scenario. These users reap a significant amount of travel time savings using the new toll roads, and they choose so in spite of the additional miles of travel.

This outcome is confirmed by the travel demand output for road Segment I2-B only. It shows that flow and vehicle miles traveled increase substantially, as expected after a significant expansion in roadway capacity. However, it also shows that total delay declines by 48 percent in the segment, while delay per mile also sharply decreases.

Annual figures for VMT and VHT were calculated by type of trip and by type of vehicle (auto commute, auto leisure, and truck) for the model build and no-build scenarios in 2025 and 2040. The following annualization rates were used for each trip type: 365 days for leisure and truck, and 260 days for commuting trips. VMT and VHT between 2025 and 2040 were obtained by linear interpolation.

The project useful life is between 2022 and 2050; therefore, the estimation of the benefits and costs starts from present day until year 2050. Since no demand model data is available from 2022 (when the project is expected to be opened to traffic) to 2025 and from 2041 to 2050, the compound annual growth rate for vehicle miles traveled in the build scenario was assumed (1.9 percent).

Travel Time Savings

Travel Time savings were calculated based on the difference between vehicle hours per mile in the build and no-build scenarios. Since the model predicts an additional amount of vehicle miles in the project area due to rerouted trips, these additional vehicles also bring about an increase in total vehicle hours. Because of the impact of induced travel on the magnitude of aggregate VHT, using this figure directly to calculate private benefits would mask the real benefits of the project. Therefore, the analysis calculates the travel time savings for each vehicle mile traveled, such as in the following equation:

$$\Delta VHT_{TT}^{User} = VMT_{Build} * (\frac{VHT_{Build}}{VMT_{Build}} - \frac{VHT_{NoBuild}}{VHT_{NoBuild}})$$

Where ΔVHT_{TT}^{User} is the change in total vehicle hours traveled calculated on a mile basis, VMT is total annual vehicle miles traveled, $\frac{VHT}{VMT}$ is the inverse of average system speed (in hours per mile) for the build and no-build scenarios. The faster vehicles travel in the build the scenario with respect to the no-build scenario, the higher the travel time savings.

In addition, the following equation was used for monetizing travel time savings for each year between 2022 and 2050 (in 2015 dollar).

$$\$TTS_{TT} = \Delta VHT_{TT}^{User} * AVO_{TT} * VOT_{TT}$$

Where $\$TTS$ is monetized travel time Savings, VHT is annual vehicle hours of travel as previously calculated, AVO is Average Vehicle Occupancy (for which 2015 American Community Survey (ACS) data for Houston Metropolitan Statistical Area was used for auto commuting trips, 2009 NHTS data used for non-work auto trips, and 1 was assumed for truck trips), and VOT is Value of Time, for which the recommended values in the FASTLANE BCA Resource Guide were used and expressed in 2015 dollars. In the formula, the types of trip include $TT = \{Commute, Leisure, Truck\}$. Table 2 summarizes the results in term of Travel Time Savings:

Table 2: Travel Time Savings

Year	Calendar Year	Travel Time Savings [Σ (ΔVHT per mile)]	Monetary Value of Travel Time Saved	NPV of Travel Time Savings	
		All Trips	All Trips	3%	7%
		Hours	$ 2015	NPV = [J/(1+3%)^A]	NPV = [J/(1+7%)^A]
5	2022	477,567	**$13,008,710**	$11,221,427	$9,275,030
6	2023	486,518	**$13,252,540**	$11,098,794	$8,830,727
7	2024	495,637	**$13,500,941**	$10,977,500	$8,407,707
8	2025	504,927	**$13,753,997**	$10,857,532	$8,004,951
9	2026	605,440	**$16,468,047**	$12,621,387	$8,957,527
10	2027	706,095	**$19,186,083**	$14,276,248	$9,753,232
11	2028	806,885	**$21,907,864**	$15,826,707	$10,408,268
12	2029	907,802	**$24,633,168**	$17,277,209	$10,937,421
13	2030	1,008,837	**$27,361,792**	$18,632,049	$11,354,171
14	2031	1,109,985	**$30,093,546**	$19,895,379	$11,670,796
15	2032	1,211,239	**$32,828,257**	$21,071,209	$11,898,471
16	2033	1,312,593	**$35,565,763**	$22,163,408	$12,047,354
17	2034	1,414,043	**$38,305,915**	$23,175,708	$12,126,672
18	2035	1,515,582	**$41,048,573**	$24,111,711	$12,144,792
19	2036	1,617,207	**$43,793,609**	$24,974,883	$12,109,298
20	2037	1,718,913	**$46,540,902**	$25,768,569	$12,027,054
21	2038	1,820,696	**$49,290,340**	$26,495,987	$11,904,262
22	2039	1,922,553	**$52,041,818**	$27,160,235	$11,746,524
23	2040	2,024,480	**$54,795,238**	$27,764,295	$11,558,885
24	2041	2,062,426	**$55,822,300**	$27,460,872	$11,005,178
25	2042	2,101,083	**$56,868,612**	$27,160,766	$10,477,995
26	2043	2,140,465	**$57,934,535**	$26,863,939	$9,976,066

Year	Calendar Year	Travel Time Savings [Σ (ΔVHT per mile)]	Monetary Value of Travel Time Saved	NPV of Travel Time Savings	
		All Trips	All Trips	3%	7%
		Hours	$ 2015	NPV = [J/(1+3%)^A]	NPV = [J/(1+7%)^A]
27	2044	2,180,585	**$59,020,438**	$26,570,355	$9,498,181
28	2045	2,221,457	**$60,126,695**	$26,279,981	$9,043,188
29	2046	2,263,095	**$61,253,687**	$25,992,779	$8,609,991
30	2047	2,305,514	**$62,401,803**	$25,708,716	$8,197,545
31	2048	2,348,727	**$63,571,438**	$25,427,758	$7,804,857
32	2049	2,392,751	**$64,762,997**	$25,149,870	$7,430,979
33	2050	2,437,600	**$65,976,890**	$24,875,019	$7,075,012
Totals =		44,120,701	$1,195,116,499	$626,860,292	$294,282,132

Note: Positive values represent benefits and negative values represent disbenefits.

Changes in Vehicle Operating Costs

Since the project generates an aggregate increase in VMT, vehicle operating costs are expected to increase. However, since they represent a user cost (in the same way as travel time), the average vehicle operating cost for each trip must be calculated. In order to do so, we base our VMT changes on the average trip length between the build and no-build scenario, according to the equation below:

$$\Delta VMT_{TT}^{User} = TotalTrips_{Build} * \left(\frac{VMT_{Build}}{TotalTrips_{Build}} - \frac{VMT_{NoBuild}}{Total\ Trips_{NoBuild}}\right)$$

Where ΔVMT_{TT}^{User} is the change in total vehicle miles traveled calculated on a trip basis, $TotalTrips$ is the vehicle flow, and $\frac{VMT}{TotalTrips}$ is the average trip length. The number of miles traveled per trip will dictate the actual increase in vehicle operating costs per trip. In fact, we find that the average trip length in the build scenario increases with respect to the no-build scenario (in spite of savings in travel time, revealing that motorists on average prefer a longer but faster route), which will lead to a disbenefit in terms of vehicle operating costs.

Changes in VOC are calculated using the following equation for each year between 2022 and 2050:

$$VOCS_{VT} = \Delta VMT_{TT}^{User} * VOC_{VT}$$

Where $VT = \{Auto, Truck\}$, $VOCS$ is Vehicle Operating Cost Savings, ΔVMT_{TT}^{User} is change in vehicle miles traveled as defined above, and VOC is Vehicle Operating Costs in dollars per mile, based on data from AAA[1]. The monetized results are shown in Table 3.

Table 3: Vehicle Operating Cost (VOC) Savings

		Change in Miles Traveled [Σ (ΔVMT per Trip)]	Value of VOC changes	NPV of Vehicle Operating Cost Saved	
		All Trips	All Trips	3%	7%
Year	Calendar Year	Miles	$ 2015	NPV = [J/(1+3%)^A]	NPV = [J/(1+7%)^A]
5	2022	13,875,398	-$10,009,705	-$8,634,460	-$7,136,781
6	2023	14,135,473	-$10,197,323	-$8,540,098	-$6,794,907
7	2024	14,400,423	-$10,388,458	-$8,446,767	-$6,469,410
8	2025	14,670,339	-$10,583,175	-$8,354,456	-$6,159,504
9	2026	14,917,165	-$10,764,265	-$8,249,913	-$5,855,047
10	2027	15,164,177	-$10,945,526	-$8,144,500	-$5,564,151
11	2028	15,411,365	-$11,126,949	-$8,038,345	-$5,286,334
12	2029	15,658,720	-$11,308,526	-$7,931,573	-$5,021,121
13	2030	15,906,234	-$11,490,248	-$7,824,300	-$4,768,044
14	2031	16,153,898	-$11,672,108	-$7,716,639	-$4,526,645
15	2032	16,401,704	-$11,854,100	-$7,608,696	-$4,296,471
16	2033	16,649,646	-$12,036,217	-$7,500,572	-$4,077,083
17	2034	16,897,717	-$12,218,453	-$7,392,365	-$3,868,049
18	2035	17,145,910	-$12,400,802	-$7,284,164	-$3,668,950
19	2036	17,394,221	-$12,583,259	-$7,176,057	-$3,479,376
20	2037	17,642,643	-$12,765,819	-$7,068,125	-$3,298,930
21	2038	17,891,172	-$12,948,478	-$6,960,445	-$3,127,227
22	2039	18,139,803	-$13,131,231	-$6,853,091	-$2,963,892
23	2040	18,388,531	-$13,314,075	-$6,746,132	-$2,808,563
24	2041	18,733,199	-$13,563,628	-$6,672,406	-$2,674,024
25	2042	19,084,327	-$13,817,860	-$6,599,487	-$2,545,929
26	2043	19,442,036	-$14,076,857	-$6,527,364	-$2,423,971
27	2044	19,806,450	-$14,340,708	-$6,456,030	-$2,307,855

1 Average costs per mile includes costs for fuel, maintenance, tires, full-coverage insurance, fees (license and registration) and taxes, depreciation, and financing. Calculated for an average auto and an average truck. Source: Your Driving Costs, 2015 Edition (AAA).

Year	Calendar Year	Change in Miles Traveled [Σ (ΔVMT per Trip)]	Value of VOC changes	NPV of Vehicle Operating Cost Saved	
		All Trips	All Trips	3%	7%
		Miles	$ 2015	NPV = [J/(1+3%)^A]	NPV = [J/(1+7%)^A]
28	2045	20,177,695	-$14,609,505	-$6,385,475	-$2,197,302
29	2046	20,555,898	-$14,883,340	-$6,315,691	-$2,092,044
30	2047	20,941,190	-$15,162,307	-$6,246,670	-$1,991,829
31	2048	21,333,704	-$15,446,504	-$6,178,403	-$1,896,414
32	2049	21,733,575	-$15,736,027	-$6,110,882	-$1,805,570
33	2050	22,140,940	-$16,030,977	-$6,044,099	-$1,719,077
Totals =		**510,793,553**	**-$369,406,433**	**-$210,007,204**	**-$110,824,499**

Note: Positive values represent benefits and negative values represent disbenefits.

Change in CO_2 emissions

The changes in the value of CO_2 emissions must be calculated as a function of aggregate VMT changes in the system. Since avoided (or additional) CO_2 is a public benefit (or cost), the base for the calculation of changes in VMT must not be trips, as used for the estimation of changes in vehicle operating costs (which is a private benefit). Higher mileage is expected to create more carbon emissions, as detailed in the equation below, calculated for years between 2022 and 2050:

$$\$CO_{2,VT} = \Delta VMT_{VT} * CO_2ER_{Speed} * SCC$$

Where $\$CO_{2,VT}$ is equal to the monetized value of the change in carbon emissions, ΔVMT is the annual change in total vehicles miles traveled systemwide, CO_2ER_{Speed} is equal to the CO_2 emission rate per gallon of gas for a given speed (the system average speed was used for each year, as estimated with the results of the TDM) and it is expressed in metric tons (with data from MOVES 2014[2]), and SCC, as described above, is the social cost of carbon per metric ton, for which the recommended monetized value in the FASTLANE Benefit-Cost Analysis guidance was used (with values that change in time up to 2050).

Table 4 summarizes the results, which are presented only with a 3-percent discount rate per FASTLANE Benefit-Cost Analysis guidance.

2 https://www.epa.gov/air-pollution-transportation.

Table 4: Avoided Social Cost of CO_2 Emissions (from total ΔVMT]

Year	Calendar Year	CO2 Emission Savings (3% SCC)	NPV of Emission Savings
		All Trips	3%
		$ 2015	NPV = [J/(1+3%)^A]
5	2022	-$197,483	-$170,350
6	2023	-$205,558	-$172,151
7	2024	-$209,411	-$170,270
8	2025	-$222,414	-$175,576
9	2026	-$234,932	-$180,056
10	2027	-$247,770	-$184,364
11	2028	-$260,927	-$188,499
12	2029	-$274,403	-$192,460
13	2030	-$288,198	-$196,249
14	2031	-$302,312	-$199,864
15	2032	-$311,089	-$199,676
16	2033	-$331,498	-$206,579
17	2034	-$346,570	-$209,681
18	2035	-$361,961	-$212,614
19	2036	-$377,671	-$215,381
20	2037	-$393,700	-$217,982
21	2038	-$410,049	-$220,422
22	2039	-$426,717	-$222,700
23	2040	-$443,704	-$224,821
24	2041	-$459,083	-$225,838
25	2042	-$482,078	-$230,243
26	2043	-$498,444	-$231,126
27	2044	-$515,254	-$231,962
28	2045	-$524,912	-$229,427
29	2046	-$542,501	-$230,208
30	2047	-$560,564	-$230,945
31	2048	-$579,115	-$231,638
32	2049	-$598,163	-$232,289
33	2050	-$626,070	-$236,045
Totals =		**-$11,232,551**	**-$6,069,417**

Note: Positive values represent benefits and negative values represent disbenefits.

Avoided Non-CO_2 emissions

Non-Carbon vehicle emissions considered in this cost-effectiveness analysis include: Volatile Organic Compounds (VOC), Particular Matter (PM), Nitrogen Oxides (NOX), and Sulfur Oxides (SOX). The project is expected bring about an increase in emission levels due the projected grow in vehicle miles traveled in the aggregate. The change in the value of these emissions can be calculated with the following equation for years between 2022 and 2050:

$$\$Emissions_{ET,VT} = \Delta VMT_{VT} * ER_{ET,VT,Speed} * EC_{ET}$$

Where $\$Emissions_{ET,VT}$ is the total monetized emission savings by type of emission and type of vehicle (truck or auto), ΔVMT is the annual change in total vehicles miles traveled systemwide, ER is equal to the emission rate per gallon of fuel for a given speed (the system average speed was used for each year, as estimated with the results of the TDM) in short tons (with data from MOVES 2014[3]), and EC is the emission cost per short ton, as indicated in the FASTLANE Benefit-Cost Analysis guidance. Table 5 describes the monetized benefits by emission type.

Table 5: Avoided Non-Carbon Emission Costs

Year	Calendar Year	VOC Emission Savings	NOx Emission Savings	PM Emission Savings	SOx Emission Savings	Total Non-Carbon Emission Savings	NPV of Non-Carbon Emission Savings	
		All Trips	All Trips	All Trips	All Trips	All Trips	3%	7%
		$ 2015	$ 2015	$ 2015	$ 2015	$ 2015	NPV = [J/(1+3%)^A]	NPV = [J/(1+7%)^A]
5	2022	-$7,032	-$95,041	-$57,183	-$4,030	-$163,286	-$140,852	-$116,421
6	2023	-$7,164	-$96,823	-$58,255	-$4,105	-$166,347	-$139,313	-$110,844
7	2024	-$7,298	-$98,637	-$59,347	-$4,182	-$169,464	-$137,790	-$105,534
8	2025	-$7,435	-$100,486	-$60,459	-$4,260	-$172,641	-$136,284	-$100,479
9	2026	-$7,693	-$103,959	-$62,569	-$4,410	-$178,631	-$136,906	-$97,164
10	2027	-$7,950	-$107,431	-$64,680	-$4,560	-$184,622	-$137,376	-$93,852

3 https://www.epa.gov/air-pollution-transportation.

11	2028	-$8,208	-$110,904	-$66,790	-$4,710	-$190,612	-$137,702	-$90,558
12	2029	-$8,465	-$114,377	-$68,901	-$4,860	-$196,602	-$137,893	-$87,294
13	2030	-$8,723	-$117,849	-$71,012	-$5,009	-$202,593	-$137,956	-$84,069
14	2031	-$8,980	-$121,322	-$73,122	-$5,159	-$208,583	-$137,898	-$80,892
15	2032	-$9,238	-$124,794	-$75,233	-$5,309	-$214,573	-$137,727	-$77,771
16	2033	-$9,495	-$128,267	-$77,343	-$5,459	-$220,564	-$137,448	-$74,713
17	2034	-$9,753	-$131,739	-$79,454	-$5,609	-$226,554	-$137,069	-$71,721
18	2035	-$10,010	-$135,212	-$81,564	-$5,758	-$232,545	-$136,595	-$68,802
19	2036	-$10,268	-$138,685	-$83,675	-$5,908	-$238,535	-$136,033	-$65,957
20	2037	-$10,525	-$142,157	-$85,785	-$6,058	-$244,525	-$135,388	-$63,190
21	2038	-$10,782	-$145,630	-$87,896	-$6,208	-$250,516	-$134,665	-$60,503
22	2039	-$11,040	-$149,102	-$90,006	-$6,358	-$256,506	-$133,869	-$57,897
23	2040	-$11,297	-$152,575	-$92,117	-$6,507	-$262,496	-$133,005	-$55,373
24	2041	-$11,509	-$155,435	-$93,843	-$6,629	-$267,417	-$131,551	-$52,720
25	2042	-$11,725	-$158,348	-$95,602	-$6,754	-$272,429	-$130,114	-$50,195
26	2043	-$11,945	-$161,316	-$97,394	-$6,880	-$277,535	-$128,692	-$47,790
27	2044	-$12,169	-$164,340	-$99,220	-$7,009	-$282,737	-$127,285	-$45,501
28	2045	-$12,397	-$167,420	-$101,079	-$7,141	-$288,037	-$125,894	-$43,321
29	2046	-$12,629	-$170,558	-$102,974	-$7,274	-$293,436	-$124,518	-$41,246
30	2047	-$12,866	-$173,755	-$104,904	-$7,411	-$298,936	-$123,158	-$39,270

31	2048	-$13,107	-$177,012	-$106,870	-$7,550	-$304,539	-$121,812	-$37,389
32	2049	-$13,353	-$180,330	-$108,874	-$7,691	-$310,247	-$120,480	-$35,598
33	2050	-$13,603	-$183,710	-$110,914	-$7,835	-$316,062	-$119,164	-$33,893
Totals =		-$296,657	**-$4,007,213**	**-$2,417,065**	-$170,634	**-$6,891,569**	**-$3,854,434**	**-$1,989,956**

Note: Positive values represent benefits and negative values represent disbenefits.

Safety Benefits

Benefits or costs associated with road safety can be calculated from two sources in this project. On the one hand, traffic accidents are expected to decrease substantially in Segment I-2B because crash rates are historically higher in two-lane and two-way roads (existing conditions) than in four-lane roads divided by a shoulder (such as in the proposed implementation). On the other hand, an increase in aggregate VMT leads to more accidents because the higher the amount of vehicle miles on the road, the higher the traffic exposure to potential crashes.

The first impact is calculated using the following equation for all years between 2022 and 2050:

$$\$Safety_{IT}^{1} = VMT_{No-Build}^{I-2B} * \left(CR_{NoBuild,IT} - CR_{Build,IT}\right) * CC_{It}$$

Where $IT = \{Fatality, Incapacitating\ Injury, Non-Incapacitating\ Injury, Property\ Damage\ Only\}$, $\$Safety^{1}$ is the monetized benefit of a change in expected crashes from a decline in crash rates, $VMT_{No-Build}^{I-2B}$ is aggregate VMT in the Segment I-2B only in the no-build scenario (vehicle miles directly benefiting from safety improvement) measured in 100 million miles, CR is the crash rate measured in incidents per 100 million miles with data for the state of Texas[4] for a two-lane and two-way road and for a four-lane road with shoulders. Finally CC are the incident costs by type of injury, which follows the values suggested by the FASTLANE BCA Resource Guide.

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[4] Source: Texas Motor Vehicle Crash Statistics (2011 to 2015). Fatality, Injury and PDO crash rates for 2-lane, 2-way road and for 4-lane divided road estimated using overall state crash rates by road type, state fatality rates, and statewide fatalities, injuries and PDO crashes.

The second impact can be calculated using the following equation for all years between 2022 and 2050:

$$\$Safety^2_{IT} = \Delta VMT * CR_{Build,IT} * CC_{It}$$

Where $\$Safety^2$ is the monetized value of a change in expected crashes as a result of the change in total VMT, and ΔVMT is the change in VMT between the build and no-build scenarios. CR and CC are defined as in the previous equation.

Table 6 shows the additional benefits and the additional costs in terms of road safety from the two calculated sources of safety impact.

Table 6: Road Safety Benefits

Year	Calendar Year	Value of Reduced Crash Rates on SH 99 Segment I-2B	Value of Crashes Avoided (from total ΔVMT)	Total Value of Avoided Crashes	NPV of Avoided Motor Vehicle Crashes	
		All Trips	All Trips	All Trips	3%	7%
		$ 2015	$ 2015	$ 2015	NPV = [J/(1+3%)^A]	NPV = [J/(1+7%)^A]
5	2022	$4,882,128	-$1,377,071	$3,505,056	$3,023,492	$2,499,057
6	2023	$4,973,636	-$1,402,883	$3,570,754	$2,990,450	$2,379,344
7	2024	$5,066,860	-$1,429,178	$3,637,683	$2,957,769	$2,265,366
8	2025	$5,161,832	-$1,455,966	$3,705,866	$2,925,445	$2,156,848
9	2026	$5,221,376	-$1,507,563	$3,713,813	$2,846,329	$2,020,068
10	2027	$5,280,921	-$1,559,160	$3,721,761	$2,769,340	$1,891,955
11	2028	$5,340,466	-$1,610,757	$3,729,709	$2,694,421	$1,771,958
12	2029	$5,400,011	-$1,662,354	$3,737,656	$2,621,517	$1,659,564
13	2030	$5,459,555	-$1,713,952	$3,745,604	$2,550,574	$1,554,292
14	2031	$5,519,100	-$1,765,549	$3,753,551	$2,481,540	$1,455,692
15	2032	$5,578,645	-$1,817,146	$3,761,499	$2,414,363	$1,363,340
16	2033	$5,638,190	-$1,868,743	$3,769,446	$2,348,994	$1,276,842
17	2034	$5,697,734	-$1,920,340	$3,777,394	$2,285,385	$1,195,826
18	2035	$5,757,279	-$1,971,937	$3,785,342	$2,223,489	$1,119,946
19	2036	$5,816,824	-$2,023,535	$3,793,289	$2,163,260	$1,048,876
20	2037	$5,876,368	-$2,075,132	$3,801,237	$2,104,653	$982,312
21	2038	$5,935,913	-$2,126,729	$3,809,184	$2,047,624	$919,968
22	2039	$5,995,458	-$2,178,326	$3,817,132	$1,992,132	$861,577
23	2040	$6,055,003	-$2,229,923	$3,825,079	$1,938,136	$806,889
24	2041	$6,168,495	-$2,271,720	$3,896,775	$1,916,955	$768,236

Year	Calendar Year	Value of Reduced Crash Rates on SH 99 Segment I-2B	Value of Crashes Avoided (from total ΔVMT)	Total Value of Avoided Crashes	NPV of Avoided Motor Vehicle Crashes	
		All Trips	All Trips	All Trips	3%	7%
		$ 2015	$ 2015	$ 2015	NPV = [J/(1+3%)^A]	NPV = [J/(1+7%)^A]
25	2042	$6,284,115	-$2,314,300	$3,969,815	$1,896,006	$731,435
26	2043	$6,401,902	-$2,357,679	$4,044,224	$1,875,285	$696,397
27	2044	$6,521,897	-$2,401,870	$4,120,027	$1,854,791	$663,037
28	2045	$6,644,141	-$2,446,890	$4,197,251	$1,834,521	$631,276
29	2046	$6,768,676	-$2,492,754	$4,275,923	$1,814,472	$601,036
30	2047	$6,895,546	-$2,539,477	$4,356,069	$1,794,643	$572,244
31	2048	$7,024,793	-$2,587,076	$4,437,718	$1,775,030	$544,832
32	2049	$7,156,463	-$2,635,567	$4,520,897	$1,755,632	$518,733
33	2050	$7,290,602	-$2,684,967	$4,605,635	$1,736,445	$493,884
Totals =		$171,813,931	-$58,428,543	$113,385,388	$65,632,693	$35,450,829

Note: Positive values represent benefits and negative values represent disbenefits.

Avoided Maintenance Costs

Additionally, another quantifiable project benefit is avoided maintenance costs, which can also arise from two different sources. First, the avoided pavement repairs on Segment I-2B (operational and maintenance costs for the new road are accounted as part of the project total costs). Second, the avoided damage to other roads from a change in VMT in the project areas other than Segment I-2B. Because of the amount of vehicles redirecting their trips from other routes, VMT in those routes will decline, causing less damage in those roads.

The first source of benefits can be calculated using the following equation for years 2022 to 2050:

$$MCS_{VT}^{1} = VMT_{No-Build}^{I-2B} * MPC_{VT}$$

Where MCS_{VT}^{2} is maintenance cost savings by vehicle type (auto or truck) as a result of the first source of benefits, $VMT_{No-Build}^{I-2B}$ is aggregate vehicle miles traveled on Segment I-2B only in the no-build scenario, and MPC is the marginal pavement cost per mile traveled in 2015 dollars by vehicle type [as detailed in FHWA (1997)[5]].

5 Source: 1997 Federal Highway Cost Allocation Study, Final Report, Table V-22.

The second source of benefits can be calculated using the following equation for years 2022 to 2050:

$$MCS^2_{VT} = \Delta VMT^{Non\ I-2B} * MPC_{VT}$$

Where MCS^2_{VT} is the maintenance cost savings by vehicle type (auto or truck) as a result of the second source of benefits, $\Delta VMT^{Non\ I-2B}$ is the change in vehicle miles traveled in the project area other than Segment I-2B, and MPC is as described in the previous equation. The total maintenance savings from the two alternative sources are shown in Table 7.

Table 7: Avoided Maintenance Costs

Year	Calendar Year	Avoided Repairs on SH 99 Segment I-2B	Avoided Damage to Roads in Project Area other than Segment I2-B	Total Avoided Maintenance Costs	NPV of Total Avoided Maintenance Costs	
		Segment I2-B Trips	Project area other than Segment I2-B	All Trips	3%	7%
		$ 2015	$ 2015	$ 2015	NPV = [J/(1+3%)^A]	NPV = [J/(1+7%)^A]
5	2022	$601,052	$33,992	$635,044	$547,794	$452,777
6	2023	$612,318	$34,629	$646,947	$541,808	$431,088
7	2024	$623,795	$35,278	$659,073	$535,886	$410,437
8	2025	$635,487	$35,939	$671,426	$530,030	$390,776
9	2026	$640,271	$30,722	$670,992	$514,260	$364,975
10	2027	$645,054	$25,504	$670,559	$498,959	$340,878
11	2028	$649,838	$20,287	$670,125	$484,113	$318,372
12	2029	$654,622	$15,070	$669,691	$469,708	$297,351
13	2030	$659,405	$9,852	$669,258	$455,732	$277,718
14	2031	$664,189	$4,635	$668,824	$442,171	$259,381
15	2032	$668,973	-$582	$668,390	$429,014	$242,255
16	2033	$673,756	-$5,800	$667,956	$416,248	$226,260
17	2034	$678,540	-$11,017	$667,523	$403,862	$211,321
18	2035	$683,324	-$16,234	$667,089	$391,845	$197,368
19	2036	$688,107	-$21,452	$666,655	$380,184	$184,336
20	2037	$692,891	-$26,669	$666,222	$368,871	$172,164
21	2038	$697,675	-$31,887	$665,788	$357,894	$160,797
22	2039	$702,458	-$37,104	$665,354	$347,243	$150,179
23	2040	$755,078	-$94,495	$660,584	$334,712	$139,348
24	2041	$769,231	-$96,266	$672,965	$331,054	$132,673
25	2042	$783,650	-$98,070	$685,579	$327,436	$126,317

Year	Calendar Year	Avoided Repairs on SH 99 Segment I-2B	Avoided Damage to Roads in Project Area other than Segment I2-B	Total Avoided Maintenance Costs	NPV of Total Avoided Maintenance Costs	
		Segment I2-B Trips	Project area other than Segment I2-B	All Trips	3%	7%
		$ 2015	$ 2015	$ 2015	NPV = [J/(1+3%)^A]	NPV = [J/(1+7%)^A]
26	2043	$798,338	-$99,909	$698,429	$323,858	$120,266
27	2044	$813,302	-$101,781	$711,520	$320,319	$114,505
28	2045	$828,546	-$103,689	$724,857	$316,818	$109,020
29	2046	$844,076	-$105,632	$738,443	$313,356	$103,798
30	2047	$859,897	-$107,612	$752,284	$309,931	$98,825
31	2048	$876,014	-$109,629	$766,385	$306,544	$94,091
32	2049	$892,434	-$111,684	$780,750	$303,194	$89,584
33	2050	$909,162	-$113,778	$795,384	$299,881	$85,293
Totals =		$21,001,480	-$1,047,383	$19,954,097	$11,602,726	$6,302,155

Note: Positive values represent benefits and negative values represent disbenefits.

Costs

The total capital costs of the project amount to $170.2 million in current dollars, and operations and maintenance between years 2022 and 2050 is expected to cost $20.1 million. The discounted total project costs are $169.4 million using a 7-percent discount rate, and $150.7 million using a 3% discount rate, as described in Table 8.

Table 8: Project Life Cycle Costs

Year	Calendar Year	Capital Costs (in 2015 Dollar)	O&M Costs (in 2015 Dollar)	NPV of Total Costs	
				3%	7%
				E + G	F + H
0	2017	$548,115	$0	$548,115	$548,115
1	2018	$20,741,234	$0	$20,137,120	$19,384,331
2	2019	$90,168,534	$0	$84,992,491	$78,756,690
3	2020	$50,549,298	$0	$46,259,768	$41,263,285
4	2021	$7,577,713	$0	$6,732,700	$5,781,001
5	2022	$615,106	$34,424	$560,290	$463,106
6	2023	$0	$37,554	$31,451	$25,024
7	2024	$0	$37,554	$30,535	$23,386

Year	Calendar Year	Capital Costs (in 2015 Dollar)	O&M Costs (in 2015 Dollar)	NPV of Total Costs	
				3%	7%
				E + G	F + H
8	2025	$0	$37,554	$29,645	$21,857
9	2026	$0	$39,974	$30,636	$21,743
10	2027	$0	$41,184	$30,644	$20,936
11	2028	$0	$41,184	$29,752	$19,566
12	2029	$0	$741,831	$520,305	$329,382
13	2030	$0	$1,325,675	$902,720	$550,108
14	2031	$0	$741,789	$490,410	$287,678
15	2032	$0	$391,465	$251,266	$141,885
16	2033	$0	$391,465	$243,948	$132,603
17	2034	$0	$391,465	$236,843	$123,928
18	2035	$0	$391,465	$229,944	$115,820
19	2036	$0	$449,845	$256,540	$124,386
20	2037	$0	$479,035	$265,230	$123,792
21	2038	$0	$479,035	$257,505	$115,693
22	2039	$0	$1,403,401	$732,424	$316,766
23	2040	$0	$1,865,583	$945,276	$393,539
24	2041	$0	$941,218	$463,017	$185,558
25	2042	$0	$479,035	$228,790	$88,262
26	2043	$0	$2,143,637	$993,993	$369,125
27	2044	$0	$1,535,054	$691,065	$247,037
28	2045	$0	$814,612	$356,048	$122,519
29	2046	$0	$590,894	$250,744	$83,058
30	2047	$0	$479,035	$197,356	$62,929
31	2048	$0	$499,284	$199,707	$61,299
32	2049	$0	$1,413,525	$548,924	$162,189
33	2050	$0	$1,865,583	$703,374	$200,055
Totals =		$170,200,000	$20,083,358	$169,378,579	$150,666,650

Summary of Benefits

The aggregation of all expected benefits from the SH 99 Segment I-2, as well as their costs are shown in Table 9 below, with discount rates of 7 percent, 3 percent, and undiscounted. All metrics show higher benefits than costs, which result in a benefit-cost ratio of 3.14 and 1.75 and a net present value of $363 and $112 million using a discount rate of 3 percent and 7 percent, respectively. The biggest share of benefits are travel time savings, which are made possible by the congestion relief that Segment I-2B will represent for autos and truck in the larger project area, as predicted by the travel demand model.

Table 9: Summary of the Benefit-Cost Analysis

Metrics	Monetary Value		
	Undiscounted	Discount Rate 3%	Discount Rate 7%
Avoided Maintenance Costs	$19,954,097	$11,602,726	$6,302,155
Travel Time Savings	$1,235,054,109	$682,310,670	$346,300,988
Vehicle Operating Cost Saving	-$369,406,433	-$210,007,204	-$110,824,499
Avoided Social Cost of Carbon Emissions	-$20,970,029	-$11,330,983	-$11,330,983
Avoided Non-Carbon Emission Costs	-$10,011,676	-$5,599,169	-$2,890,487
Safety Benefits	$113,385,388	$65,632,693	$35,450,829
Total Benefits =	**$968,005,456**	**$532,608,733**	**$263,008,003**
Capital Costs	$170,200,000	$159,200,791	$146,171,983
O&M Costs	$20,083,358	$10,177,788	$4,494,667
Total Costs =	**$190,283,358**	**$169,378,579**	**$150,666,650**
Net present value =		$363,230,154	$112,341,353
Benefit-Cost Ratio =		3.14	1.75

In addition to the default analysis, four sensitivity analyses (shown in Table 10) were performed by changing key parameters in the model. They all show that regardless of the underlying assumptions, the project maintains a strong Benefit-Cost Ratio of between 2.1 and 3.3 with a discount rate of 3% and between 1.4 and 1.9 with a discount rate of 7 percent.

The first change in assumptions modifies the year the project is opened to traffic from 2022 to 2025 (the first year of the travel demand model estimation), which leads to Benefit-Cost ratios between of 1.5 and 2.9. The second change modifies the horizon year from 2050 to 2040, and only the metrics with a 3% discount rate are more affected (with a change in discount rate from 2.1 to 1.4). The third change involves the assumption about the vehicles which will benefit from changes in crash rates on Segment I-2B, including the increase in trips in the build scenario improves slightly the cost effectiveness of the project. Finally, the last sensitivity test assumes that only weekdays generate delays in travel time (using

260 days per year for all auto trips and truck trips), which results in a small reduction in the benefit-cost analysis metrics.

Table 10: Sensitivity Analysis

	Analysis (1)	Analysis (2)	Analysis (3)	Analysis (4)	Analysis (5)
Opening Year	2022	2025	2022	2022	2022
Horizon Year	2050	2050	2040	2050	2050
Crash Rate Reduction – Vehicles Affected[1]	Baseline	Baseline	Baseline	Build	Baseline
Maintain Travel Assumptions[2]	Yes	Yes	Yes	Yes	No
B/C Ratio (3% disc.)	3.1	2.9	2.1	3.3	2.5
B/C Ratio (7% disc.)	1.7	1.5	1.4	1.9	1.4
NPV (3% disc., millions)	$363	$313	$183	$395	$254
NPV (7% disc., millions)	$112	$72	$54	$129	$58

1. Modified assumption: all trips in the build scenario benefit from reduced crash rates in Segment I-2B.

2. Modified assumption: only weekdays generate travel time savings.