Updating and Implementing the Grade Severity Rating System (GSRS) for Wyoming Mountain Passes

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1. Introduction

This proposed project is designed to reduce the risk of runaway or out of control trucks during downgrade descent on Wyoming mountain passes. Two main tasks are proposed for the study. The first task involves reviewing, updating and validating the current Grade Severity Rating System (GSRS). The product from this task will be a GSRS application capable of advising various truck weight category drivers on safe downgrade descent speeds. The second task will carry out a comprehensive evaluation of the current mountain pass warning systems in Wyoming as well as the most current state of the practice. This will result in a recommendation for the safest system for communicating the outputs from the updated GSRS model in a safe and timely manner to truck drivers.

2. Study Objectives

The proposed study is aimed at achieving two main goals. First, the FHWA's GSRS model will be updated to reflect the current truck population characteristics. This will be achieved by carrying out field tests with an instrumented vehicle to update parameters in the model that reflect current truck characteristics and braking systems. The second objective of the study is to evaluate Wyoming mountain passes and their warning systems with regard to truck downgrade crashes. By doing this, the best means of communicating with truck drivers to reduce the probability of runaway truck incidences can be recommended.

By achieving the two goals, the study will present recommendations that will counter the occurrence and severity of downgrade truck crashes on Wyoming mountain passes. A new software will be developed for estimating maximum safe speeds for truck weight categories using the new parameters. The estimates from the new software will be more consistent with current truck characteristics and a combination of these estimates with an effective warning system will encourage compliance by truck drivers.

3. Background

From January to September 2014, seven downgrade truck crashes were recorded on US 14 near Dayton (VanOstrand, 2014). The number of accidents was more than double the number of truck crashes from 2004 to 2013. Wyoming Department of transportation (WYDOT) suspected truck driver unfamiliarity with the road and terrain to be the cause of these crashes. On December 2015, a fatal truck crash occurred on a section of US 14 despite a recently reduced speed zone of 40 mph (Burr, 2015). The crash was attributed to brake failure and was a strong indication for the need to develop road signs with truck weight specific speed advisories instead of the general speed limit signs. The weight specific speed signs can reduce the incidence of out-of-control trucks due to brake failure on downgrade descents.

The Grade Severity Rating System (GSRS) and the Weight Specific Speed (WSS) signs developed by the Federal Highway Administration (FHWA) have been identified as a means of reducing downgrade truck crashes for Wyoming mountain passes. This background section includes a literature review on the development and implementation of the GSRS model as well as current trucking practices in the truck industry. The review led to a proposal to update the existing model to enable estimation of accurate safe descent speeds for modern trucks of various weight categories.

Since the 1960's, four main GSRS models have been developed. Each model improved on the immediate previous model until the last model which was developed in the 1970's. The following sections discuss the development of each of the four models to make a case for updating the current FHWA model that was developed over 25 years ago.

3.1. Bureau of Public Roads Rating System

In the 1950's, the Bureau of Public Roads (BPR) had an arbitrary rating system for rating and posting grades. This system combined the length and percent of grade (Hykes, 1963) to warn downgrade traveling drivers about the severity of descents. The BPR rating system was developed by surveying grades and placing them in three categories:

1. Greater than 3 percent and greater than 10 miles long.
2. Greater than 6 percent and greater than 1 mile long.
3. Greater than 10 percent and greater than 1/5 mile long.

Beyond the arbitrariness of the categories, Hykes stated that such a classification system created a problem where there is too much variation within each category.

3.2. Hykes Grade Rating System

This system was proposed in the early 1960's by Hykes (Hykes, 1963). An earlier related study developed a system that rated brakes by their overall heat dissipation capacity expressed in horsepower (Fisher, 1961). Hykes developed a recommendation that utilized the horsepower rating to predict the downhill performance capabilities of commercial trucks (Hykes, 1963). A "grade ability formula" was developed from the results of Fisher's study and additional field tests that determined the performance of vehicles on level and ascending grades. The basic "grade ability formula" is presented in Equation 1.

$$\theta = \frac{hp \times 37{,}500}{WV} \tag{1}$$

Where: θ = the grade expressed in percent
W = the weight of the vehicle in pounds
V = the speed of the vehicle
hp = the horsepower available from all sources as a retarding or accelerating effect.

Hykes expanded the Grade Ability Formula to create a downhill energy equation that considered the following grade retardation elements - brake horsepower, rolling resistance horsepower, chassis friction horsepower, air resistance horsepower, engine brake horsepower, and retarder's horsepower. The expanded equation enabled the prediction of safe grades for a vehicle with certain characteristics and speed. Based on this theory, a typical truck with a gross weight of 40,000 lb., frontal area of 80 sq. ft., engine speed of 3,200 rpm, and a descent speed of 30 mph was determined to be able to descend a 5.42 percent grade safely.

Tests were performed to validate the proposed grading system on a nine mile long and five percent grade road. The test vehicles were of gross weights 10,000, 20,000, 50,000, and 70,000. The first test determined the retardation horsepower available from forces other than brakes by running drift tests on the level in gears selected for mountain descent. The second test determined the maximum safe speed of descent. This involved calculating the overall horsepower required in each descent minus the retardation horsepower determined from the drift tests. This enabled an estimation of safe speed limits. A hot stop was made immediately after each descent to prove that the brakes were still in good working order.

The test results indicated a good correlation between the model's ratings and single unit vehicle performance. However, the model's rating was found to be inadequate for tractor-trailer combinations because of (1) trailer axle hop and bounce caused by the suspension type used, and (2) poor brake balance between tractor and trailer with the trailer brakes doing most of the braking and thus experiencing brake fade from overwork. The study recommended an improvement of the brake balance in tractor-trailer combinations to ensure conformance to regulations and to enable a more accurate prediction of safe downgrade descent speeds. The inability of the model to adequately predict safe speeds for tractor-trailer combinations resulted in Hykes recommending an alternative rating system that was not based on the Grade Ability Formula.

Hykes tried to improve on the BPR rating system by suggesting a system of rating that increased the grading categories from three to ten. The new categories from Category 1 to Category 10 represented increasing levels of severity. The resulting rating system by Hykes is presented in Figure 1. The study placed the onus on drivers to use their experience and training to determine the appropriate gear and speed for descending a downgrade once they are notified of the grade's rating.

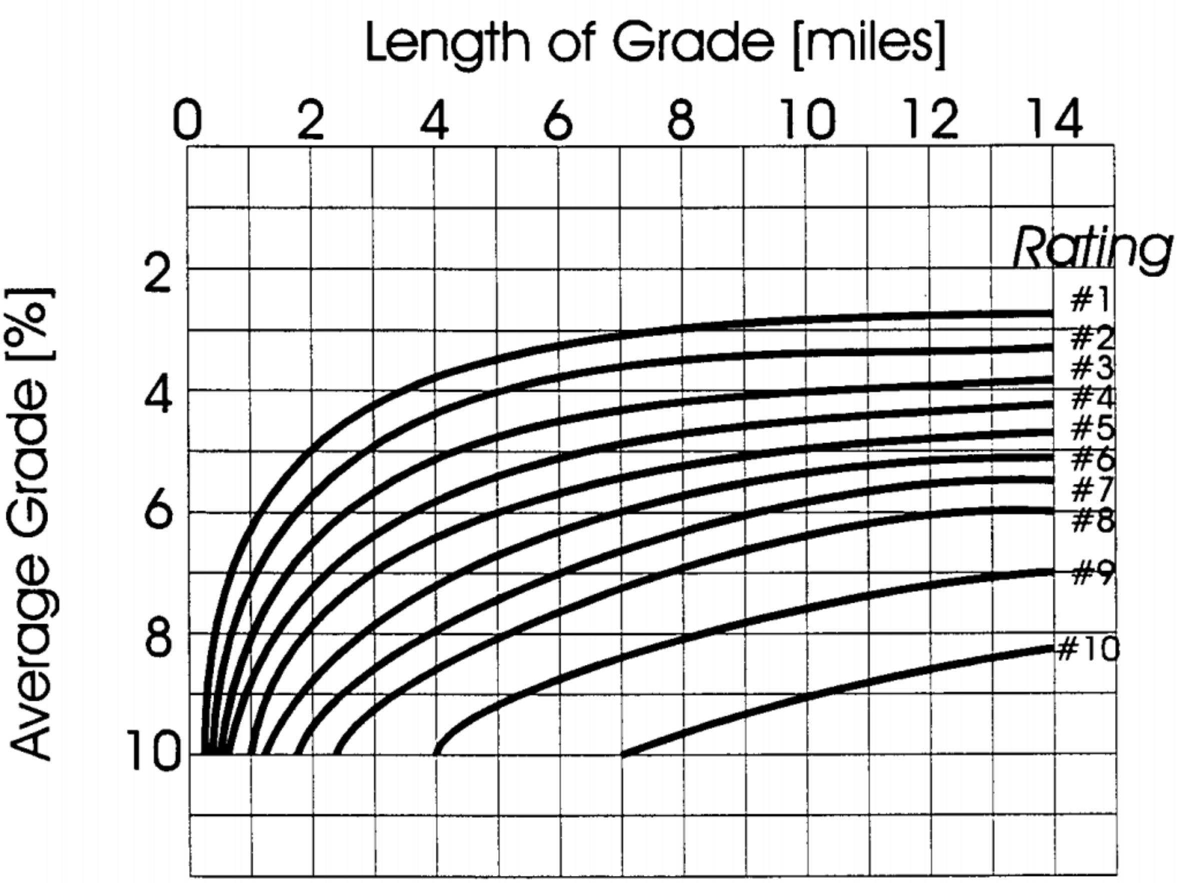

Figure 1: Proposed grade rating system by Hykes (Hykes, 1963)

3.3. Lill's Grading System

This system was proposed to improve on the Grade Ability Formula (Lill, 1975; Federal Highway Administration, 1977). Lill's system introduced the following concepts to the models used in warning truck drivers about the severity of grades:

- The concept of rating hills by their effect on a representative truck.
- The inclusion of the effect of hill length through consideration of brake fade effects.
- The use of stopping distance criterion as a measure of available braking capacity.

Lill's model was based on the work-kinetic energy equation applied to braking on a grade. The equation used to solve for the maximum descent speed which will allow stopping in a criterion distance. The model included brake terms derived from non-faded brake field test results and non-brake terms from a modification of the non-faded brake test results using brake fade factors developed by Hykes. The brake fade factor was utilized by Lill to introduce a brake equivalent time concept. This concept is defined as the hill descent time multiplied by the percent of brake use. The concept allowed the computation of a maximum safe speed that would allow stopping within a criterion of 250 ft.

Based on Lill's concept, a grade severity rating system was introduced with various speed bands for indicating the severity of grades with higher speed bands corresponding to least severe, and lower speed bands corresponding to most severe. A chart of Lill's grade severity rating system is presented in Figure 2.

3.4. The FHWA (Myers, Ashkenas, & Johnson) Grading System

The Bureau of Motor Carrier Safety (BMCS) carried out an investigation of 497 unusually severe truck accidents from 1973 to 1976 (Lill, 1977). The study found that six percent (28 crashes) of the crashes were downgrade related crashes but that small proportion of the crashes contributed to 40 percent of the truck accident fatalities. The investigations found the downgrade truck accidents to be caused by six primary factors:

1. Failure to downshift on the grade, improper shifting, or the use of excessive speed (82 percent of the downgrade accidents).
2. Drivers who were inexperienced or at least unfamiliar with the specific area (43 percent of the accidents).
3. Inadequate signing for the downgrade (14 percent of the accidents).
4. Defective truck brakes or improper brake adjustment (36 percent of the accidents).
5. Indications of driver impairment such as the use of alcohol or fatigue due to excessive driving time (21 percent of the accidents).

The investigation recommended a solution for factors 1, 2, and 3 , that involved the development of a GSRS and appropriate warning signs to aid drivers in choosing the correct speed and gear with special emphasis on the inexperienced driver.

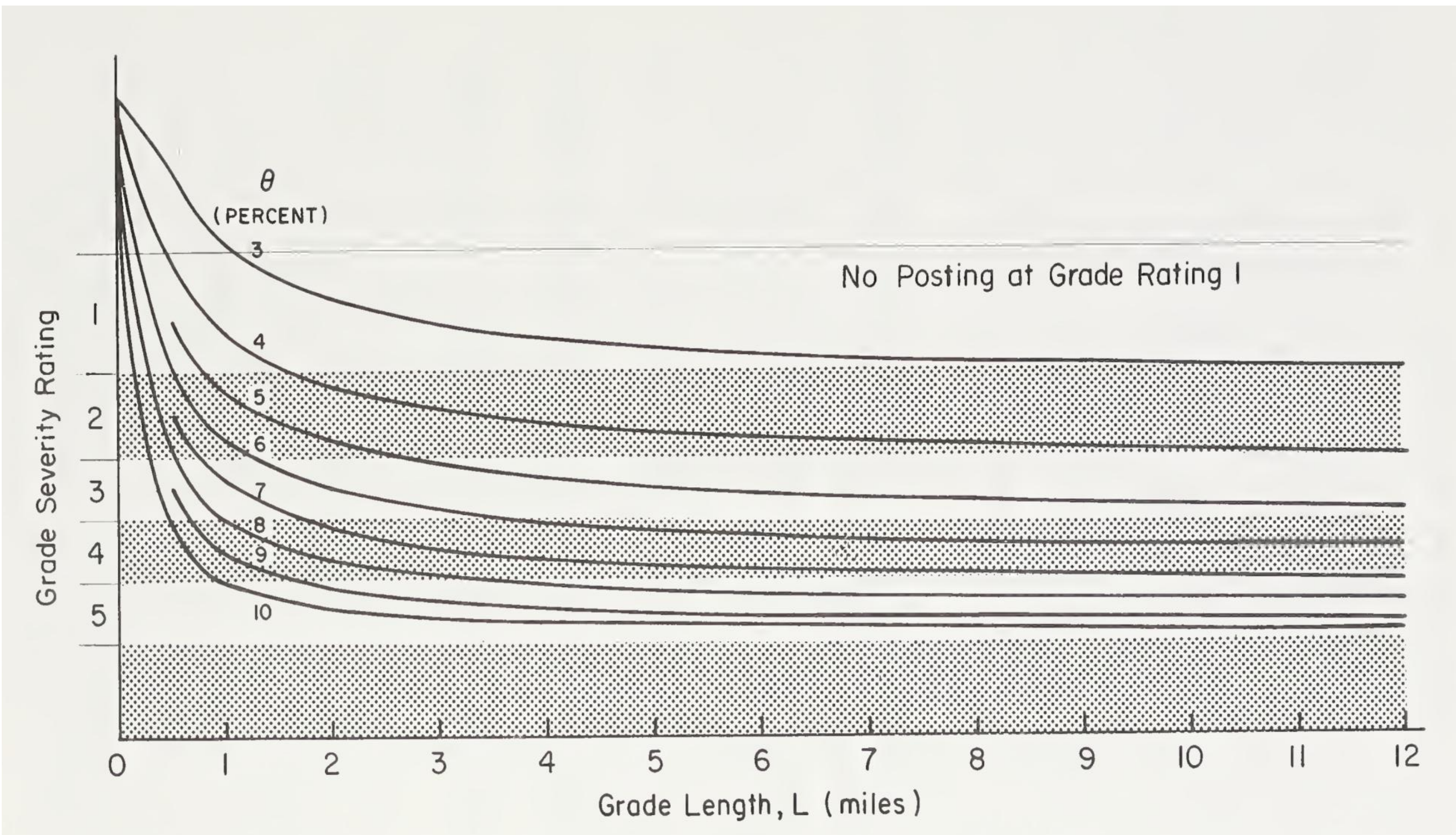
θ
(PERCENT)
3
4
5
6
7
8
9
10
No Posting at Grade Rating I
Grade Severity Rating
1
2
3
4
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Grade Length, L (miles)

Figure 2: The Grade Severity Rating System proposed by Lill (Federal Highway Administration, 1977)

This investigation and its findings led to the development of the current Federal Highway Administration (FHWA) GSRS model and the Weight Specific Speed (WSS) sign. The program to develop the GSRS model began with a review of previous grade severity systems and truck industry practices relevant to the downgrade trucking problem. The information obtained was used to develop a model (Equation 2, using results from equations 3, 4, and 5) for estimating brake temperature during descent. Field tests using an instrumented vehicle were carried out to determine the inverse heat transfer parameters K_1 and K_2, and the brake force F_B.

$$T(x) = T_O + \left[T_\infty - T_O + K_2 HP_B\right]\left[1 - e^{-K_1 X/\hat{V}}\right]^2 \ {}^{\mathrm{O}}\mathrm{F} \qquad (2)$$

$$HP_B = \frac{F_B \hat{V}}{375} = \left(W\theta - F_{drag}\right)\frac{\hat{V}}{375} - HP_{eng} \qquad (3)$$

$$F_{drag} = \left(375 - 0.15W\right)\sqrt{V} - \left(0.0076 + 0.00009\hat{V}\right)W + 0.24\hat{V}^2 \qquad (4)$$

$$HP_{eng} = 73 + 100K_{ret} \qquad (5)$$

Where:
T_o = the ambiant air temperature (90 ^{O}F)
T_∞ = the initial brake temperature (150 ^{O}F)
X = the distance travelled (mi)
V = the speed of the truck (mph)
W = the total truck weight (Ib)
Kret = 0 (engine brake off); *Kret* = 0.5 (engine brake low);
Kret = 1 (engine brake high)
F_B, K_1, and K_2 determined from field tests with an instrumented vehicle

The instrumented vehicle 3-S2 tractor-semitrailer loaded to 75,500 Ib was utilized in the field tests. The truck had temperature sensors (thermocouples) installed in the brake linings, and an eight channel recorder to measure the vehicle speed, engine speed, and brake application pressure throughout the tests. There were three types of field tests carried out in the study. The first type was the Coast-down Test and involved allowing the instrumented truck to decelerate from 40 mph on a level ground while the transmission was in neutral. Thus the truck came to a stop by means of only drag forces. The second test was the Cool-down test and this test was used to determine the inverse thermal constant, K_1. This test involved dragging the brakes until they reached moderately high temperatures and then releasing them until they cooled. The final test was the Grade Descent test used to determine the inverse of the total heat transfered, K_2. This is achieved by descending down constant grades at a constant speed using various retarder settings (Kret).

The study determined that a sufficient braking capacity was necessary to enable safe stopping of a truck to avoid the incidence of an out of control vehicle (Bowman & Coleman, 1990). However, when the brakes are applied during descent of a downgrade, heat is generated through the conversion of mechanical energy into heat energy. The FHWA GSRS model recognized that the heat generated is higher for heavier trucks travelling at higher speeds on longer and steeper slopes. Bowman et al. indicated that at high temperatures of about 375 ^{O}F, brake fade begins to occur as the brake drum begin to deform and the contact surface between the brake pads and the drums reduce. The reduction in the contact surface reduces the braking capacity of the truck. At a higher temperature of 500 ^{O}F, the contact surface reduces to the extent that the brakes fail completely and the driver looses control of the vehicle. Thus the aim of the model (using equations 2 to 5) is to predict the maximum speed of a truck descending a specific downgrade that will not result in brake temperatures approaching and exceeding 500 ^{O}F.

A DOS computer program was developed for the model that enabled its implementation to determine maximum safe downgrade speeds. Inputs of the program are information pertaining to truck weight (Ib), speed (miles per hour), and percent and length of downgrade. The program uses this information to generate the outputs of maximum safe downgrade speeds for different truck weights (see Figure 3).

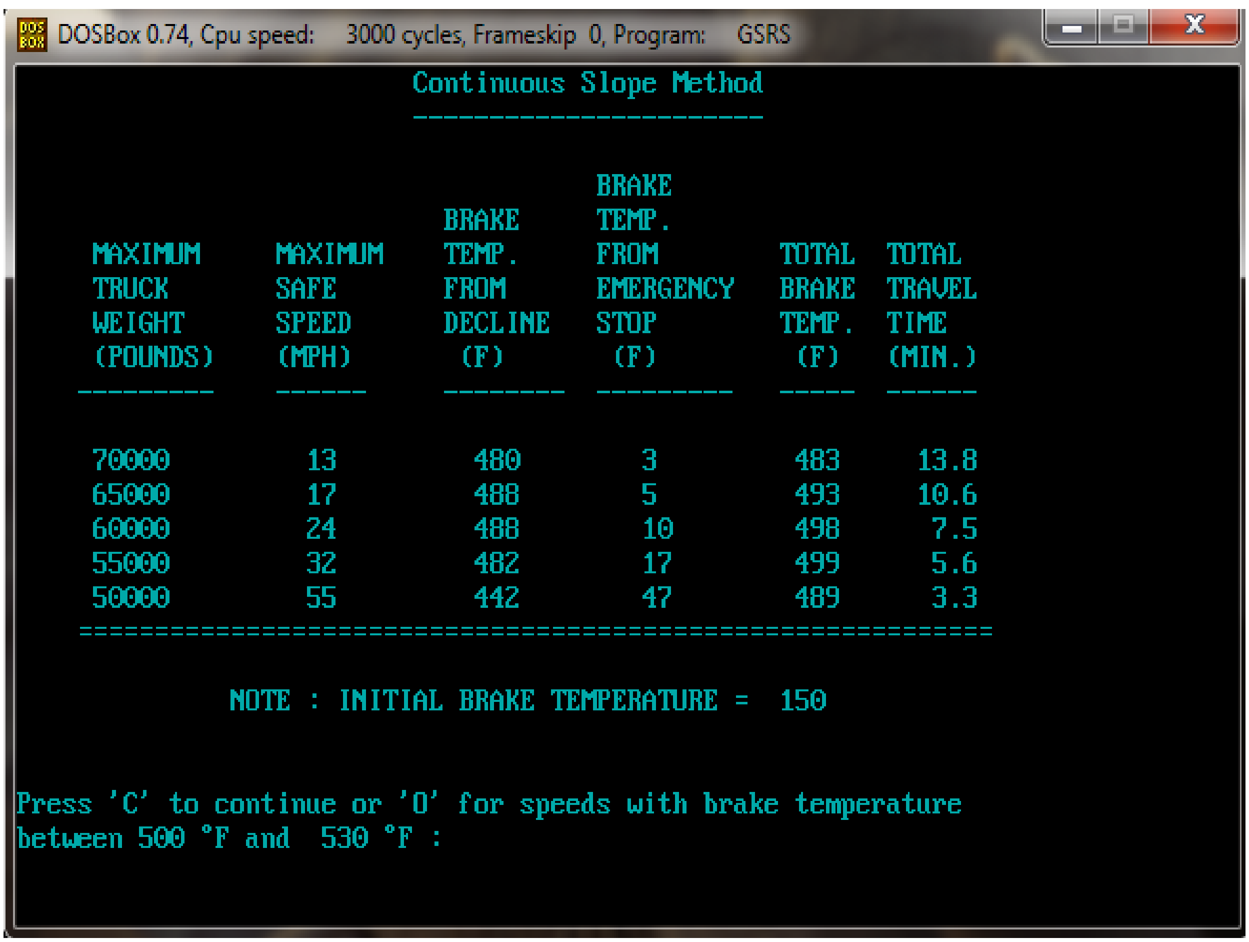

Figure 3: FHWA GSRS DOS program output

The maximum safe descent speeds are utilized in WSS signs as advisory signs for various truck weight category drivers. An example of a WSS sign is shown in Figure 4.

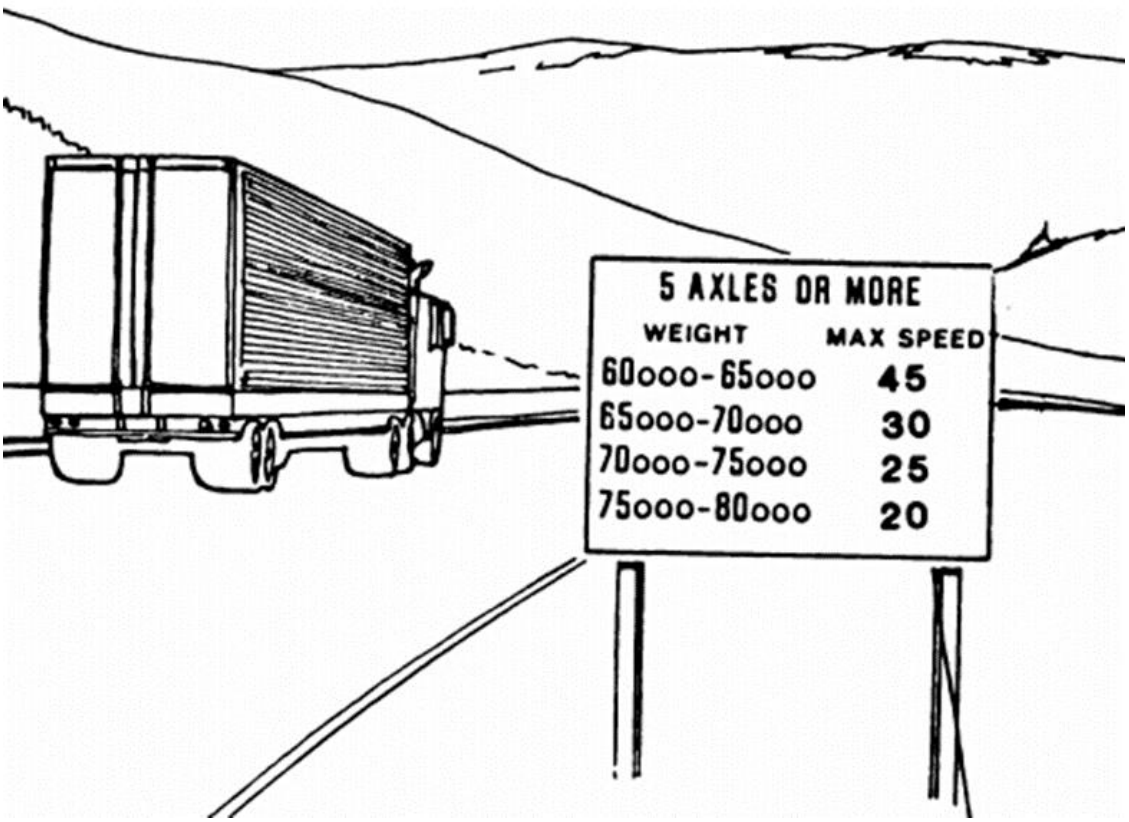

Figure 4: GSRS based WSS road sign

After the development of the FHWA GSRS model and the WSS signs, tests were conducted to determine the feasibility of utilizing the WSS signs to reduce truck runaway incidents (Hanscom, 1985). These tests indicated that the WSS signs were effective in reducing downgrade truck crashes since they simplified the driving task and emphasized the severity of the downgrade.

Beyond being used for estimating maximum safe truck descent speeds, the FHWA Grade Severity Rating System was recommended for locating downgrades where there is a high probability for brake failure (AASHTO, 2011). After identifying the dangerous downgrades, a brake temperature profile is generated for various truck weight categories using the GSRS software to determine truck escape ramp locations where runaway vehicles can safely stop. The GSRS model also serves as a tool for downhill truck accident analysis.

Two projects have been identified in the literature that have utilized the FHWA GSRS model. The projects are the Dynamic Downhill Truck Speed Warning (DDTSW) system carried out in Colorado, and a runaway lanes study conducted in British Colombia, Canada.

From 1997 to 1998, a DDTSW system using Intelligent Transportation System (ITS) technologies was developed and tested on Interstate 70 around the Eisenhower Tunnel in Colorado (Janson, 1999). The system operated by automatically weighing and classifying trucks as they approached a long downhill section of the highway. Considering the weight and the class of the vehicle, the system calculated a safe descent speed and each truck receives a vehicle-specific recommended safe speed on a variable message sign. The algorithm utilized by the system was based on the GSRS mathematical model developed by the FHWA. The project was implemented and tested to show that the DDTSW system was effective in reducing the probability of truck downgrade crashes on the roadway.

In the second study, the need, location, and design of runaway lanes in British Colombia, Canada was reviewed (Yee, 1996). In carrying out the review, Yee evaluated and modified the FHWA GSRS brake temperature model to account for the eight axle truck configurations existing in British Columbia. A detailed description of the instrumented test vehicle was given in this study. The test vehicle was a five axle, single articulation tractor-trailer supplied by Peterbilt Trucks Pacific Inc. The driver was protected by fitting an aluminum bulkhead behind the cab. The trailer was a typical flatbed style with a deck surface consisting of rough wooden planks bolted to the frame and was loaded with 8 banded units of economy grade lumber as shown in Figure 5. The tests were however not for validating the temperature equation but were used to evaluate the performance of the arrester beds of the runaway lanes. Thus the measurements taken were mainly to determine the vehicle dynamics and no measurement of brake temperatures were taken.

Figure 5: Instrumented Test Vehicle (Yee, 1996)

4. Limitations of the FHWA GSRS Model

The DDTSW study in Colorado made one main recommendation to revise the advisory speeds obtained using the FHWA GSRS algorithm (Janson, 1999). This was because of the risk of the advisory being too low and thus resulting in drivers ignoring the advisory signs as unrealistic. This issue is especially relevant for upgrading the model since current truck braking systems have improved to comply with the National Highway Traffic Safety Administration's (NHTSA) rule of reducing stopping distance of trucks by 30 percent in 2013 (Bendix Spicer Foundation Brake LLC, 2013). These brake improvements mean the current GSRS models are recommending maximum safe speeds for trucks that are too conservative and can lead to lower compliance rate by truck drivers.

In developing the FHWA GSRS model a recommendation was made to revise the model when truck characteristics changed in the future (Myers, Ashkenas, & Johnson, 1979). This was done in 1989 and the re-evaluation of the model determined that some modification of the GSRS model was required to account for the fuel conservation measures introduced for trucks at the time. These measures included improved aerodynamic from airfoils, streamlined tractor designs, and reduced frontal areas. The increased use of lower profile radial tires (2 in (5 cm) smaller in diameter compared to typical tires) also led to the rate of kinetic energy absorption of the brakes increasing due to the faster revolution of the smaller diameter tires. Truck engine improvements also led to less engine friction. The modification was to increase a grade by 0.34% over the actual grade in calculations to determine maximum safe speeds from brake temperature estimates. For example, when the actual grade is 8.0%, then the corrected grade to be used in the analysis will be 8.34%. This modification was determined over 25 years ago and there have been more advances in the aerodynamics, engine and braking features of current trucks. This makes it necessary to undertake another review of the FHWA GSRS model to determine the need for any modifications for the model.

Finally, the GSRS model suggests that brake fade and brake failure occur at temperatures of 458 ^{O}F and 500 ^{O}F. respectively. These predetermined temperature limits for brake fade and brake failure have to be re-evaluated for current trucks since they contribute significantly in determining appropriate maximum safe speeds for various truck weight categories.

5. Methodology

The overall methodology of this study is aimed at meeting two main goals. The methodology is summarized in Figure 6. The first goal is to evaluate Wyoming mountain pass warning systems to recommend the "best" warning system to implement for reducing truck crashes. This will involve tasks that include site visits to examine the current road signs and road geometry. Crash and citation data involving mountainous terrain will also be analyzed to determine which warning systems are effective.

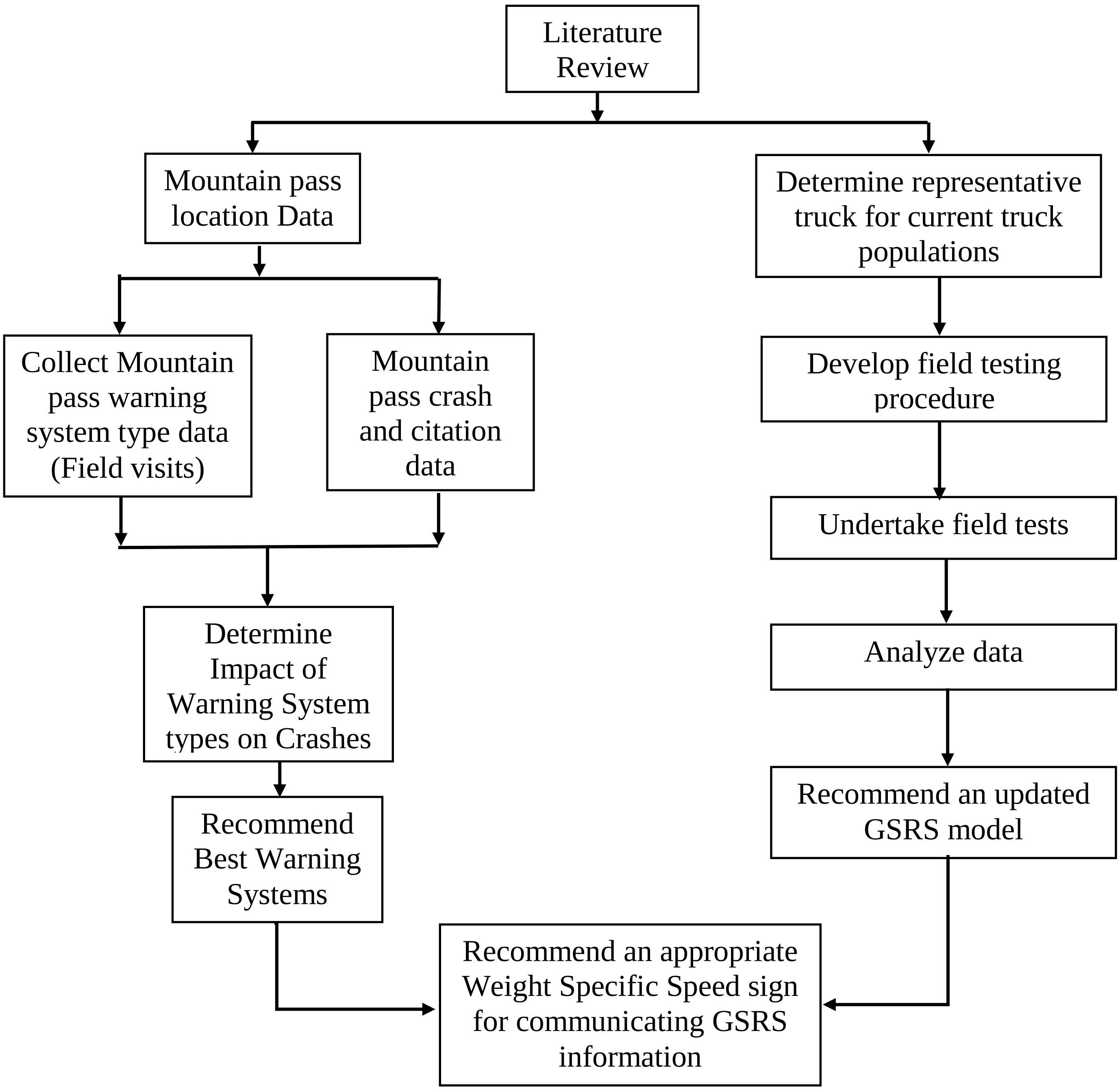

Figure 6: Research Project Methodology

The second goal is to review and update the FHWA GSRS model for estimating safe truck descent speeds. This goal will be achieved by carrying out tasks that include determining an appropriate truck type that is representative of current truck populations. The representative truck will be used in field tests to update and validate the GSRS model parameters to enable estimation of accurate maximum safe truck descent speeds that are more applicable to current truck populations.

The test vehicle(s) that will be utilized for the field tests will be determined based on reviewing current truck characteristics and types, as well as current weight and safety regulations in the trucking industry. The vehicle will be fitted with some sensors to carry out various measurements (Myers, Ashkenas, & Johnson, 1979). The typical measurements and the instruments or sensors utilized for developing the FHWA GSRS model are presented in Table 1. A schematic of the instrumentation system used is also presented in Figure 7.

Table 1: Typical vehicle sensors for field tests.

Measured Quantity	**Instrument or Sensor**
Brake Temperature	Thermocouple
Vehicle speed	Fifth wheel
Engine speed	Tachometer generator
Brake application pressure	Electrical pressure transducer
Trailer brake pressure	Electrical pressure transducer
Ambient temperature	Bulb thermometer
Ambient wind velocity	Hand held wind meter

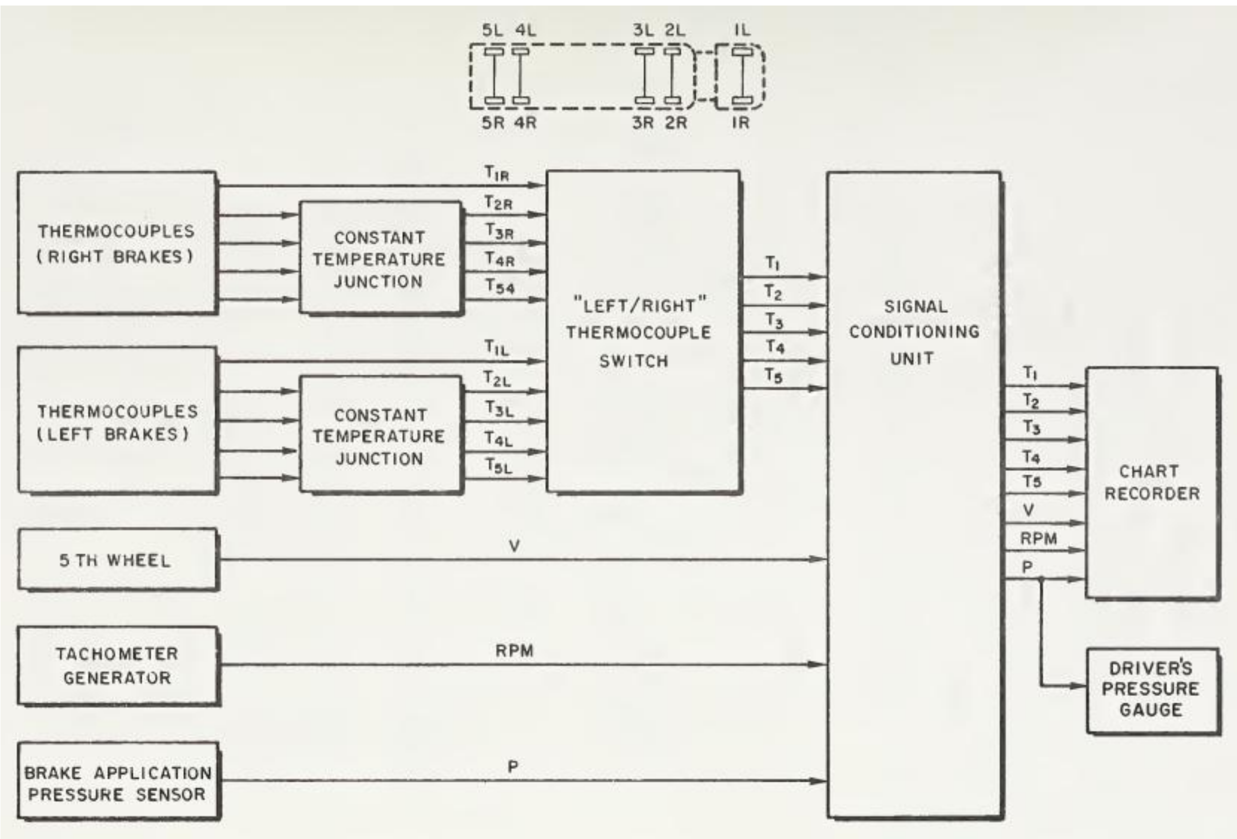

Figure 7: The FHWA GSRS Instrumentation system (Myers, Ashkenas, & Johnson, 1979)

The instrumentation system in the test vehicle comprised sensors for various measurements, thermocouple reference junctions, switches, a signal conditioning unit, a chart recorder, and power supplies (Figure 7). For this proposed study, it is recommended that the instrumentation system be similar in terms of the parameters to be measured. This is because similar tests are going to be designed in this study for verifying the applicability of the model to current trucks and for updating the model. The proposed study will utilize modern technologies to collect the various data needed for verifying and updating the model. This will include a modern data acquisition system, more accurate infrared temperature sensors and a transducer for brake sensor measurements. The speed and distance measurements will be recorded from the truck computer system using the CAN controller. A list of the instrumentation system components for the representative truck during the field tests are presented in Table 2.

Table 2: Instrumentation of the Representative Truck for Field Tests

Item	**Explanatory Notes**
NEMA 4 Enclosure	Package container for the data acquisition system
NI Compact RIO Controller	Data acquisition system component
NI 9214 temperature module	Data acquisition system component
NI 9208 4-20 –A input	Data acquisition system component
CAN input	Data acquisition system component
Digital input	Data acquisition system component
Battery	To provide a standalone power for system
PX transducer	For measuring brake pressure
Brake lining temperature sensor (IR sensors)	For measuring brake lining temperature
FLIR IR temperature gun	To validate truck brake temperature after descent
Cables	For connecting various components
Portable Computer	For data collection and analysis

Figure 8 shows a typical modern signal conditioning and recording unit assembled from the aforementioned components.

Figure 8: A typical modern data acquisition unit.

The results from the tasks performed will be combined in a final task to recommend a model for WYDOT to determine safe descent speeds for various truck weight categories and the most effective warning system to communicate this information to drivers. The recommendations will help reduce incidences and severity of truck crashes on downgrade descents due to brake failure or out of control trucks.

6. Study Tasks

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

Task 1: Literature Review

The literature review will be aimed at obtaining insight on the following issues: (1) warning systems for trucks descending downgrades - this will involve identifying the types of road signs recommended by the Manual on Uniform Traffic Control Devices (MUTCD) and other guides meant for advising truck drivers descending hills on appropriate precautions to take; (2) Grade Severity Rating Systems, including the mathematical models for downgrade trucks and a thorough description of the field tests and instrumented vehicles that have been used to develop and evaluate those models; (3) current truck characteristics - these include improvements in brake systems, truck brake temperatures at brake fade and brake failure, improvements in truck aerodynamics, and any recent changes in weight limits and trucking laws that may impact truck descent safe speeds.

Task 2: Evaluate Existing Warning Systems on Wyoming Mountain Passes

Task 2.1: Collect Data on Mountain Pass Locations

Data on the locations of the various mountain passes will by obtained from WYDOT. These will include associated posted speed limits, percentage grade, and other road geometric characteristics. If available, information on the warning systems used on those mountain passes will be obtained including their years of installation.

Task 2.2: Carry out Site Visits to Determine Warning Sign Types

A field assessment of the warning signs on the mountain passes identified in Task 2.1 will be carried out. The field assessment will determine the type of warning systems used and the condition of these warning systems.

Task 2.3: Obtain Crash and Citation Data at Mountain Pass Locations

Crash and citation data in the vicinity of the mountain passes will be obtained from WYDOT and prepared for statistical analysis to determine the impact of the warning systems on crashes and compliance to speed advisories.

Task 2.4: Determine Safety Effectiveness of the Warning Systems

This task will involve some statistical analysis to determine the impact various downgrade warning systems have on truck downgrade crashes. The statistical analysis may give an indication of the safety effectiveness of the warning system types utilized in Wyoming.

Task 2.5: Recommend the Most Effective Warning System

Based on Task 2.4, a recommendation will be made for the best warning system(s) for Wyoming mountain passes that can reduce the occurrence of truck downgrade crashes.

Task 3: Review and Upgrade the FHWA GSRS Model

Task 3.1: Determine a Truck Type to be used as a Representative Test Vehicle

Based on the literature on current truck characteristics and trucking industry practices. A truck type will be recommended that is most representative of current generation truck types.

Task 3.2: Develop Field Testing Protocol

A testing protocol will be developed that considers the types and number of tests need to modify and validate the truck downgrade descent mathematical model, the instruments required for measuring appropriate truck parameters, test location, and safety. The testing protocol will be developed and approved by all stakeholders involved in the study.

Task 3.3: Carry out Field Testing with Instrumented Vehicle

A test truck will be provided by the trucking industry and WYDOT. This truck will be instrumented by the University of Wyoming research team. Field tests will be then conducted as described in the testing protocol. It is required that the district would provide traffic control while conducting the experiment. It is also required that the district will provide space in the maintenance shop to instrument the truck prior to testing.

Task 3.4: Analyze and Develop Parameters from the Results of the Field Tests

Combining the field tests and the mathematical model for truck downgrade descent, appropriate modifications and parameters will be recommended for updating the model.

Task 3.5: Propose an Updated Model for Estimating Maximum Safe Truck Descent Speeds

An updated model will be recommended for estimating safe downgrade descent speed of various truck categories. This model will be developed into a software that can be implemented easily by WYDOT.

Task 4: Recommend an Appropriate Warning System for Implementing the Updated GSRS Advisories for Truck Drivers

An appropriate warning system will be recommended for communicating the outputs of the updated GSRS model to truck drivers.

Task 5: Prepare final report. Present findings and recommendations

A final report will be prepared that documents the processes used to develop the GSRS model and the evaluation of the mountain pass warning systems.

7. Timeline and Staffing

The entire study will be performed in 30 months beginning July 1, 2016. The data collection for the evaluation of Wyoming Mountain pass warning systems and the instrumented truck field tests will be spread over two summers. A final report and several presentations to appropriate WYDOT personnel as well as the trucking industry are anticipated at the conclusion of the study. In addition, recommendations will be made for implementation of the study outcomes to reduce incidents and severity of truck downgrade crashes. The proposed timeline is presented in Figure 9.

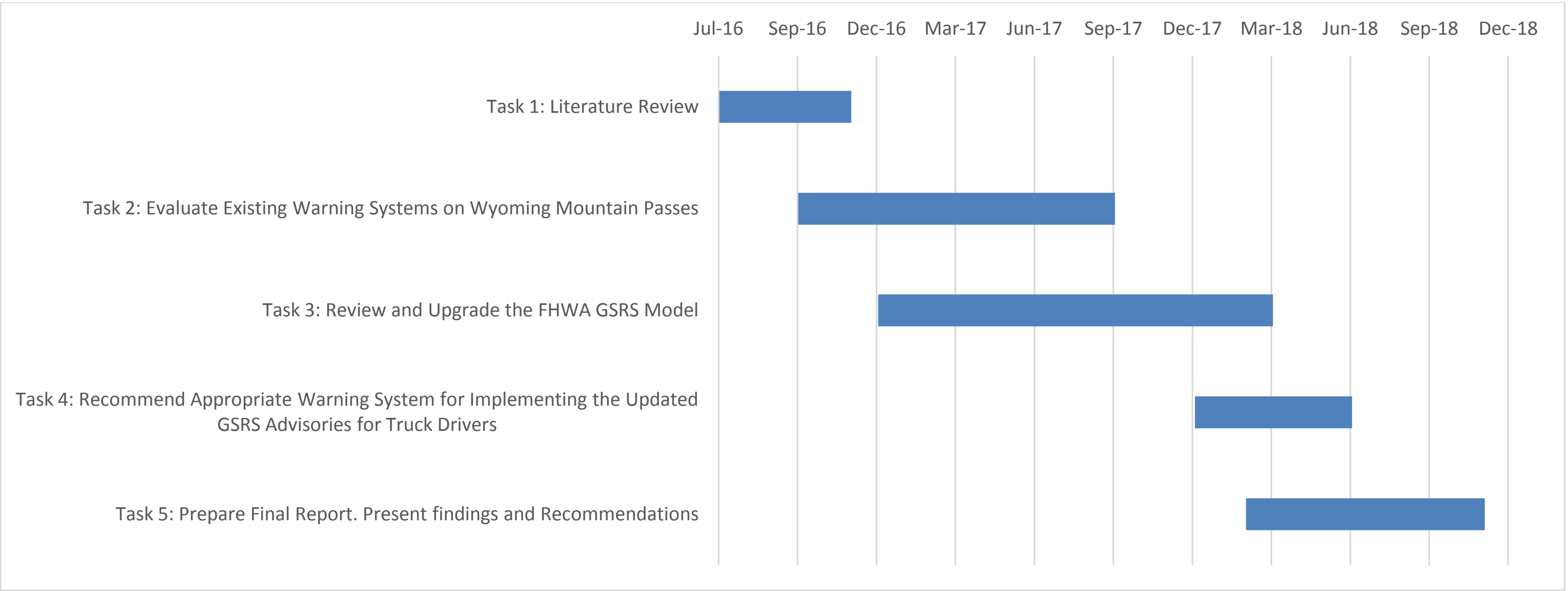

Figure 9: Proposed timeline for the study

8. Budget

The total budget for this study is $157,004. Table 3 shows the breakdown of the budget. The field component of the study will require the purchase of instrumentations as described in the previous section.

Table 3. Budget for the GSRS Study

July 1, 2016 – December 31, 2018

CATEGORY	Budgeted Amount	Explanatory Notes
Faculty Salaries	$ 19,500	
Instrumentation Technician Salary	$ 8,000	
Engineer Salary	$ 9,000	
Student Salaries	$ 22,600	One graduate Student
Fringe Benefits	$ 18,337	
Total Salaries and Benefits	$ 77,437	
Permanent Equipment	$ 26,000	Computer plus Instrumentations
Expendable Property, Supplies, and Services	$ 3,000	Final report
Domestic Travel	$ 11,200	Data collection and presentations to insure proper technology transfer
Foreign Travel	$	
Other Direct Costs (specify)	$ 13,200	Tuition and Fees
Total Other Direct Costs	$ 53,400	
F&A (Indirect) Costs	$ 26,167	
TOTAL COSTS	$ 157,004	

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