Operational and Safety Analysis with Mitigation Strategies for Freeway Truck Traffic in Wyoming

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1. Introduction

Trucking is an indispensable component of any country's prospering and growing economy. It is the foundation of many logistic and supply-chain network. The State of Wyoming (WY) is experiencing a high percentage of truck traffic along all highways, especially Interstate 80 (I-80), because of an expansion in oil and gas production. I-80 was designed and constructed 60 years ago, and at the time such high truck traffic was not anticipated. The increased interactions between trucks and other vehicles have raised many operational and safety concerns along I-80.

This study will investigate impacts of truck traffic on selected freeway segments along I-80 in WY and potential mitigation strategies to improve traffic efficiency and safety. A special attention will be given to the roadway geometry (horizontal and vertical alignment, as well as the existing climbing lanes) and traffic characteristics along the corridor. The analysis will include the effectiveness of existing climbing lanes, and identify potential locations where the introduction of climbing lanes will be justified. Other control strategies, such as different speed limits for trucks, truck lane restrictions along certain segments, and truck no-passing zones will also be assessed. The issue of high speed limits of 80 mph along certain sections and the ability of conventional truck tires to handle these speeds will also be studied in this research.

The safety data include a 9-year period between 2008 and 2016, since the quality of data needed for this study was improved starting 2008. A preliminary safety analysis has already been performed, and it shows a greater tendency of trucks to be involved in crashes under certain conditions. Some major crash contributing factors, divided into road, weather and driver condition, driver action, as well as crash types, have been identified. Certain roadway characteristics (horizontal curves and vertical grades) also have different impacts on truck-related crashes, which can lead to identification of segments that have a higher probability of truck-related crashes.

2. Study Objectives

The goal of this study is to quantify impacts of truck traffic on selected freeway segments along I-80 in WY and propose potential mitigation strategies, through analyses of operational and safety implications that result from the interactions between trucks and passenger vehicles. A special attention will be given to the roadway geometry (horizontal and vertical alignment, as well as the existing climbing lanes) and traffic characteristics to identify impacts on traffic efficiency and safety. The analysis will include the effectiveness of existing climbing lanes, and identify potential locations where the introduction of climbing lanes will be justified. Other control strategies, such as different speed limits for trucks, truck lane restrictions along certain segments, and truck no-passing zones will also be analyzed. Differential speed limits for trucks have been implemented by some US states, so this study will review and summarize the state of practice and its effectiveness on operations and safety. Another potential issue with truck traffic on WY freeways is the speed limit of 80 mph along certain segments. This raises a concern of

the ability of conventional truck tires to handle such high speeds. The study will investigate this issue through a review of literature and practice, as well as through crash data analysis to identify the potential relationship between truck tire failure and crash characteristics.

The review of literature and practice will include operational and safety impacts of truck traffic and existing mitigation strategies. The effectiveness of climbing lanes, differential truck speed limits, truck lane restrictions, no-passing zones for trucks, updates in horizontal and/or vertical and cross section features of the road, updates in roadside, and installation or update of safety devices will be researched throughout the study.

The research team will collaborate with WYDOT to select freeway segments along I-80 that will be included in the analysis. The focus will be on segments with specific geometry, such as critical horizontal and vertical curves, specific upgrades/downgrades and selected freeway ramps. Operational and safety analysis on these segments will be performed using existing data on freeway volumes (vehicles and trucks and the corresponding miles traveled), vehicle speeds, lane occupancies, crash frequencies and crash characteristics. It is recommended to use about ten to fifteen locations with different characteristics. The research team has already divided the entire I-80 in Wyoming into 20 sections, with each section of approximately 20 miles. Some critical sections have been identified, and further focus can be directed to those sections.

The research team will identify the traffic data needed for the analysis, and the existing data sources. At the minimum, the data need to include geometrical characteristics of selected locations (horizontal and vertical alignments, cross section elements, roadside elements, ramp characteristics, auxiliary lane dimensions), operational characteristics (traffic volumes, traffic composition, lane utilizations, lane speeds) and safety data (crash locations, frequencies and crash types). Some roadway geometry and safety data have already been obtained and are currently being analyzed.

The collected data will be used to perform operational and safety analysis for the selected segments. Within the operational analysis, measures of effectiveness such as segment capacity, distribution of vehicle speeds and headways, variations in speeds, densities, percentage of time spent following and the Level of Service (LOS) will be included. The analysis will be performed using a combination of methods, such as Highway Capacity Manual (HCM) methodology, shock wave analysis, microsimulation modeling and other methodologies recommended in the literature. Safety analysis will study the distribution of crash rates and crash types, as well as the crash causation factors for different segments. Special attention will be given to truck tire failures and potential link to high truck speeds. Preliminary safety analysis using 9-year data has already been performed, and it shows a greater tendency of trucks to be involved in crashes under certain conditions. Some major crash contributing factors, divided into road, weather and driver condition, driver action, as well as crash types, have been identified. Certain roadway characteristics (horizontal curves and vertical grades) also have different impacts on truck-

related crashes, which can lead to identification of segments that have a higher probability of truck-related crashes.

The research team investigate different control strategies that can be implemented at selected locations in order to improve operational and safety performance. Some of these strategies and improvements may include introducing differential truck speed limits, adding climbing lanes, truck lane restrictions, introducing no-passing zones for trucks, changes in horizontal and/or vertical features of the road, changes in cross section, changes in roadside, and installation or update of safety devices (guardrails, delineators, chevrons, speed advisory signs, pavement markings and similar).

3. Background

The State of Wyoming road network is characterized by heavy truck traffic. In 2016, truck traffic comprised approximately 21% of Vehicle Miles Traveled (VMTs) along all routes in WY, according to the WYDOT Annual Traffic Report. The heaviest truck traffic exists along I-80, with about 47% truck VMTs. Trucks have significantly different physical and driving characteristics than passenger cars, especially on grades, which has impacts on operational efficiency, safety and pavement deterioration. The presence of heavy vehicles reduces the capacity of freeway segments, with the reduction being more significant along specific grades. Trucks generally decrease speed by more than 7% on upgrades as compared to their operation on level terrains, according to the Highway Capacity Manual (HCM) 2010. The maximum speed that can be maintained by trucks on upgrades primarily depends on the length and steepness of the grade, as well as the truck's weight-to-power ratio. On the other hand, the operation of passenger vehicles is much less impacted by the grade. This leads to variations in speeds between trucks and passenger vehicles, with more complex interactions between the two types.

The trucking industry continues to contribute significantly to the economy of the United States. Although leading to economic growth, these developments have led to a sharp increase in the proportion of freight traffic along key routes, many of which pass through rural areas. As one example, I-80 forms a major corridor for transporting goods between the west coast and major cities in the east. This facility carries a heavy truck traffic proportion, ranging from 40% in urban areas, to 60% in rural areas. These increases in heavy truck traffic on the nation's highways have raised concerns about safety, particularly on the Interstate system.

3.1. Operational Performance of Trucks on Grades

According to the HCM, passenger cars can negotiate upgrades of 4% to 5% without a noticeable loss in speeds maintained on level roadways. On the other hand, the performance of trucks is greatly affected by vertical grades. Trucks start losing their speeds at freeway grades of about 1%. Trucks generally decrease speed by more than 7% on upgrades as compared to their operation on level terrains. The reduction in truck speeds depends on the rate and length of grades, as summarized by the HCM and presented in Figure 1. This causes a lot of friction

between passenger cars and trucks on upgrades, with a noticeable difference in speeds. Also, because of the high truck percentage, it is very common for trucks to use the left lane, which causes a queue buildup behind them and leading to deteriorated traffic conditions.

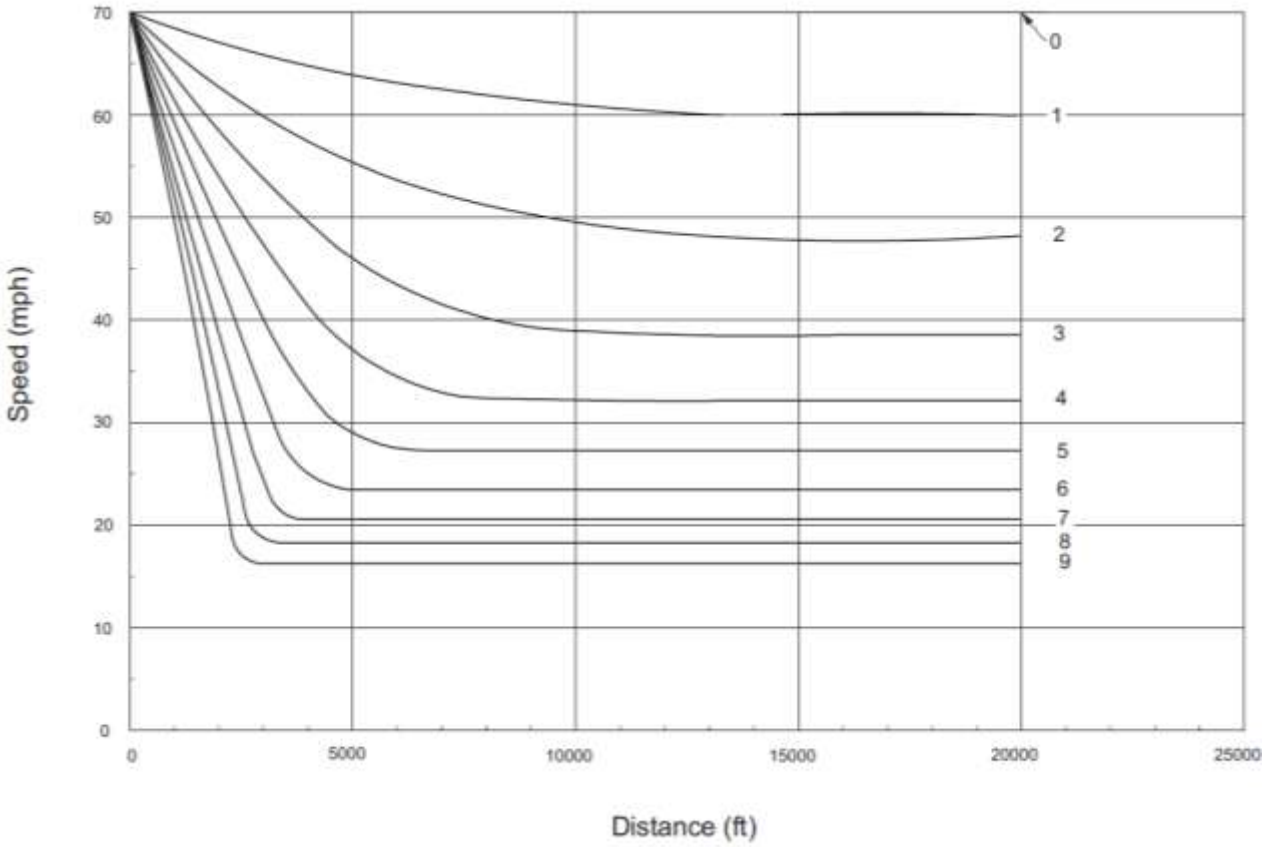

Figure 1: Speed-Distance Curves of a Typical Heavy Truck (Source: HCM)

About 8% of I-80 in Wyoming (in both directions) is within vertical grades of more than 3%, where certain sections reach grades of close to 7%. These grades can cause significant truck speed reduction on upgrades, leading to a large speed difference between trucks and passenger cars. There is also a significant speed difference between trucks, depending on their loads and weight-to-power ratio, so it is a common occurrence that trucks pass each other using the left lane, as shown in Figure 2. This causes a queue buildup behind the slower moving trucks in both lanes, significantly deteriorating traffic conditions.

The operational analysis will study these occurrences along selected sections. A combination of methods will be used, such as HCM methodology, shock wave analysis and a detailed analysis through traffic microsimulation. This will allow for a comparison between regular cross sections and sections that include climbing lanes, as well as alternative analysis with added climbing lanes and other truck strategies to evaluate their effectiveness.

Figure 2: Trucks Passing and Occupying Left Lane

3.2. Truck Safety Implications

Truck safety has significant implications to motorists, transportation agencies, industry and the general public. Safety is a major consideration for the trucking industry. Of the approximately 415,000 police-reported crashes involving large trucks in 2015, there were 3,598 fatal crashes and 83,000 injury crashes in United States. The correlation between the percentage of large trucks and crash rates on the transportation facilities should be of particular concern to state DOT engineers. This especially applies to the Wyoming DOT, who operates facilities with large percentages of trucks on roads, such as I-80. During the nine year period (2008 – 2016), close to 4,800 truck-related crashes occurred on I-80 in WY (on average, 530 truck-related crashes each year), which speaks about the importance of the truck safety problems on this corridor. Due to the nature of traffic along I-80, the operational performance is closely related to the safety performance. Because of this, the two analyses will complement each other.

A preliminary analysis of contributing factors for the truck-related crashes included road condition, weather condition, driver condition, driver action, and crash types, as shown in Table 1. The results showed that, on the nine-year average, 54% of crashes occurred during icy road conditions, and 32% of crashes occurred during dry road conditions. Snowy and wet road conditions contributed to 8% and 4% of crashes, respectively. The analysis of the impacts of weather conditions on crashes showed that about 46% of crashes occurred during snowy weather conditions. About 6% and 4% of crashes occurred during strong wind and cloudy conditions, respectively.

Table 1: Truck-Related Crash Contributing Factors and Crash Types

		2008	2009	2010	2011	2012	2013	2014	2015	2016	Percent
Road Condition	Dry	170	134	133	174	182	155	185	199	234	31.67
	Wet	29	25	23	20	29	20	24	21	28	4.43
	Slush	8	7	4	11	4	3	3	4	9	1.07
	Snow	61	67	46	43	25	64	41	30	39	8.41
	Ice or Frost	520	248	269	303	252	286	331	185	279	54.05
	Other	7	2	3	1	1	0	2	0	2	0.36
Weather Condition	Clear	278	167	198	226	220	203	222	235	267	40.77
	Cloudy	23	24	19	19	20	21	39	16	32	4.31
	Fog	6	7	6	0	11	2	3	3	1	0.79
	Rain/Sleet/Hail	8	13	12	11	9	15	10	13	15	2.14
	Snowing/Blizzard	426	250	224	257	193	264	275	151	218	45.66
	Strong Wind	51	21	18	38	40	23	37	20	57	6.17
	Unknown	2	1	1	1	0	0	0	1	1	0.14
Driver Condition	Apparently Normal	740	444	439	497	442	469	512	398	530	90.41
	Emotional	9	3	5	2	1	4	1	0	1	0.53
	Fatigued	5	1	2	3	2	2	9	5	7	0.73
	Fell Asleep/Faint	5	8	7	14	12	8	14	13	14	1.92
	Ill or Sickness	4	1	1	3	1	4	6	0	2	0.44
	Alcohol or Drug use	1	4	1	1	4	2	2	0	2	0.34
	Other	31	22	23	32	31	39	42	23	35	5.62
Driver Action	Avoiding an object	9	8	7	7	12	11	8	9	10	1.64
	Ignore Traffic Signs	24	5	8	16	16	19	22	7	19	2.75
	Drove too fast	352	192	200	189	142	161	172	93	157	33.53
	Careless/Aggressive	6	1	2	12	9	2	5	6	6	0.99
	Improper lane	44	28	52	55	58	60	88	66	109	11.32
	Following too close	27	19	17	16	16	19	20	18	16	3.40
	No improper driving	201	130	107	133	125	136	137	116	135	24.67
	Other improper acts	48	32	28	34	37	28	36	32	42	6.41
	Ran Off road	54	35	36	61	45	53	61	61	64	9.50
	Swerve	9	14	9	13	19	15	17	8	9	2.29
	Unknown	21	19	12	16	14	24	20	23	24	3.50
Crash Types	Angle	47	31	25	37	23	30	33	26	31	5.72
	Head On	3	2	2	2	0	1	1	2	3	0.32
	Single vehicle	479	299	320	353	326	335	375	260	399	63.62
	Rear End	161	87	73	106	77	97	98	78	95	17.63
	Sideswipe	79	59	53	46	54	56	75	70	61	11.18
	Other	26	5	5	8	13	9	4	3	2	1.52

The analysis of driver condition showed that about 90% of crashes occurred in apparently normal state. Falling asleep contributed to approximately 2% of crashes. Emotional, fatigued, sickness, alcoholic and other driver conditions accounted for the rest of crashes. The next contributing factor was driver action. It indicated that driving too fast and driving in improper lane contributed to approximately 45% of crashes. About 25% of crashes showed no apparent improper driving. Following too close, running off road, and other improper driving action accounted for about 19% of crashes. This analysis can provide some guidelines for the mitigation strategies to be considered in order to reduce the truck-related crashes.

The manner of collision shows different crash types, such as: angle, head on, single vehicle, rear end, sideswipe etc. The analysis showed that about 64% of the truck crashes along I-80 were single vehicle crashes. The rear end and sideswipe collision contributed to about 18% and 11% respectively. Trucks have large physical dimensions, more restrictive acceleration and braking capabilities and large blind spots that could be responsible for the rear end and sideswipe collisions. Angle and other type of collisions accounted for the rest of crashes.

The preliminary safety analysis also investigated the correlation between horizontal and vertical alignment and truck-related crashes. About 23% of the length of I-80 in WY is within horizontal curves, and about 8% within vertical grades larger than 3%. Most truck-related crashes occurred within horizontal curves with a 4,000 to 6,000 ft radius, and within vertical grades of 2% to 3% range.

4. Methodology

The three main parts of this study will consist of operational analyses, safety analyses and recommendation of mitigation strategies with a focus on truck traffic along I-80 in WY. The study will use the review of literature and practice, collection and analysis of the existing field data, such as geometrical characteristics of freeway segments, operational characteristics (traffic volumes, traffic composition, lane utilizations, lane speeds) and safety characteristics (crash locations, frequencies, types, causes) to determine the measures of operational and safety effectiveness of freeway truck traffic. Based on the results of the analysis, potential mitigation strategies will be discussed and analyzed. The overall methodology process is given in Figure 3.

The operational analysis will include measures of effectiveness such as segment capacity, distribution of vehicle speeds and headways, variations in speeds, densities, percentage of time spent following and the LOS. The analysis will be performed using a combination of methods, such as the HCM methodology, shock wave analysis, traffic microsimulation modeling and other methodologies recommended in the literature. The focus will be on sections with specific roadway alignment where a higher reduction of truck speeds is observed, causing a difference in speeds between different vehicle types and formation of queues behind slower moving vehicles. Similar analysis will be performed for sections with climbing lanes to assess the effectiveness of this truck management strategy. This analysis will identify potential sections where the

implementation of climbing lanes would be justified through analysis of different alternatives, and their effectiveness will be assessed through traffic simulation. The similar alternative analysis will be performed for other truck strategies, such as differential speed limits, lane restriction and truck passing restrictions.

The safety analysis will study the distribution of truck-related crash rates and crash types, as well as the crash causation factors for different segments. It will be based on the methodologies provided in the Highway Safety Manual, as well as others methodologies recommended in the literature and practice for truck traffic analysis. Horizontal, vertical and climbing lanes roadway data will be cross-referenced with the safety data to assess the contribution of different roadway elements on truck-related crashes. A special attention will be given to crashes where tire failure was the main contributing factor to identify impacts of higher speed limits along I-80.

The study will produce several outcomes beneficial for WYDOT to improve operations and safety along I-80. The first outcome of the study will be a synthesis of existing literature and practice related to freeway truck traffic, as well as the existing strategies used by agencies in order to improve operations and safety on freeways with high truck volume percentage. The second outcome will be complete sets of roadway and traffic data collected under the existing conditions. The data will be useful for engineers, educators and other interested stakeholders including, but not limited to, WY institutions, and can be used in potential future projects. The third outcome will be the assessment of current operational and safety conditions for freeway segments with high truck volume percentage and challenging geometric features. It will provide insights for potential problems, and the ways how to mitigate them. The study will describe current conditions, impacts, and mitigation recommendations. The research team will provide all methodologies and models that will be used in this study to WYDOT for a potential use in future projects.

This study will have a relevance related to truck safety assessment. A significant portion of crashes on WY freeways involve trucks, or are caused by trucks. Discovering major causes and implementing certain strategies for operational and safety improvements can help mitigate some of those problems and improve safety for all users. Because of the specific conditions that exist along I-80, traffic operations and safety are directly related, and this relationship will be explored here. The study will also be relevant to economic competiveness. Transporting goods safely and on time is of high importance to the trucking industry, so any strategies that can improve operations and safety for trucks will be very beneficial. Reduction of crash costs through safety improvements is another important element related to this goal. Both improved operations and safety have impacts on the environmental sustainability. Better operations of truck and car traffic reduce emissions and energy consumption, while reduction of crashes reduces impacts on environment by eliminating debris and spills, especially from trucks that transport certain hazardous materials.

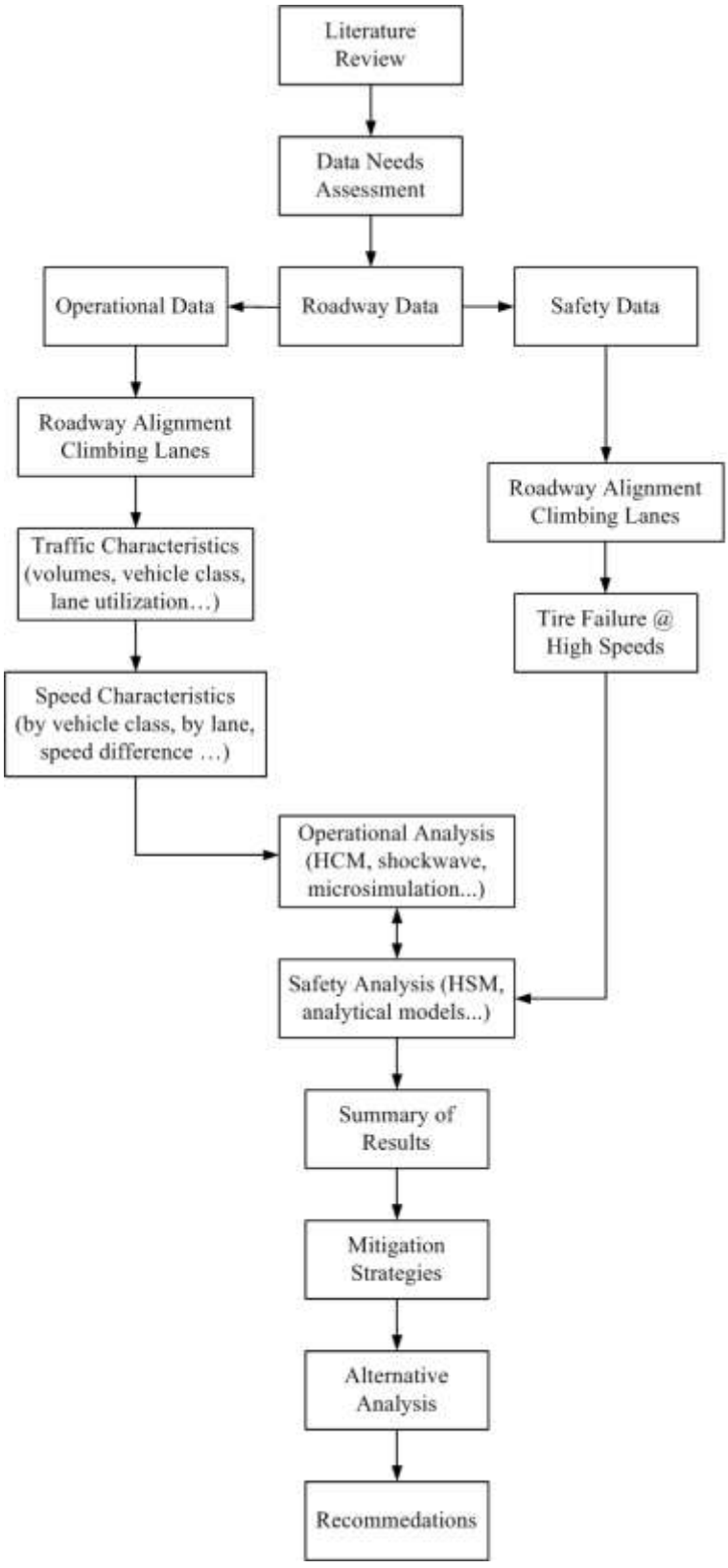

Figure 3: Research Project Methodology

5. Study Tasks

The tasks necessary to implement the study successfully are detailed as follows:

Task 1: Conducting Literature Review

The research team will review the existing research studies, guidelines and best practices from different agencies related to the analysis of truck traffic on freeways. The literature review will provide some recommendations for the selection of data, analysis methodologies, results interpretation, and potential improvement strategies. The main focus of literature review will be on operational analysis of different truck strategies implemented on the freeways, and the methodologies used in these analyses. The safety analysis will use the Highway Safety Manual, as well as recommendations from previous safety studies.

Task 2: Selecting Case-Study Segments and Collecting Data

The research team will collaborate with WYDOT to select freeway segments along I-80 that will be included in the detailed analysis. The focus will be on segments with specific geometry, such as critical horizontal and vertical curves, specific upgrades/downgrades and selected freeway ramps. The research team will identify the traffic data needed for the analysis, which, at the minimum, need to include geometrical characteristics of selected locations (horizontal and vertical alignments, cross section elements, roadside elements, ramp characteristics, auxiliary lane dimensions), operational characteristics (traffic volumes, traffic composition, lane utilizations, lane speeds) and safety data (crash locations, frequencies, types and causes for a minimum of five years). The data will be collected from the existing databases and field studies.

At this point, the UW research team has obtained roadway geometry data and nine years (2008 – 2016) of crash data which were used in the initial safety analysis. I-80 in Wyoming has been divided into 20 sections, each having approximately 20 miles, and the preliminary safety analysis has been performed for each section.

Task 3: Analyzing Existing Data

The collected data will be used to perform a comprehensive operational and safety analysis for the selected segments. The operational analysis will include measures of effectiveness such as segment capacities, distributions of vehicle speeds and headways, variations in speeds, densities, the percentage of time spent following (PTSF) and the Level of Service (LOS). The PTSF is a methodology used for two-lane highways, but it could be useful to assess certain sections where trucks occupy both freeway lanes, causing queue build up behind the trucks. The operational analysis will be performed using a combination of methods, such as the HCM methodology, shock wave analysis, traffic microsimulation models and other recommended methodologies. An example of a microsimulation model is given in Figure 4, where the desired and actual speeds of trucks and cars occupying different lanes are shown. The example shows a deteriorating LOS for

cars caused by truck lane blockage. Microsimulation modeling will be used for alternative analysis, where different mitigation strategies will be simulated and compared.

The safety analysis will summarize and discuss the distribution of crash rates and crash types, as well as the crash causation factors for different segments. It will be based on the methodologies provided in the Highway Safety Manual, as well as others methodologies recommended in the literature and practice for truck traffic analysis.

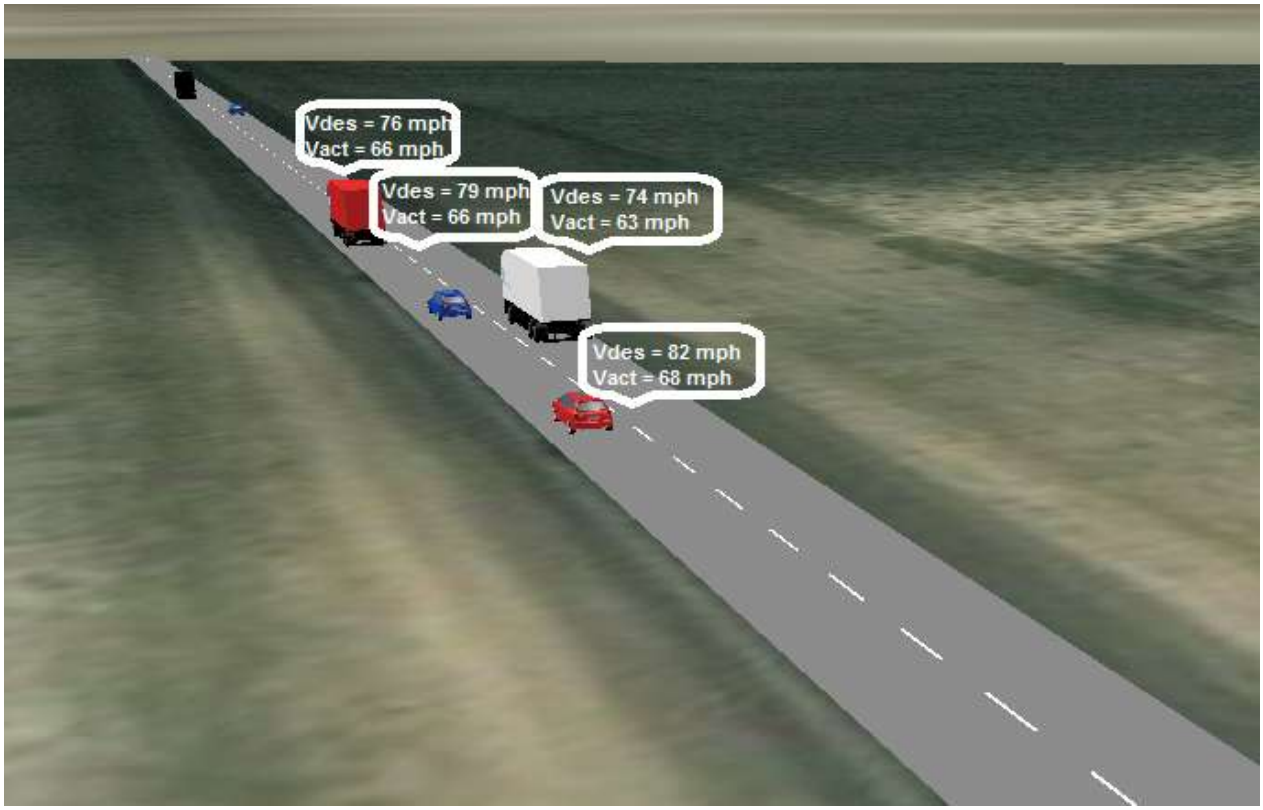

Figure 4: Simulation Representation of Truck Traffic

Task 4: Identifying and Analyzing Control and Mitigation Strategies

The analysis of existing data will provide operational and safety measures of effectiveness, which will allow the research team to identify and analyze different control strategies that can be implemented at selected locations in order to improve traffic performance. Some of these strategies and improvements may include differential speed limits for trucks, adding climbing lanes, truck lane restrictions, introducing no-passing zones for trucks (Figure 5), changes in horizontal and/or vertical features of the road, changes in cross section, changes in roadside, and installation or update of safety devices (guardrails, delineators, chevrons, speed advisory signs, pavement markings and similar). The recommended mitigation strategies will be assessed through alternative analysis, using analytical and microsimulation models. The alternatives will then be compared and rated.

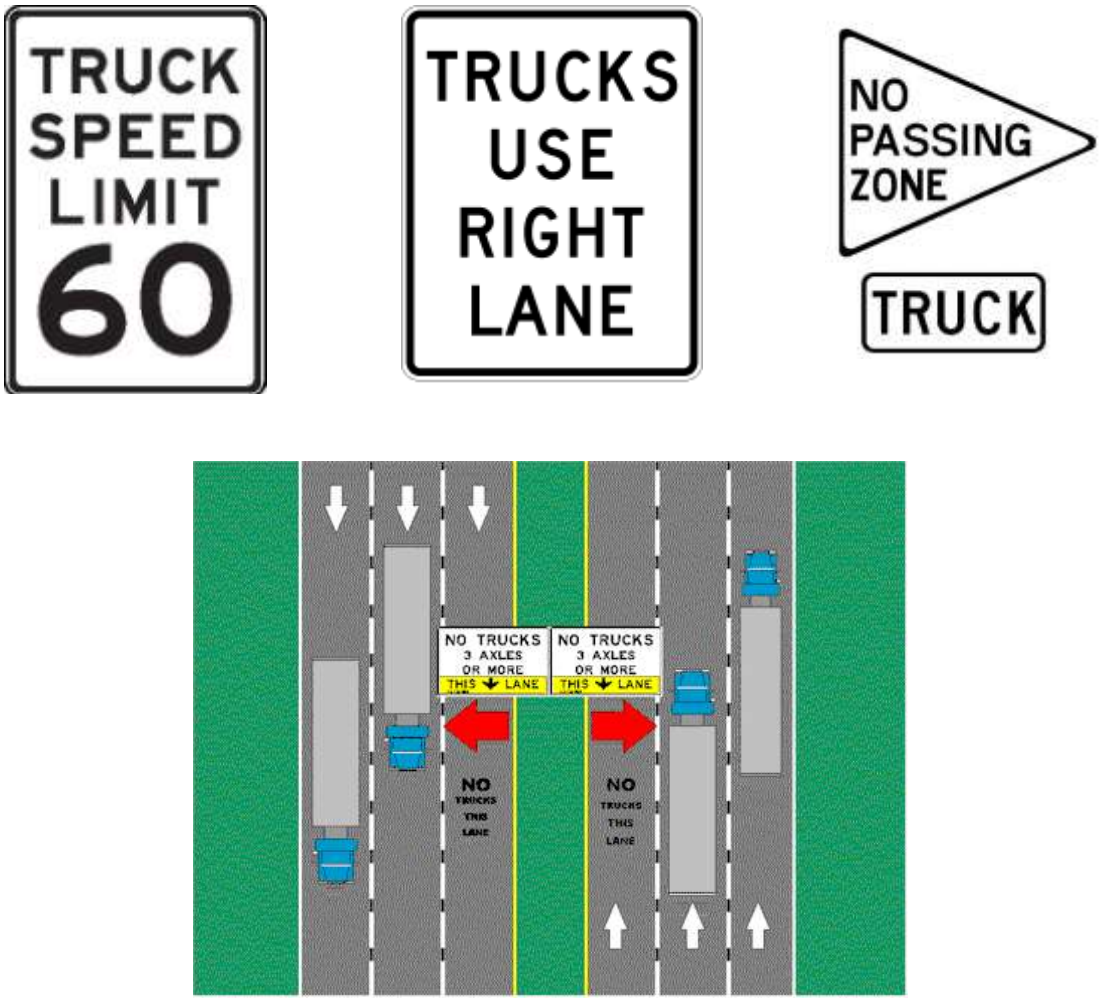

Figure 5: Truck Strategies

Task 5: Preparing Final Report and Presenting Findings and Recommendations

A final report will be prepared that documents the processes and models used to analyze operational and safety effectiveness of truck traffic. Quarterly progress reports will also be submitted to WYDOT.

6. Timeline and Staffing

The study will be performed in 24 months beginning January 15, 2018. Progress reports will be submitted to WYDOT quarterly. A final report and several presentations to appropriate WYDOT personnel and other stakeholders are anticipated to take place at the conclusion of the study. Recommendations for potential mitigation strategies will be made and discussed with WYDOT. The proposed timeline is presented in Figure 6. This will be the main timelines, however some of the tasks will be performed throughout the entire study (such as literature review with new information, new available data and analysis, and progress reports).

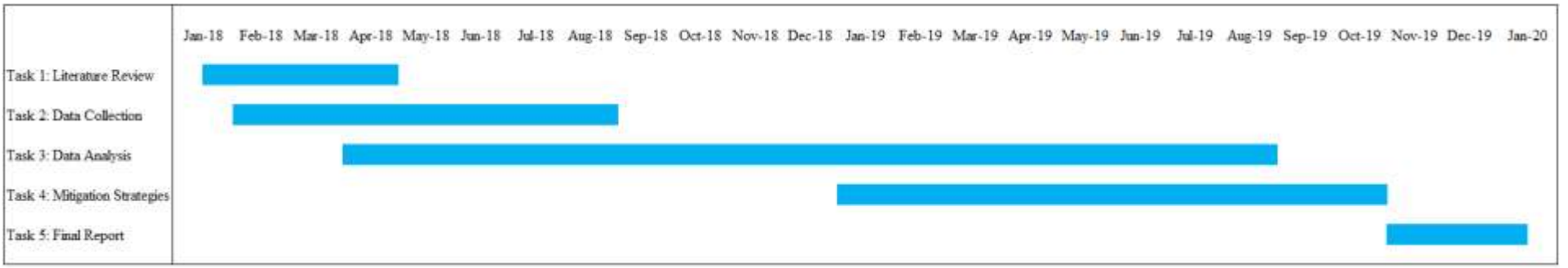

Figure 6: Proposed timeline for the study

7. Budget and Matching Funds

As shown in Table 2, the WYDOT cost for this study will be $143,184. UW has obtained funds from the Mountain Plains Consortium (MPC) in the amount of $53,269 as matching funds for completing initial parts of this study.

Table 2: Budget for the I-80 Truck Study

January 15, 2018 – January 14, 2020

CATEGORY	WYDOT Cost	Explanatory Notes	MPC funds
Faculty Salaries	$34,400	Two faculty members	$9,635
Grad Student Salaries	$32,208	Two year stipend for GA	$15,650
Undergrad Student Salaries	$4,000	Salary for undergrad researcher	
Fringe Benefits	$18,062		$4,804
Total Salaries and Benefits	$88,670		$30,089
Expendable Property, Supplies, and Services	$4,500	Reports and research supplies	
Domestic Travel	$11,200	Data collection and presentations	
Other Direct Costs (specify)	$17,940	Two year student tuition and fees	$9,940
Total Other Direct Costs	$33,640		$9,940
F&A (Indirect) Costs	$20,874		$13,239
TOTAL COSTS	$143,184		$53,269

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