TRUCK MODELING ALONG GRADE SECTIONS

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Abstract

This research effort first characterizes the trucks traveling along US highways by analyzing data from Interstate 81. It is hypothesized that I-81 is typical of US highways and thus can provide some insight into typical truck characteristics. These truck characteristics are important for the development of an exhaustive vehicle performance procedure. Analysis was done based on data collected at the Troutville weigh station. The characterization involves an analysis of vehicle class distribution, GVW (Gross Vehicle Weight) distribution, vehicle volume distribution, Average Weight on Tractive Axle (AWTA), and typical weight-to-power ratios.

The thesis then assembles a database of systematic field data that can be utilized for the validation of vehicle performance models. This database is unique because it was conducted in a controlled field environment where the vehicle is only constrained by its dynamics.

Using the assembled field database, a simple constant power vehicle dynamics model for estimating maximum vehicle acceleration levels based on a vehicle's tractive effort and aerodynamic, rolling, and grade resistance forces was tested and validated. In addition, typical model input parameters for different vehicle, pavement, and tire characteristics are included in the thesis. The model was found to predict vehicle speeds at the conclusion of the travel along the section to within 5 km/h (3.1 mi/h) of field measurements, thus demonstrating the validity and applicability of the model.

Finally, the research effort introduces the concept of variable power in order to enhance current state-of-the-art vehicle dynamics models and capture the build-up of power as a vehicle engages in gearshifts at low travel speeds. The proposed enhancement to the current state-of-practice vehicle dynamics model allows the model to reflect typical vehicle acceleration behavior more accurately. Subsequently, the model parameters are calibrated using field measurements along a test roadway facility.

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Dedication

I would like to dedicate this thesis to my grate immediate family for their continuous support and generous encouragement through my graduate study. To my splendid and beloved husband Panta, this thesis is acknowledgment to his beautiful love, patient, support and understanding for all the time that we did not spend together through my study and this research.

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CHAPTER 1: INTRODUCTION

Truck transportation plays an important role in the US economy. For example, trucks transport approximately 25 percent of all freight in the US. Consequently, trucks constitute approximately 26 percent of all traffic on US highways and pay approximately $25 billion in Federal and State taxes (Federal Highway Administration (FHWA), 1999).

The performance of trucks on roadways is affected by a number of factors including the vehicle’s length, its weight-to-power ratio, the vehicle’s aerodynamic features, the roadway pavement surface, and the roadway grade.

1.1 PROBLEM DEFINITION

The capacity impact of trucks is typically quantified using the Highway Capacity Manual (HCM) procedures. These procedures provide vehicle performance curves for a typical truck, which is characterized as a truck with a weight-to-power ratio of 121 kg/kW (200 lb/hp). The vehicle performance curves indicate the speed of a truck as a function of its initial speed, the grade of the roadway, and the length of travel along the roadway. Unfortunately, the procedures were developed a number of decades ago and thus may not be reflective of trucks on current roadways. Furthermore, the procedures fail to incorporate other factors that affect the performance of trucks including the roadway surface and the effect of vehicle dynamic features of the vehicle performance.

1.2 THESIS OBJECTIVE

The objective of the thesis is to develop an analytical procedure that is reflective of typical trucks that travel along US highways. This procedure overcomes the shortcomings of the current state-of-practice HCM procedure. Specifically, the objective is to develop an analytical procedure that is not only sensitive to the vehicle weight-to-power ratio, the roadway grade, and the length of the grade, but is also sensitive to the vehicle aerodynamic features, tire characteristics, and pavement surface conditions.

Furthermore, the procedure is developed based on vehicle dynamics so that it can be incorporated within a microscopic traffic simulation model.

1.3 THESIS CONTRIBUTION

The thesis makes four significant contributions. First, the thesis attempts to characterize trucks traveling along US highways by analyzing data from I-81. It is felt that I-81 is typical of US highways and thus can provide some insight into typical truck characteristics. These truck characteristics are important for the development of an exhaustive vehicle performance procedure.

Second, the thesis collects a database of systematic field data that can be utilized for the validation of vehicle performance models. This database is unique because it was conducted in a controlled field environment where the vehicle is only constrained by its dynamics.

Third, the thesis validates a state-of-the-art constant power vehicle dynamics model that has been presented in the literature using field data that were collected along the Smart Road test facility. In addition, the thesis identifies typical input parameters and validates these parameters against field measurements.

Forth, the thesis extends the vehicle dynamics model by introducing the concept of variable power in order to capture the buildup of power as the vehicle engages in gearshifts. The proposed enhancement results are a significant enhancement to the current state-of-the-art vehicle dynamics model.

1.4 THESIS LAYOUT

The thesis consists of six chapters. The second chapter provides an overview of the truck characteristics, its impacts on traffic flow and pavement structure, Weigh-in-Motion technology (WIM), and current state-of-the-art procedures for quantifying the operational impacts of trucks. Subsequently, a characterization of the trucks traveling along I-81 is presented in Chapter 3. The characterization serves as a first step in developing a comprehensive analytical procedure for the evaluation of the capacity impacts of trucks.

Chapter 4 presents a state-of-the-art vehicle dynamics model, identifies typical input parameters that capture different vehicle and roadway characteristics.

Chapter 5 enhances the state-of-the-art vehicle dynamics model by introducing the concept of variable power in order to capture the buildup of power during gearshifts. The model is validated against data collected along the Smart Road test facility.

Finally, the conclusions of the thesis are presented in Chapter 6 together with recommendations for further research.

CHAPTER 2: LITERATURE REVIEW

This chapter provides an overview of research that has been conducted on trucks that relate to the research that is presented in this thesis. Initially, studies that have characterized trucks and the evolution of truck characteristics are presented. Subsequently, various studies that have attempted to characterize the impact of trucks on roadway capacity are presented. In addition, various modeling approaches of trucks are presented. The impact of trucks on pavement deterioration is discussed together with the various WIM technologies and accuracies of these technologies.

2.1 TRUCK CHARACTERISTICS EVOLUTION AND IMPACTS ON TRAFFIC FLOW

Truck characteristics and their impacts on traffic are very important for traffic analysis, modeling, including safety, management, and geometric design of roads. Heavy vehicles are specific in terms of their characteristics such as: size, weight-to-power ratio, acceleration, deceleration, etc. Trucks accelerate different than other vehicles and its characteristics on the grades vary. Trucks also reduce traffic capacity because they need more space and it causes other drivers to be careful. Truck performances and effects also vary with road design, number of lanes and their width, traffic conditions, and many other factors. Because truck characteristics change over the years, continuous research is required. For example, truck speeds, sizes, weights and dimensions have increased over the years in most of the countries and the impacts on traffic flow and road design also become much different.

It should be noticed here that the HCM, which was established in 1965 and continues to be the most comprehensive in analysis of road capacity, traffic management, level of service and traffic congestion, also including effects of heavy trucks (OECD Road Research Group, 1982). The HCM is essential for this study because it contains truck performance curves that should be updated to be reflective of the technology. Chapter 4 will discuss in detail about these curves and its importance.

Operations and characteristics of heavy vehicles on the road network and their influences on the safety and efficiency of the highway transportation system are very essential. Roads should be design to accommodate heavy vehicles and vice versa. The major situations and truck characteristics of interest are as follows (Fancher and Gillespie, 1997):

1. Turning at intersections and on horizontal curves;
2. Acceleration and braking;
3. Crash avoidance;
4. Pavement loading, highway fatigue, rutting, and bridge loading;
5. Congestion, capacity, and passing sight distance;
6. Design of heavy trucks and trailers;
7. Weights and dimensions (primary parameters by which acceptable vehicles are defined in road use laws – every state has their own limitations);
8. Mechanical Characteristics: running gear, braking system, propulsion systems, steering systems, suspension systems, and cabs; and
9. Truck Effects on Traffic Flow (highway capacity and passing sight distance) with two significant effects:
    - Reduce the maximum service on a segment of highway because they are longer then cars (have less acceleration capability) and
    - Grate passing sight distance, because of its lengths.

Each of those mentioned characteristics are essential, but for this research acceleration/deceleration on various grades, weights and dimensions, some of mechanical characteristics of heavy vehicles are the most important.

Operational truck characteristics on the US roads are usually dominant in all studies connected with trucks. Frequent types of trucks in western Canada are five – (3-S2) and six – axle (3-S3) tractor semitrailers. Fekpe (1997) analyzed trends in truck fleet mix and described operational characteristics of mentioned types of heavy vehicles. These analyses are very good and useful because it is important to know what types of trucks with which characteristics and loads are on the roads. There are numerous and various reasons for that such as use those data to predict pavement damage, number of lanes, and many other important issues.

During this study the author analyzed percentage of these types of trucks in 1991 year and their changes after. The percentage of 3-S2 decreases from about 70% in 1991 to about 50% in 1994 year. The percentage of 3-S3 increase from 9% to 20% in the same period of time. These changes the author explained by the following various characteristics:

- Flexible payload handling capability;
- Operating efficiency measured by the possible pavement damage per unit payload are better; and
- Higher productivity indicated by the possible payload capacity actually utilized.

Going through these major characteristics of heavy trucks there is possibility to explain changes in fleet focusing on the next important variables:

- Average operating Gross Vehicle Weight (GVW);
- Average payloads; and
- Operating efficiency.

After this analysis, the author made the following conclusions:

- Dynamic performances of these two types of trucks 3-S2 and 3-S3 are very similar.
- The second one is more efficient operationally in terms of payload handling and possible pavement damage.
- Also the second one is more suitable and flexible for weight-based commodities and commodity handling.
- The possible payload capacity and the amount actually utilized are higher.
- The number of 3-S3 type of trucks will increase in the next few years.

Increases in truck weights and dimensions in the last few decades all over the world, especially in the North America needs to make some changes in highway design criteria. At the other side, increasing in payload cause reduction in unit transportation costs (Hutchinson, 1990).

Truck characteristics and their changes along the time are very important for the geometric design and capacity analysis of urban roads, and intercity highways. Current standards consider mainly properties of passenger vehicles in case of highway design criteria. This approach is acceptable when there are not dramatically changes between trucks and passenger cars weights, dimensions, and performance characteristics. The highway infrastructure design criteria has to be reviewed in terms of recent changes in truck properties. The problem can be analyzed using the next vehicle characteristics:

1. Dynamic characteristics (friction demands in turns, braking characteristics, rearward amplification);
2. Axle group characteristics (spacing, tire properties, loads, suspension properties);
3. Vehicle dimensions (length, width, height);
4. Articulation geometry of long combination vehicles; and
5. Gross vehicle mass (GVM).

In Addition to the vehicle characteristics, highway transportation characteristics should be included, such as:

1. Geometric characteristics (vertical and horizontal alignment);
2. Capacity and safety of traffic streams;
3. Intersection properties (turning radii, capacities, and signal timing); and
4. Design of bridges and pavements.

Subsequently, analysis of lane-distribution characteristics of truck traffic is very important. Fwa and Li (1995) conducted study on five different road classes in Singapore. Four important factors that effects on the lane-distribution of trucks are:

- The number of traffic lanes;
- The functional class of the road;

- The total directional traffic volume; and
- The volume of trucks traffic.

Data were collected for five road classes: expressways, arterials, collectors, industrial roads, and local urban streets. It contains surveys that provided detailed hourly counts by vehicle class for each lane of the road surveyed. Three procedures have been used to estimate the proportion of trucks in the most critical lane (function of total daily directional traffic and the number of traffic lanes; function of the total directional commercial vehicles only; function of the number of traffic lanes only).

The study is based on modeling of lane-use characteristics. The lane distribution of truck traffic was affected by the following factors: number of traffic lanes, functional class of roads (e.g., three-lane expressways versus three-lane collectors, and two-lane local urban streets versus two-lane industrial roads), level of hourly directional traffic volume, and level of hourly directional truck volume. The lane-distribution characteristics, based on hourly traffic, could be used to compute traffic loads in the design lane for pavement design as follows:

- Identify the distribution of hourly traffic in representative day for the specific road;
- Compute the design lane truck volume for each hour of the specific day;
- Sum up all the hourly design –lane truck volumes of the day to arrive at the total design daily volume; and
- Compute the yearly design volume for the selected design life span of the road pavement.

Fwa et al. (1994) present the results of a study related to the truck characteristics in Singapore. They conducted surveys on five different roads (expressways, arterials, collectors, industrial roads, and local urban streets) such as in previous study. Several surveys connected with counting of vehicles by axle-configuration at 219 sites in a period of almost two years. Based on surveyed data, they have studied aspects of truck traffic in Singapore such as:

- The major routes of truck traffic;
- Time distribution characteristics of truck traffic by different classes of roads;
- Composition of truck traffic;
- Lane use characteristics of truck; and
- Relationship between trucks traffic volume and total directional traffic volume.

During the study, the authors found that the time distribution of truck travel were different on all classes of mentioned roads. Also the lane distribution characteristics of truck traffic are different from road to road. It depends on the class of road and the number of traffic lanes.

Dominated type of trucks in truck traffic in Singapore is single-unit truck. Percentage of those trucks on arterials is 81.7% and on local roads is about 97.0%. Comparing the relative proportions of single-unit trucks and multiple-unit trucks in different lanes, changes are not significantly. Analysis showed that truck traffic volume varied from less than 5% on local roads to more than 20% on industrial roads.

2.2 TRUCK IMPACTS ON PAVEMENT STRUCTURE

Heavy vehicles have high influence on pavement structure at the roads. Karamihas and Gillespie (1993) paid attention on pavement damage from trucks and how to predict dynamic loads along the roadways. The validity of the models is presented.

The authors focused on characteristics of trucks and pavement, and also their interaction. Representative types of trucks are used for their research. The objective was to simulate truck operating on the roads to predict loads, than use those loads in simulation models to predict responses in the pavement structure. The responses are used to estimate damage on the roads. The heavy vehicles have a huge spectrum of various characteristics and some of them have directly influences on pavement loading while others do not. The most important truck characteristics with primary influence on pavement loading are:

1. Weight (gross vehicle weight, gross combination weight);
2. Axles (number, locations, loads);
3. Tires; and
    - Type (conventional, wide-base single, low-aspect ratio);
    - Pressure/contact area;
    - Dual/single arrangements;
4. Suspensions (stiffness/ damping, static and dynamic equalization).

Pitch-plane models are used to predict truck dynamic loads in their research. They computed dynamic axle loads by models and compared with measured. These models assume the same road profile input to both wheels on an axle, which means that models do not distinguish dynamics in individual wheel trucks.

York and Maze (1995) briefly described applications of trucks size and weights standards in the US. This research contains evaluation of truck size and weight regulation in the United States and classification of performance criteria that are follows:

- Interaction between the vehicle and the pavement and/or bridge infrastructure;
- Control the interaction between the vehicle and the traffic safety environment; and
- Control the vehicle interactions with both the highway infrastructure and the traffic safety environment.

The interaction between vehicle and pavement through tires is important for this thesis, especially type of tires. Vehicle configurations of New Zealand and Australia are described in this paper. Those two countries are specific because of various extremely long multiple-trailer combinations. In general, the number of axles and axles spacing determines gross weights for all vehicle configurations.

2.3 TRUCK MODELING

Trucks modeling along various grades, pavement conditions, and different road characteristics are very important for this research. Not so many authors were using dynamics models to predict maximum vehicle acceleration levels based on vehicle’s characteristics, performances, and road conditions. Here will be presented several studies connected with dynamics models and its validation with trucks different performances.

Mannering and Kilareski (1990) and Fitch (1994) introduced basic vehicle dynamics model that computes the vehicle’s acceleration based on its instantaneous speed using equation from second order motion model, as it is demonstrated with Equation 2.1. Acceleration is in a function of force, total resistance and vehicle mass.

$$a = \frac{F - R}{M} \tag{2.1}$$

Where a: maximum truck acceleration (m/s^2);

F: tractive effort (N);

R: total resistance force (N); and

M: vehicle total mass (kg).

The model was used in few studies and the most important (Demarchi et al., 1996) shows model that provides truck performance curves along upgrade sections including several major factors such as:

1. Vehicle-to-vehicle interaction;
2. Vehicle-to-control interaction;
3. Vehicle dynamics;
4. Vehicle characteristics (power, weight, weight on tractive axle, frontal area, transmission efficiency);
5. Pavement characteristics (rolling resistance); and
6. Location (altitude).

The developed model presented by Equation 2.1 was applied to the three HCM typical trucks:

- The heavy truck – 300 lb/hp
- The average truck – 200 lb/hp
- The light truck – 100 lb/hp

and two hypothesis were considered such as:

- The method used to develop the HCM curves is different and
- The vehicle parameters are different.

Model was incorporated within Integration microscopic simulation and assignment model. This study includes simulation of the truck performance on upgrades using INTEGRATION in order to validate the microscopic model against HCM performance curves. They made two scenarios. The first is a two-lane undirectional highway with constant grade and the second one with composite grade. The grade magnitude varied from 0 % to 8 %, and they considered two initial speeds: 88.5 km/h and 0 km/h. Results are very good if we compare with HCM curves. Curves show relationship between distance and speed. Their recommendations are next:

- Update HCM curves using real data.
- Compare conditions under which vehicle dynamics result in highway capacity impacts.

The model validation/calibration with actual data is not presented.

Archilla and De Cieza (1996) conducted study based on the same model, second order motion model. The validation of the model is presented. Speed prediction model is used to find acceleration and deceleration curves on grades on National Highway 7 in Argentina. Validation of the model is presented with comparison of collected and estimated data. Speed profiles are obtained on upgrades for trucks with known weight-to-power ratios. The validation is not accurate, because the authors were using actual road with high traffic demand and trucks could not accelerate with maximum acceleration.

Characteristics of trucks have changed along the time and the same situation is with other vehicle classes. Because of that it is appropriate to update information, what was idea of Khan et al. (1990) in their study about heavy vehicle performances on different grades and climbing. The objectives of this research are:

1. To update truck speed-distance curves;
2. To develop realistic metric speed-distance curves which includes characteristics of existing and forthcoming heavy vehicles; and
3. To review MTO warrants for climbing lanes based on mentioned realistic curves and on the principles of cost-effectiveness on grade.

There is a wide range of loading vehicle levels and the authors selected the following weight-to-power ratios to simulate vehicle performances on grade:

- Trucks: 60, 120, 180, and 210 kg/kW
- Recreational vehicles: 40 kg/kW

The authors evaluated two models. The first model supports a detailed simulation of vehicle performance. It is based on vehicle characteristics such as mechanics and dynamics. The second model is based on the Truck Ability Prediction Procedure, which is recommended by the Society of Automotive Engineers (SAE). The outputs from the both models were reasonable and in comparing with field data. In cases of warrants that are used by various agencies for the provision of climbing lanes, there are similarities and differences.

The study was conducted in Ontario region and recommendations that presented are applicable for that region. The major conclusions are:

- Representative heavy trucks are with weight-to-power ratio from 200 kg/kW to 180 kg/kW for most places in mentioned region.
- 90 km/h is recommended speed for most two-lane rural highways.
- On roads where recreational vehicles and truck traffic dominate, performances of recreational vehicles should be used to estimate critical length of grade.

2.4 WEIGH-IN-MOTION TECHNOLOGIES

Vehicle weight and dimension (VWD) regulations are defined in the US, but they vary from state to state. Set of VWD regulations is a complex of important rules and new regulations are required with increases in truck weight and dimensions, which are connected with economic efficiency. WIM systems are established around all over the world to regulate/control weights and dimensions of trucks. Truck weight data have been obtained for more than 50 years. The uses of truck weight data can be categorized into the following areas:

- Pavement design, monitoring, and research;
- Bridge design, monitoring, and research;
- Size and weight enforcement;
- Legislation and regulation; and
- Administration and planning

WIM systems are important in road transportation and required equipment should follow changes in truck performances. The earliest effort in developing weight equipment was reported in 1952 by Normann and Hopkins (Bureau of Public Roads). Axle weights, axle spacing, and vehicle speeds were computed by manually oscilloscope readings not only in the US. UK, Japan, and Sweden were used the same procedure to measure heavy vehicle's weights and dimensions. Research into portable WIM devices began at about the same time (1952).

During the last 10 years, WIM stations have been using equipment that is effective in measuring the dynamic wheel forces of moving vehicles, but it is important to say that WIM equipment is not capable of obtaining information that is derived from interviews of drivers or from close inspection of the vehicles such as model year, engine specifications including curves, and other characteristics. The data, which can be obtained by WIM systems, related to the heavy vehicles (source Troutville WIM station) are:

- Year, date, and time;

- Vehicle class;
- Total length of vehicle;
- GVW;
- 18-K Equivalent Single Axle Loading (ESAL);
- Weights on each axle;
- Spacing between axles;
- Body type;
- Warning messages (overweight, too long, speed change, etc.); and
- Different reports (class counts, speed counts, error vehicle counts, etc.).

Operational characteristics of WIM devices are important and they can classifieds into the following (National Cooperative Highway Research Program, 1999):

- *Accuracy*

  WIM stations should be accurately in measuring of weights and it depends on various factors. Some of influences are: type of roadway, traffic volume, and environmental factors. Besides that, it is important to determine level of accuracy, but there is no standard method used to indicate that level. The most common used measure is the mean error expressed as a percentage of the weight.
- *Portability*

  This operational factor is not a significant factor, but it is important to have good mobility of the equipment. Various equipments need different time to install or reinstall components. For example, weight sensors are the most portable devices and can be installed and reinstalled in less then an hour.
- *Conspicuousness*

  This factor has also important influence on WIM operations and there are differences if weighing done when it is known or not.
- *Durability, Reliability and Efficiency*

  These issues are significant for quality of WIM equipments. Durability is connected with number of wheel-load measured and it shows tolerance of weight sensors before replacement. Reliability refers to various failures during the normal life of devices. WIM stations should be equipped with very fast and quality devices. Efficiency is important to state agencies and subject is how to work with minimum personnel and provide desirable data.

- *Maintainability, Repairability, and Calibration*

  WIM devices that required minimum and simple maintenance are desired before it should be repaired. Calibration is an important effect on efficiency of WIM devices. Some equipment needs to be calibrated once, but the others should be calibrated every time before reinstallation. The quick periodically check in calibration is necessary for better results.

- *Data storage capacity and capability*

  Data obtained at WIM stations need to be placed somewhere and capacity is important issue. Approaches for data storage are differ from station to station and it can be done by accumulating axle weights into weight cells by hour or information about each truck can be record with the time of day when it was observed.

- *Communication, Safety (setup, installation, operation, takedown), and Power Requirements*

  To have good integrated WIM system that provides good communication is also important issue. Safety is the most important factor in WIM operations and procedure should be that makes that zone safe. All signs, signals, and markings must be install and designed to provide easy guidance to all trucks. Also, equipment needs to be installed, reinstalled and personnel should operate at WIM stations safely. Power for whole system at WIM stations is required to be determined and should be installed on appropriate place in terms of safety.

The WIM systems have their advantages and disadvantages. Both of them vary from station to station and depend on equipment and personnel too. The major advantages of WIM technology include:

- Short vehicle processing rate;
- Improved safety;
- Automated processing of truck-weight data;
- Availability of dynamic loading information;

- Increased coverage;
- Minimized scale avoidance; and
- Reduced unit cost for trucks;

The important disadvantages of WIM technology are as follows:

- Difficulty in comparing the accuracy of WIM equipment versus static weighing devices;
- Unavailability of data usually obtained from driver interviews;
- The complexity of installing or deactivating a WIM site;
- High initial cost; and
- Increased staff technical requirements.

Accuracy of WIM systems and studies based on comparing data from WIM stations and field data are significant, as it is mentioned. Zhi et al. (1999) conducted survey in their research at two WIM sites in Manitoba with idea to compare truck dimension measurements, truck weights and vehicle classification between WIM systems and those obtained manually. Results from the analysis are:

1. WIM axle-spacing data were outside the tolerance for 95% conformity specified by American Society for Testing and Materials.
2. The WIM system underestimated about 90% of truck weights in the survey period.

Accuracy of WIM equipment is very essential to the road design. Sharma et al. (1999) conducted the study, which is based on analysis of WIM system installed on Trans-Canada Highway west Regina. WIM is used to collect the spot speed data. The objectives of this research are:

1. Compare collected spot speed data with the measurements taken by a radar meter.
2. Compare WIM data on axle spacing with manually collected data.
3. Compare WIM data on dynamic weights with static weights.

The analysis indicated that there is no significant difference between the WIM system and the radar technique. Differences are in the range of absolute 5 km/h at 95% confidence level. Comparing WIM data on axle spacing with manually collected data, there is evidence that WIM data provides reasonable accurate data. WIM data for weight enforcement at normal highway speeds cannot be used, because of a wide range of errors. The authors made several recommendations based on their knowledge after research and the major is that the WIM system should be calibrated properly once a year in order to provide reasonable data.

It is well known that the US developed ground transportation much better than railroads. The road network is big and wide all over the country. Also it is important to say that trade between the US and neighbor's countries have been growing these years, especially with Mexico. Harrison et al. (1998) analyzed truck traffic across the southern Texas border, focusing on truck axle loads. This is the first comprehensive analysis about truck's traffic in this area. WIM systems were installed because of this study at the Laredo and El Paso ports-of-entry. The data were collected on both WIM stations during weekdays, then have been analyzing. Weekends are not included in this research, because traffic is much less then on weekdays. About 450000 trucks were weighed, during the truck's counting period of 14-th months and 60 percent of tandem axle load trucks are exceeded the US weights regulations (25 percent at El Paso and 35 percent at Laredo). Also, the other observed data were exceeds the US weights limits. Those data were collected during 1995 year and after that in early 1996, the Texas Department of Public Safety (DPS) began with safety program at these sites. New data show very big difference and it is evident decreasing in the numbers of overloaded trucks, which are passing Texas-Mexico border over the mentioned two sites. General Accounting Office is recommended to use WIM stations, because it is good way to make infrastructure safe and protected. Also it is important way to comply all international trucks with federal and state lows. The authors experiences show that WIM stations are not expensive and can be used to screen for overloaded trucks and it is possible adopt it for low-speed traffic through ports-of-entry.

2.5 CONCLUSION

Historical data and recent studies were very useful for this research and could be helpful for further researches in studied area. Information and various studies about WIM technology in the past and today were used to make good data analysis and characterization of heavy vehicles on typical US interstate highways. It is good to know what kinds of data are provided by WIM systems, its characteristics, and equipment. Truck characteristics and its impacts on traffic give basic knowledge connected to the heavy vehicles and other vehicle types, which is important to apply vehicle dynamics models on trucks. Many authors were using constant power vehicle dynamics model in their studies and they helped to make this study better and with innovations.

CHAPTER 3: I-81 TRUCK CHARACTERIZATION

Trucks are specific in terms of their characteristics, because of the significant variability in vehicle characteristics in comparison with other vehicles. Weight, size, ability to accelerate/decelerate, and other important characteristics have significant impacts on their performances on the road. The performance of vehicles is typically quantified in terms of vehicle speeds along roadway sections.

Speed is a fundamental measurement of the traffic performance on the highway system. The maximum and normal acceleration rates for various vehicle types decrease with increased weight–to-power ratios, with steeper grades, and with higher running speeds. Because of the higher weight–to-power ratios that are characteristic of trucks compared to automobiles, grades have a more substantial effect on truck performance.

A first step in quantifying the performance of trucks along grade sections is to characterize these trucks in terms of their weight–to-power ratios. This chapter attempts to characterize typical trucks that travel along US highways. Specifically, two data collection efforts were conducted as part of the characterization effort. The first data collection effort involved collecting data on truck weight characteristics over a number of years, using the Troutville weigh station data along I–81. The second data collection effort involved conducting a survey of truck characteristics at the Troutville weigh-in-motion station in order to assemble additional data on truck power and aerodynamic features.

The chapter initially summarizes the data that were available at the Troutville weigh station and were analyzed to conduct the analysis that is presented in this chapter. Subsequently, a classification of vehicle class distributions, truck demand distributions, and truck weight distributions are presented. The following section presents the results of a classification of vehicle power and aerodynamic features. Finally, the conclusions of the chapter are presented.

3.1 FHWA TRUCK CLASSIFICATIONS

The FHWA classifies vehicles into 13 vehicle classification as follows:

1. Motorcycles
2. Passenger Cars
3. Two-Axle and Four-Tire Single Units
4. Buses
5. Two-Axle and Six-Tire Single Units
6. Three-Axle Single Units
7. Four or More Axle Single Units
8. Four or Less Axle Single Trailers
9. Five-Axle Single Trailers
10. Six or More Axle Single Trailers
11. Five or Less Axle Multi-Trailers
12. Six Axle Multi-Trailers
13. Seven or More Axle Multi-Trailers

Vehicles traveling on US highways must follow requirements that vary from state to state. For example, the state of Virginia has its own regulations about requirements related to vehicle size (max length, max width, max height, max number of vehicles in combination), weights, and axle spacing limitations and also equipment requirements. Weights and dimensions are the primary parameters. Weight characteristics have influences on vehicle capabilities in operating situations, which cause direct influence on pavement design and operations, pavement life, level of service, and safety. Size characteristics are also very important and for example longer vehicles have less offtracking, need longer time to maneuver, and have low acceleration/deceleration performances. Heavy vehicles are defined as motor vehicles with gross vehicle weights (GVW) or gross combination weights (GCW) of 12000 kg (26000 lb) and greater. Very large trucks can be seen in some regions of North America.

3.2 TRUCK WEIGHT CHARACTERIZATION

The conduction of the truck characterization that is presented in this chapter is based on weigh station data and a survey that was conducted at the Troutville weigh station. This section first describes the data that were assembled before describing the analyses that were conducted using these data.

3.2.1 Data Collection Description

The data that were analyzed were assembled at the Troutville weigh station using a plate–type WIM technology. These data included the time, day, month, and year at which the truck was observed, the direction of motion (southbound or northbound), the vehicle speed, the vehicle class, the vehicle length, its GVW, the weight on each axle, and the spacing between axles. Table 3.1 summarizes the days of data that were available for the analysis that is presented in this thesis.

Table 3.1: Days which data were analyzed

		Northbound	**Southbound**
1998	**April**	-	20, 21, 22, 23, 24, 25, 26
	May	-	4, 5, 6, 7, 8, 9, 10
	June	-	5, 6, 8, 9, 10, 11, 12
	July	-	6, 7, 8, 9, 10, 11, 12
	August	-	3, 4, 5, 6, 7, 8, 9
	September	-	14, 15, 16, 17, 18, 19, 20
1999	**April**	-	5, 6, 7, 8, 9, 10, 11
	May	-	3, 4, 5, 6, 7, 8, 9
	June	-	7, 8, 9, 10, 11, 12, 13
	July	-	19, 20, 21, 22, 23, 24, 25
	August	-	2, 3, 4, 5, 6, 7, 8
	September	6, 7, 8, 9, 10, 11, 12	6, 7, 8, 9, 10, 11, 12
2000	**April**	-	11, 12, 13, 14, 15, 16, 17
	May	1, 2, 3, 4, 5, 6, 7	1, 2, 3, 4, 5, 6, 7
	June	5, 6, 7, 8, 9, 10, 11	5, 6, 7, 8, 9, 10, 11
	July	10, 11, 12, 13, 14, 15, 16	10, 11, 12, 13, 14, 15, 16
	August	7, 8, 9, 10, 11, 12, 13	7, 8, 9, 10, 11, 12, 13
	September	11, 12, 13, 14, 15, 16, 17	11, 12, 13, 14, 15, 16, 17

Data for a 3-year period were analyzed over five months, as summarized in Table 3.1. A single week of data were extracted from each month for purposes of conducting the analysis. Because the weigh station was not open 24 hours 7 days a week, some data were missing for Saturdays and Sundays. Specifically, the weigh station was closed from midnight to 8am for each Saturday and Sunday over the 3-year analysis period.

The fact that the weigh station was closed during a portion of the day on Saturdays and Sundays resulted in lower truck volumes for these days, however it is not clear if the lower demand is reflective of a lower daily demand or by the fact that only a portion of the day was considered.

3.2.2 Vehicle Class Distribution

The first analysis of the data was to characterize the distribution of vehicle classes that travel along I–81. Specifically, **Figure** 3.1 illustrates the distribution of trucks that travel along I–81 in the state of Virginia. The charts clearly demonstrate that the majority of trucks that travel along I–81 fall into vehicle classification 9 (85 percent of total truck volume). The charts also demonstrate that the truck class distribution is fairly consistent over the three years of data that were analyzed. **Figure** 3.2 also demonstrates that the vehicle class distribution is consistent by month-of-the-year and direction-of-travel. Having established that the majority of trucks along I–81 are vehicle class 9, the remainder of the chapter focuses on the general truck volume and vehicle class 9 in specific.

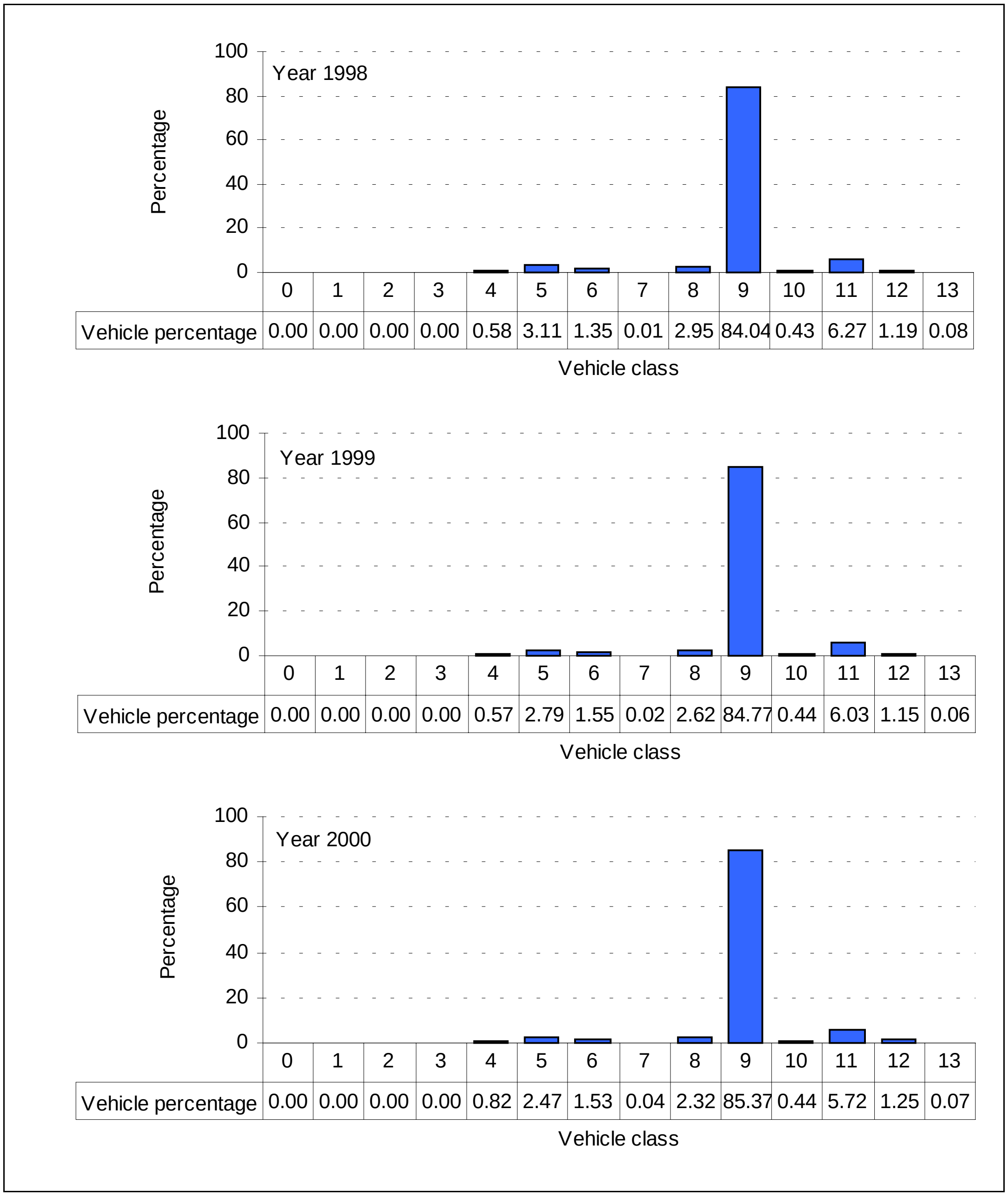


Figure 3.1: Truck percentages by vehicle class for three years

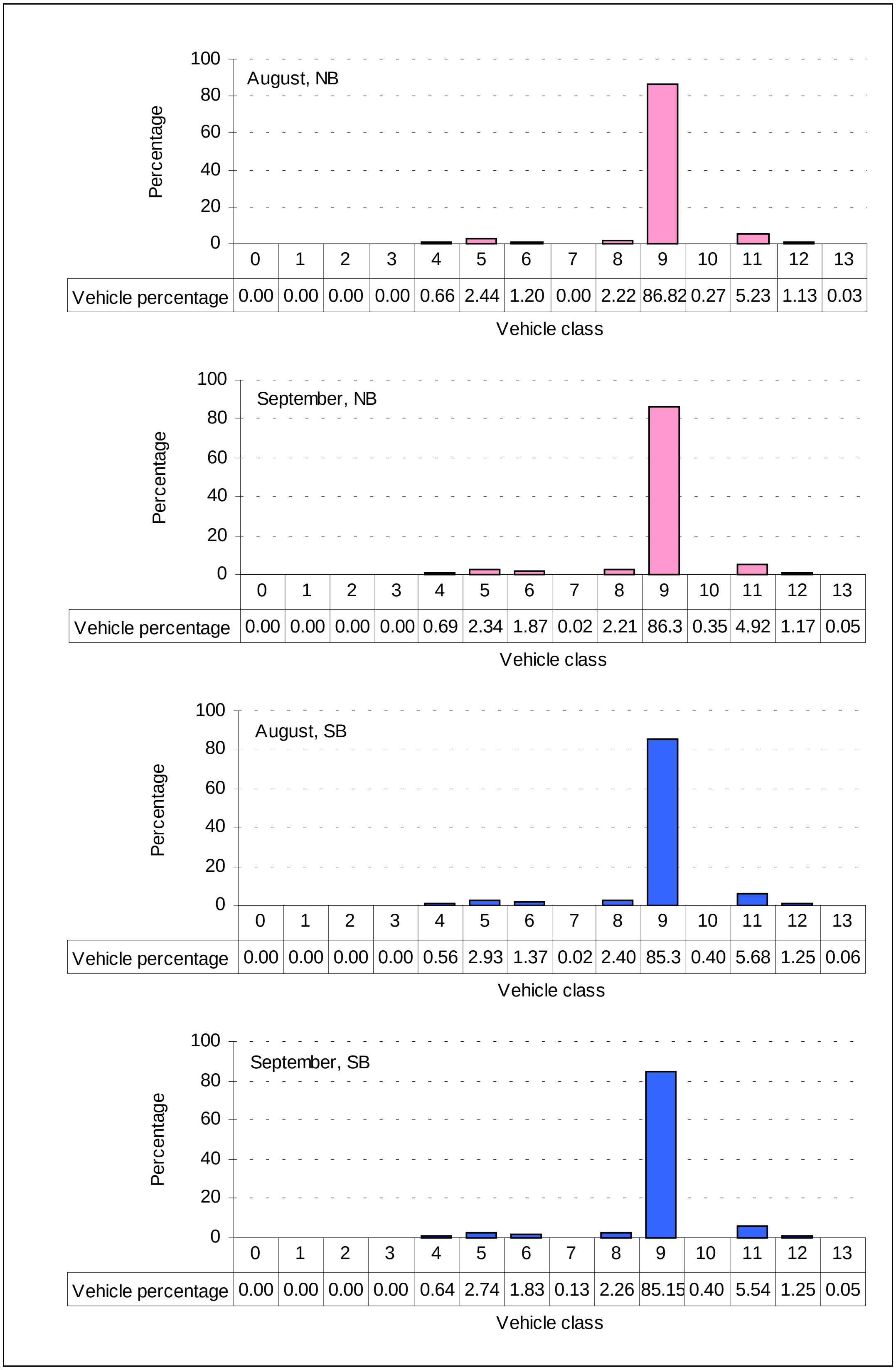


Figure 3.2: Truck percentages per vehicle class for August and September 2000

3.2.3 Truck Volume Distribution

The next step in characterizing the trucks along I–81 was to characterize the temporal variation in truck volumes. **Figure** 3.3 illustrates the truck volume variation traveling in the southbound direction for all vehicle classes and vehicle class 9 separately. The figure illustrates a low increase in the Average Annual Daily Truck (AADT) volume over the three-year analysis period in the southbound (SB) direction. Table 3.2 and Table 3.3 further summarize the truck volume for each of the days that were analyzed in southbound direction for all vehicle classes and class 9 separately. The table demonstrates that the truck demand ranged from a low of approximately 3000 trucks/day to 7000 trucks/day during typical weekends.

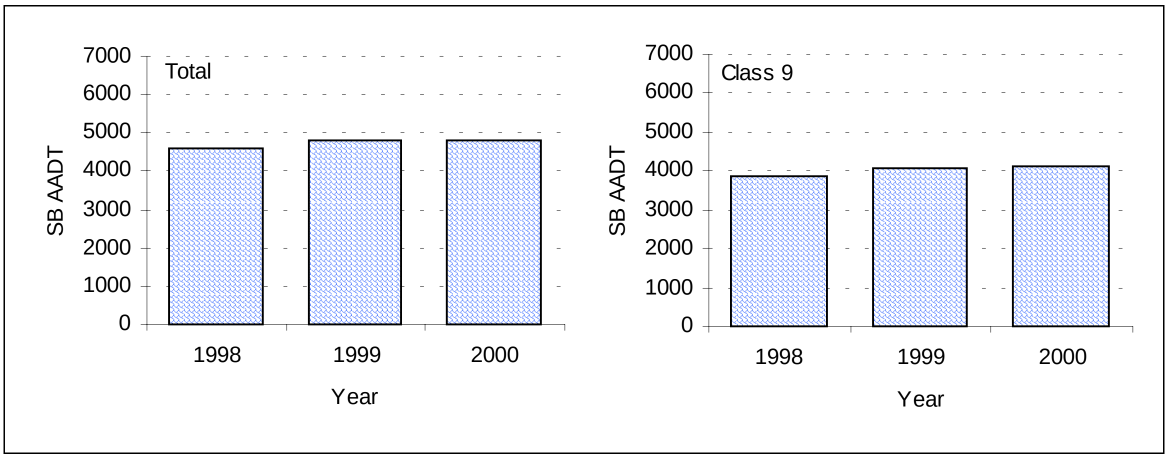


Figure 3.3: Sample of truck volume distribution for southbound direction

Year 2000 was analyzed in detail and **Figure** 3.4 clearly shows that the volume distributions for both directions of travel are similar with a slightly higher northbound demand. September is the heaviest month for southbound travel and June for northbound direction for both cases (total and vehicle class 9). Volumes in all figures are based on average daily traffic using the data that are summarized in Table 3.2 and Table 3.3.

Table 3.2: Truck volumes by day-of-the-week for all vehicle classes over the three-year period

Year	Day	April	May	June	July	August	September
1998	Monday	3882	2036	3931	2990	4014	4149
	Tuesday	5995	4542	5960	5321	6011	6388
	Wednesday	5946	4664	6032	5575	5994	6223
	Thursday	3530	5046	5285	5459	5855	5549
	Friday	5360	4572	5355	5203	5277	5206
	Saturday	4080	4200	5449	4050	3863	3147
	Sunday	2556	2352	5383	2381	2531	2277
1999	Monday	3766	4428	4330	4202	4035	797
	Tuesday	6022	6527	6409	6153	5885	5831
	Wednesday	6250	6416	6481	5883	6473	6683
	Thursday	6028	6346	6152	6121	5635	6343
	Friday	4762	5453	5748	5665	274	5525
	Saturday	4079	4434	4440	4398	4495	3481
	Sunday	2159	2391	2616	2657	2648	3328
2000	Monday	6931	1401	4231	3928	4375	4412
	Tuesday	6830	5580	6109	6108	6787	6761
	Wednesday	6609	6664	1749	6586	4209	7094
	Thursday	6110	6728	3529	6469	4464	6708
	Friday	4834	6102	6200	5919	5864	5848
	Saturday	2112	4720	4810	4471	4656	3562
	Sunday	111	2370	2733	2215	2754	2497

Table 3.3: Truck volumes by day-of-the-week for vehicle class 9 over the three-year period

Year	Day	April	May	June	July	August	September
1998	Monday	3161	1670	3212	2423	3260	3351
	Tuesday	5112	3939	5060	4562	5085	5407
	Wednesday	5006	3918	5110	4695	5033	5236
	Thursday	2967	4189	4355	4535	4867	4582
	Friday	4464	3721	4388	4316	4359	4285
	Saturday	3593	3707	4492	3553	3394	2799
	Sunday	2200	2025	4465	2045	2180	1987
1999	Monday	3108	3597	3565	3388	3239	598
	Tuesday	5191	5592	5519	5231	4983	4991
	Wednesday	5331	5423	5451	4972	5450	5725
	Thursday	5064	5322	5140	5121	4712	5321
	Friday	3998	4528	4802	4747	239	4667
	Saturday	3643	3906	3930	3871	3992	3039
	Sunday	1898	2059	2298	2309	2320	2741
2000	Monday	5997	1059	3472	3320	3621	3666
	Tuesday	5801	4754	5280	5297	5879	5827
	Wednesday	5597	5653	1493	5640	3569	6026
	Thursday	5115	5646	2970	5455	3802	5607
	Friday	4308	5111	5213	4994	4909	4838
	Saturday	1805	4164	4302	3967	4104	3188
	Sunday	98	2044	2395	1947	2409	2235

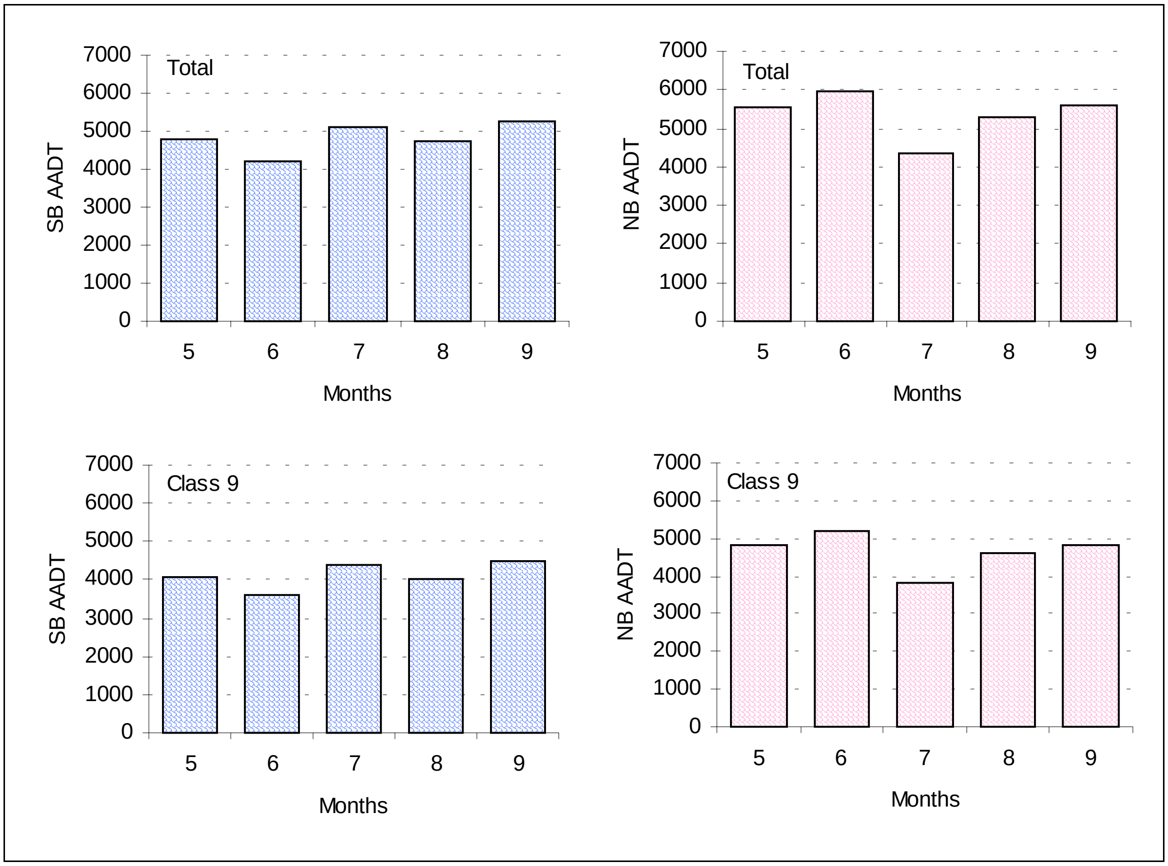


Figure 3.4: Sample truck volume distributions per months for both directions

Figure 3.5 illustrates the variation in truck volume by day-of-the-week for September 2000, for both directions of travel, for all vehicle classes, and for vehicle class 9. The figure demonstrates that the volume distributions for all these cases are consistent. The middle of the week experienced higher demand with the demand decaying over the weekend.

The daily variation in traffic demand demonstrates that the AADT's is approximately 15 percent of the weekly volumes, as summarized in Table 3.4 and Table 3.5. Saturdays typically carry the lowest daily demand in northbound direction and Sundays in the southbound direction. However, caution should be exhibited in the analysis of the results given that the weigh station was closed for an 8 hours on Saturdays and Sundays.

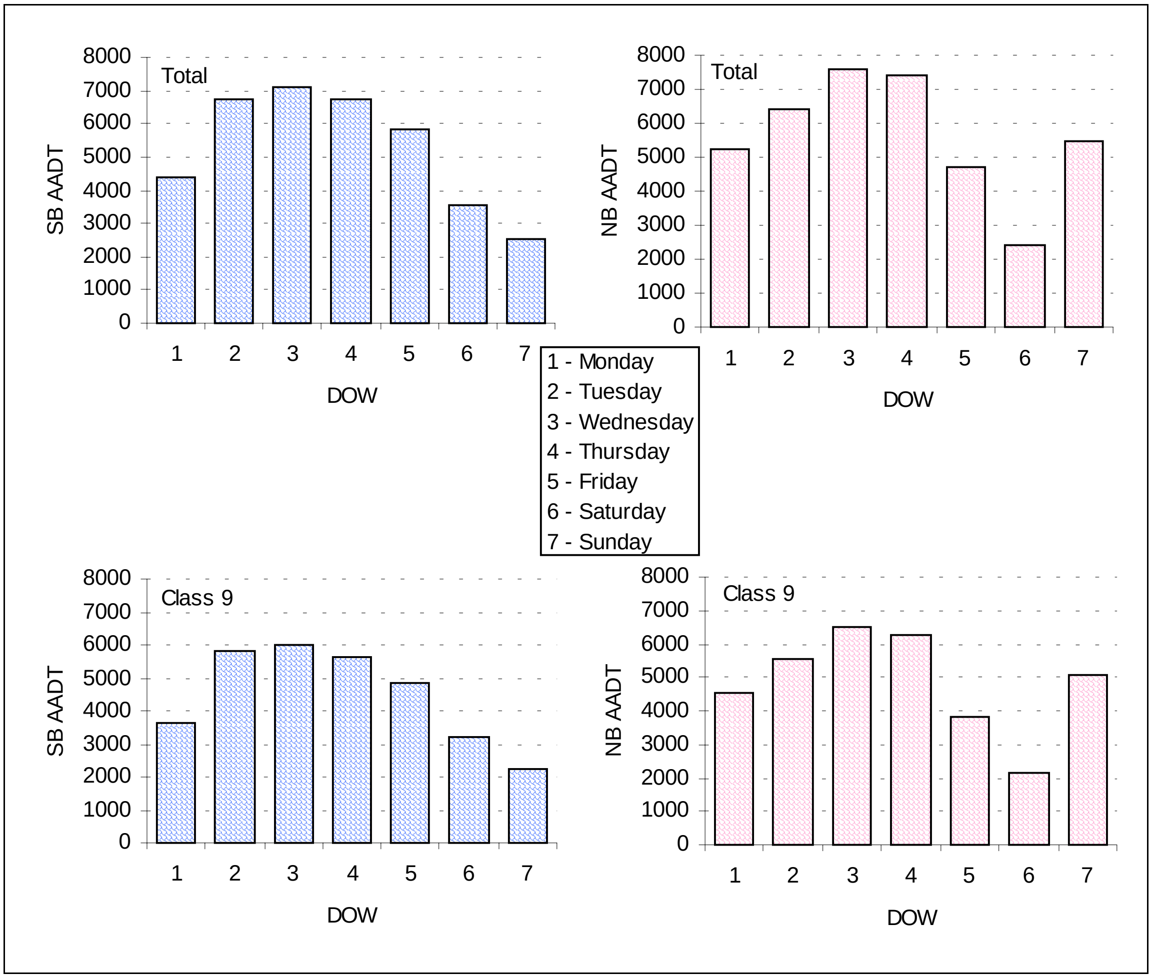


Figure 3.5: Truck volume distributions by day-of the-week for September 2000

Table 3.4: Percent of vehicle frequency for August 2000

	Percentage			
	Northbound		Southbound	
Day	**All vehicle classes**	**Vehicle class nine**	**All vehicle classes**	**Vehicle class nine**
Monday	15.49	15.50	13.39	12.98
Tuesday	18.05	18.09	20.23	20.51
Wednesday	12.12	12.12	12.46	12.39
Thursday	16.95	16.82	13.36	13.30
Friday	12.79	11.93	17.69	17.32
Saturday	9.32	9.32	14.25	14.68
Sunday	15.27	16.22	8.61	8.82

Table 3.5: Percent of vehicle frequency for September 2000

	Percentage			
	Northbound		**Southbound**	
Day	**All vehicle classes**	**Vehicle class nine**	**All vehicle classes**	**Vehicle class nine**
Monday	13.57	13.66	12.22	11.93
Tuesday	15.83	15.81	18.18	18.35
Wednesday	19.39	19.18	18.86	18.84
Thursday	18.58	18.37	18.14	17.81
Friday	12.09	11.28	15.97	15.56
Saturday	6.33	6.46	9.67	10.17
Sunday	14.21	15.24	6.96	7.34

Figure 3.6 and **Figure** 3.7 illustrate the hourly variation in truck volume along I-81 for each day-of-the-week for the northbound direction for all vehicle classes and for vehicle class 9. The figures illustrate a similarity in traffic volumes across the various weekdays. The latter part of Saturday appears to be similar to weekday trends.

Lack of truck volumes in the early morning on the weekend days is caused because the weigh station was closed at that time, as was described earlier. Similar temporal variations in truck volumes are observed for the southbound direction, as illustrated in **Figure** 3.8 and **Figure** 3.9.

This analysis provides important conclusions for the development of comprehensive truck models, as follows:

1. Vehicle class nine is the most frequent vehicle class (85% of total demand);
2. The monthly variation in truck volumes appears to be in the range of 30%;
3. The day-of-the-week variation in truck volumes appears to be significant (70% variability). Sundays and Saturdays appear to carry the lowest SB demand while Fridays and Saturdays carry the lowest NB demand; and
4. The daily variations in truck volumes indicate that the truck volumes typically peak between 10 am and 10 pm.

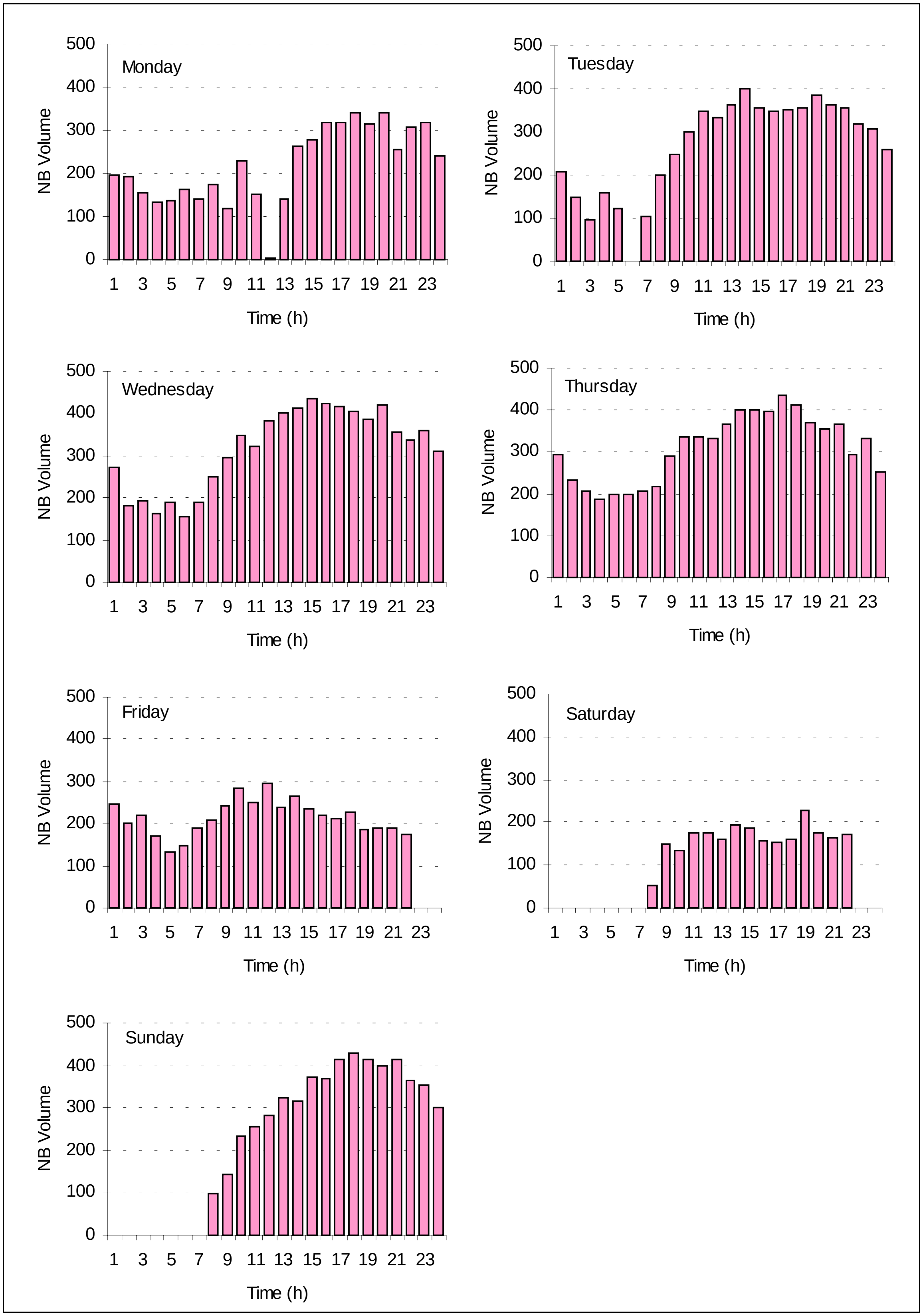


Figure 3.6: Truck volume distributions by hour for all vehicle classes for September 2000

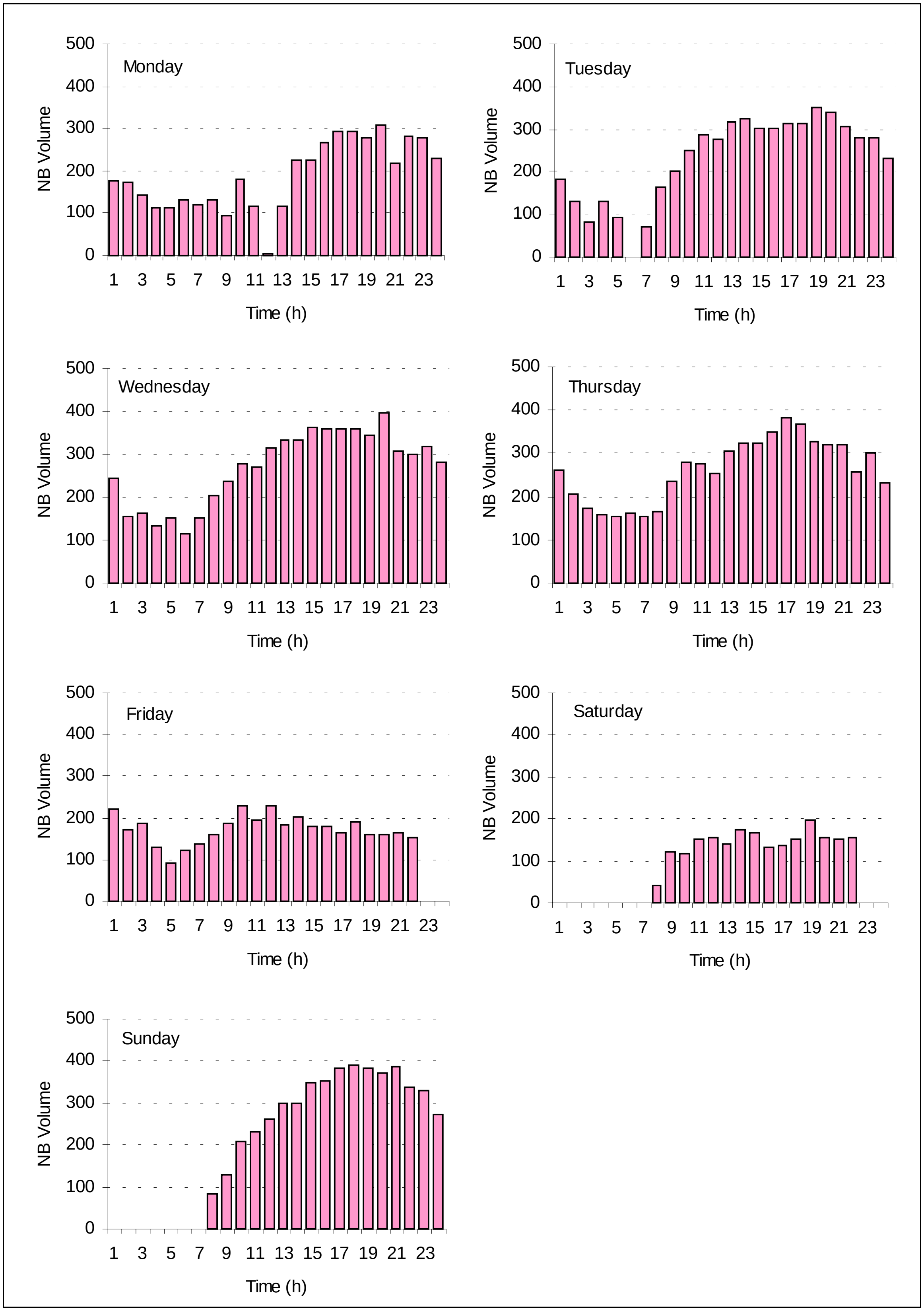


Figure 3.7: Truck volume distributions by hour for vehicle class 9 for September 2000

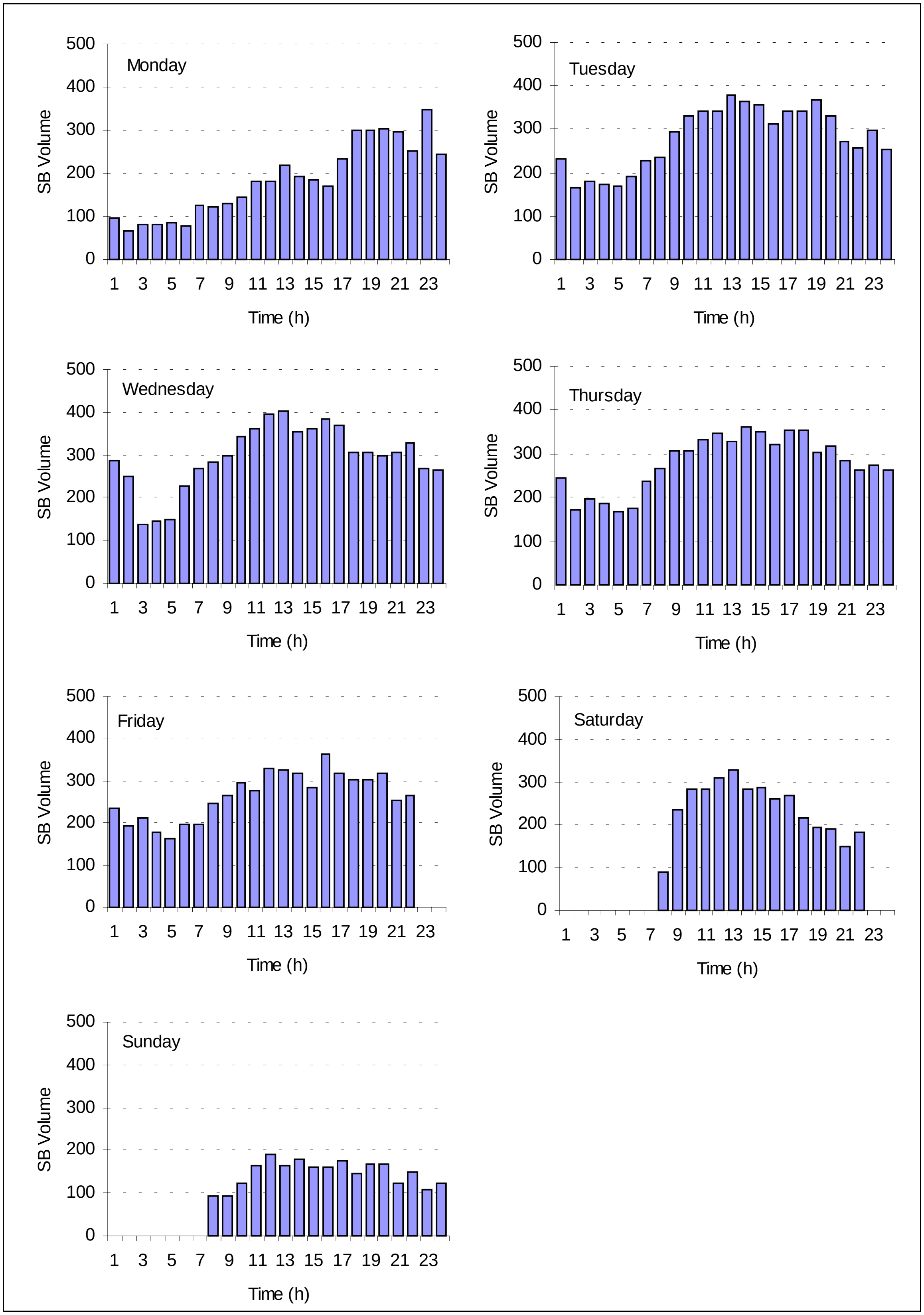


Figure 3.8: Truck volume distributions by hour for all vehicle classes for September 2000

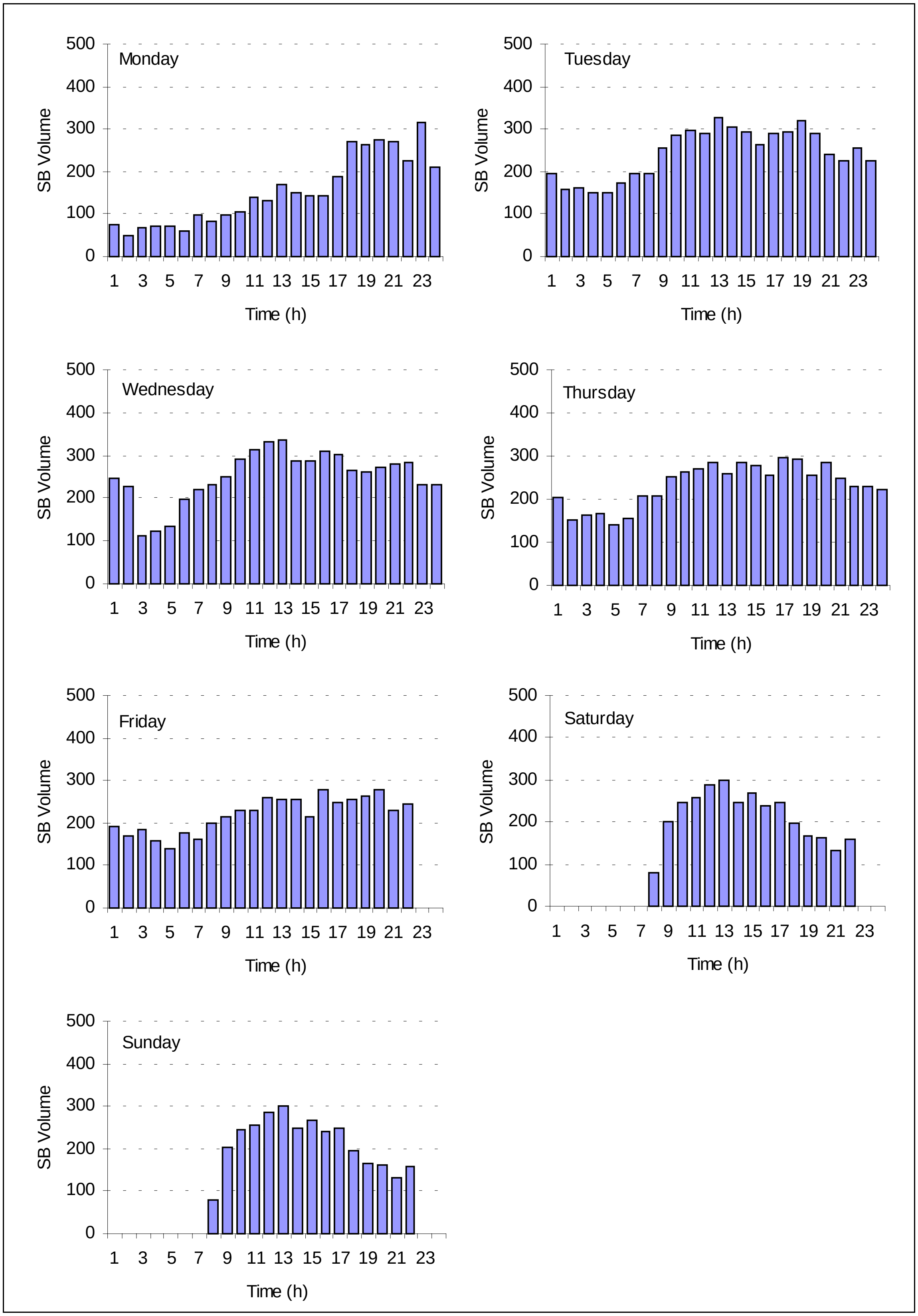


Figure 3.9: Truck volume distributions by hour for vehicle class 9 for September 2000

3.2.4 Gross Vehicle Weight Distribution

The next step in characterizing the trucks along I–81 was to characterize the GVW's of these trucks. **Figure** 3.10 illustrates the distribution of truck weights for all vehicle classes over the 3-year analysis period. The figure clearly demonstrates a consistent distribution of truck weights over the 3-year analysis period. Similar findings were observed for vehicle class 9, as illustrated in the same figure. In general, the vehicle mass ranged from 5000 kg (11000 lb) to 45000 kg (99000 lb) for all truck classes and for vehicle class 9.

Figure 3.11 and **Figure** 3.12 demonstrate the variation in vehicle weight distribution by month for southbound direction of travel in 2000 year for all vehicle classes and vehicle class 9 respectively. Figures clearly illustrate similar distributions for all analyzed months. September carry slightly more loads than other months and the next step is to analyze September in details by day-of-the-week. **Figure** 3.13 illustrates the variation in vehicle weight distributions by day-of-the-week for all vehicle classes in September 2000. This figure compares the northbound and southbound directions over a 7-day period. The figure demonstrates consistency in the truck weight distribution. The mode of the distribution typically occurs in the 30000 kg (66000 lb) to 35000 kg (77000 kg) range. Similar trends are observed for vehicle class 9, as illustrated in **Figure** 3.14.

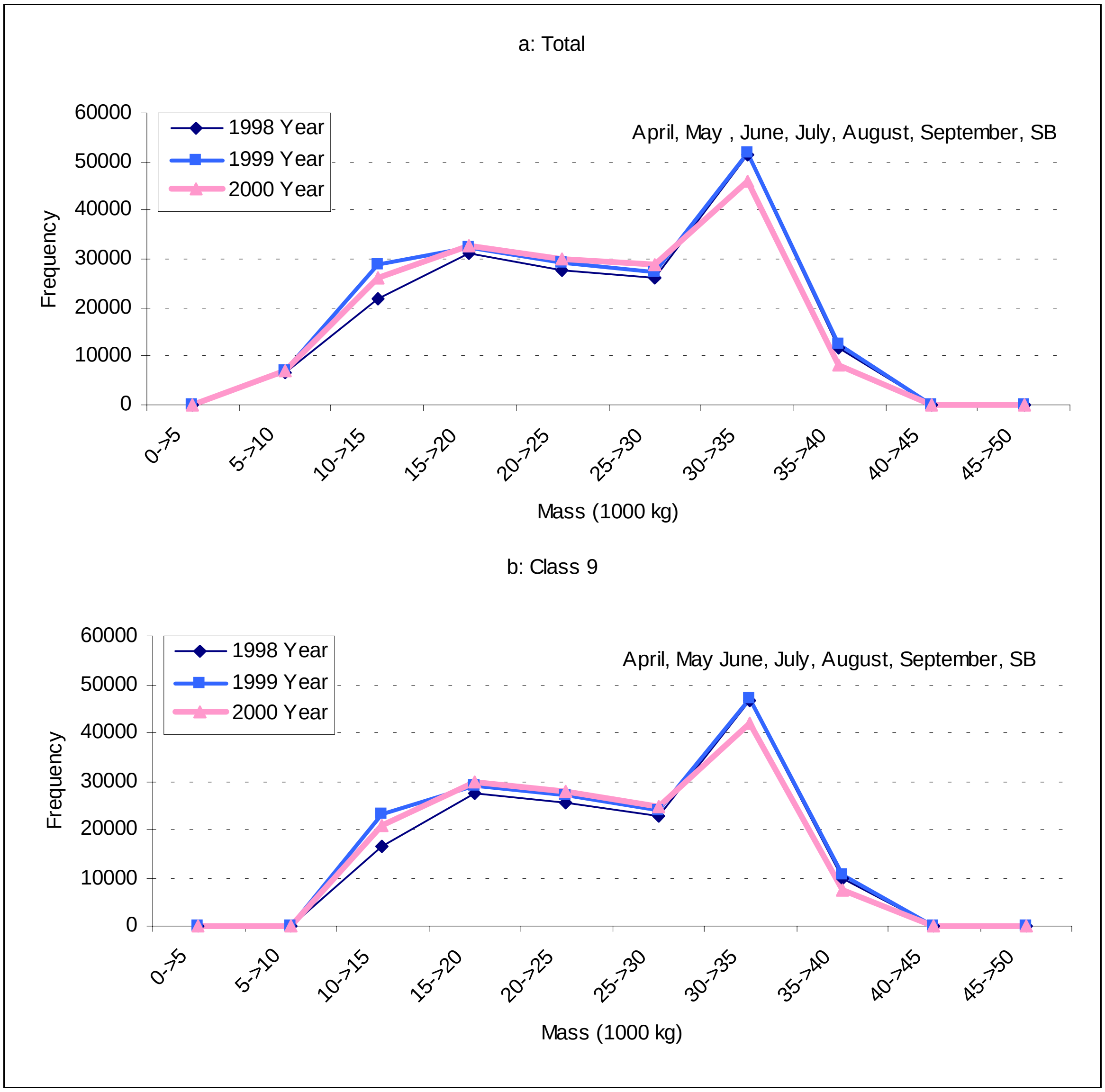


Figure 3.10: Truck weight distributions over three-year period

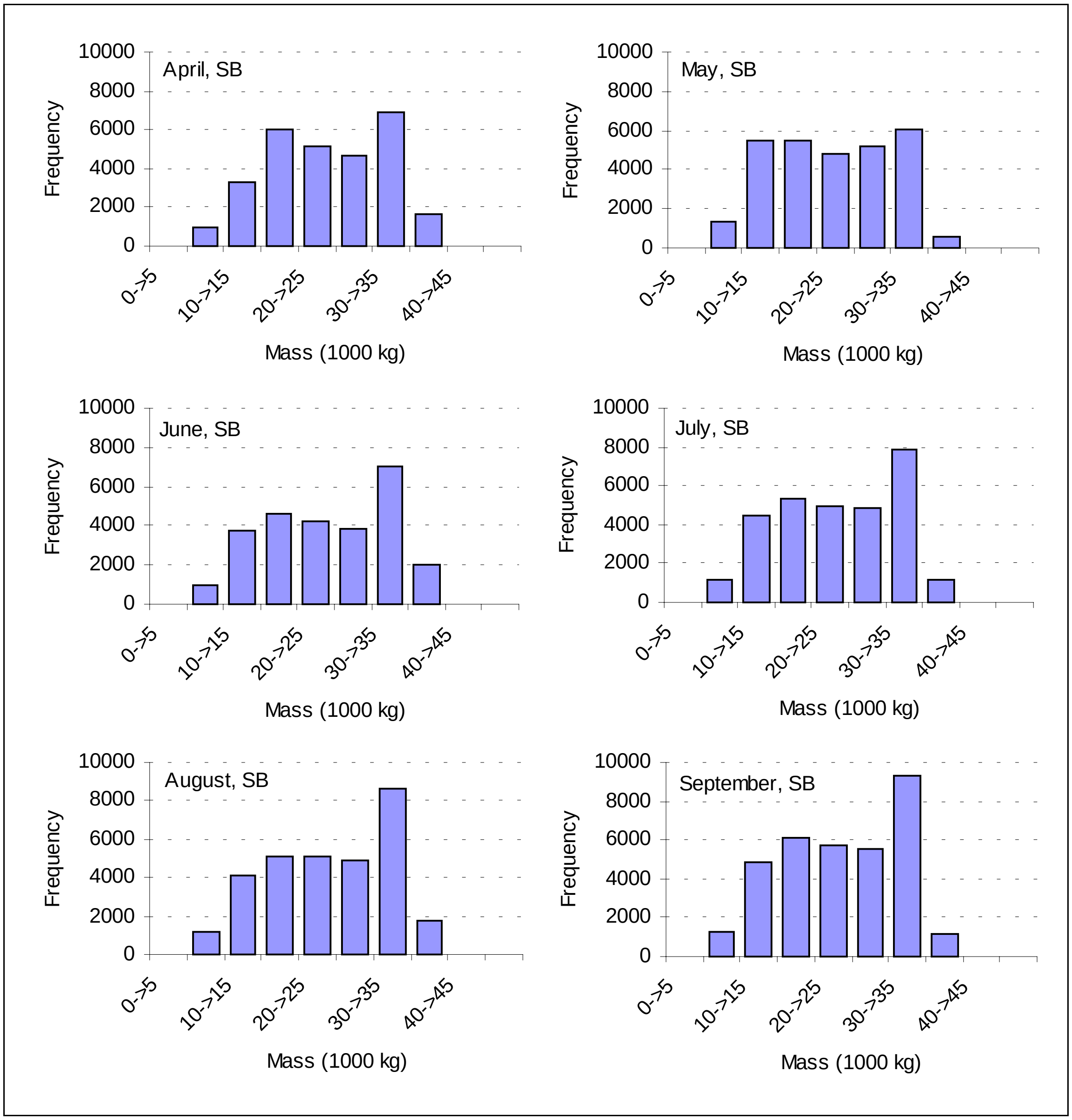


Figure 3.11: Truck weight distributions by month in 2000 year for all vehicle classes

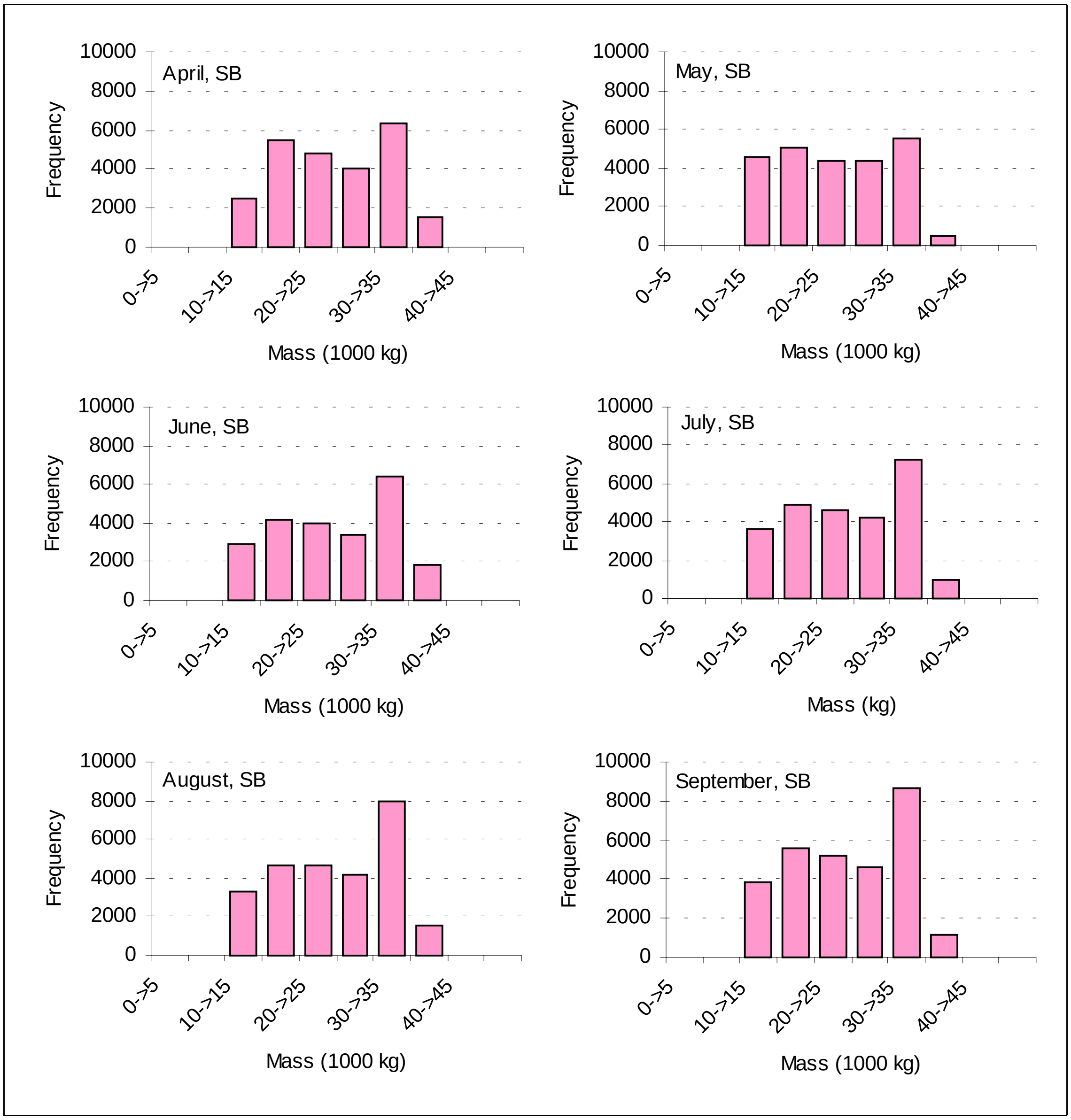


Figure 3.12: Truck weight distributions by month in 2000 year for vehicle class 9

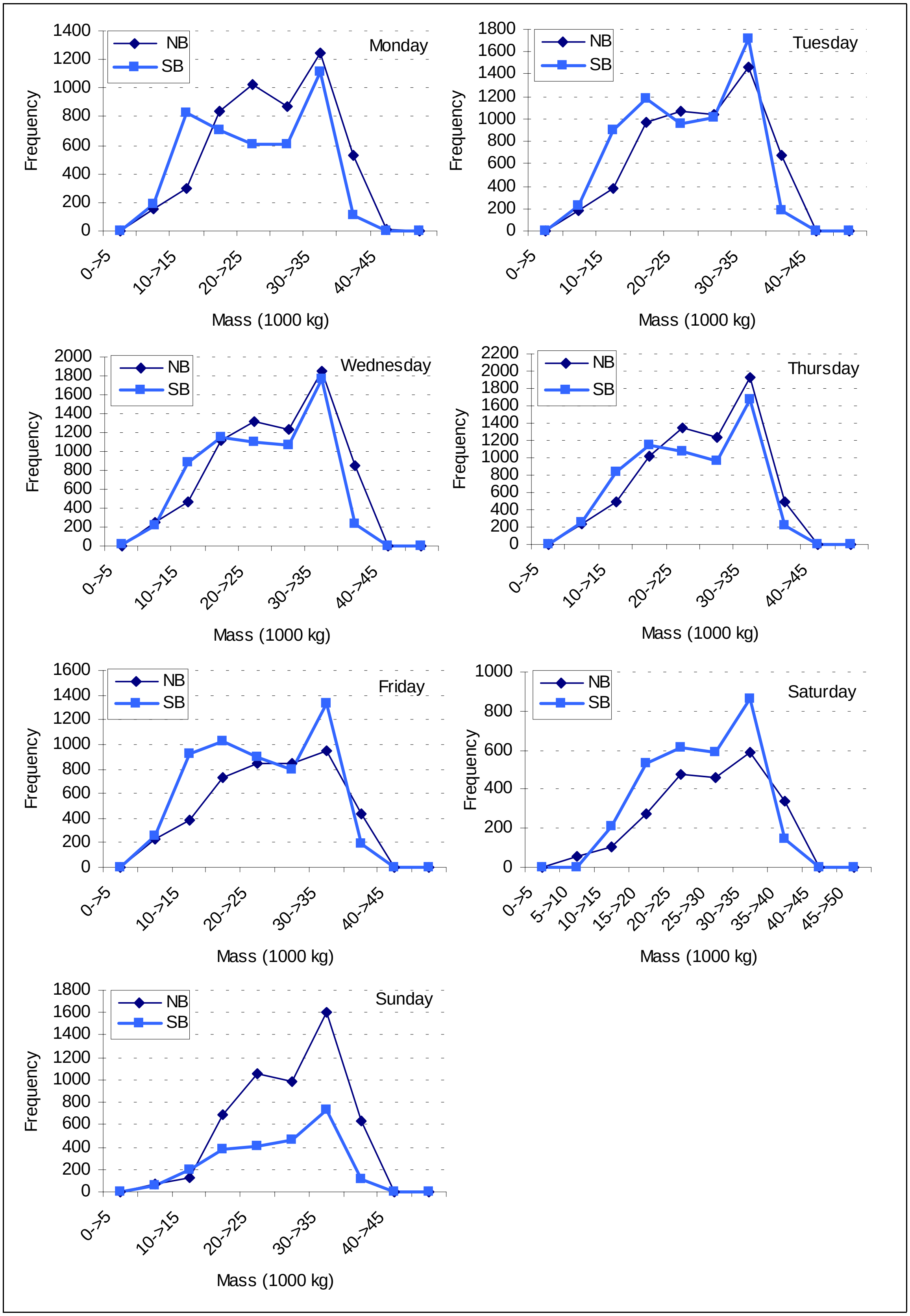


Figure 3.13: Truck weight distributions for all vehicle classes for September 2000

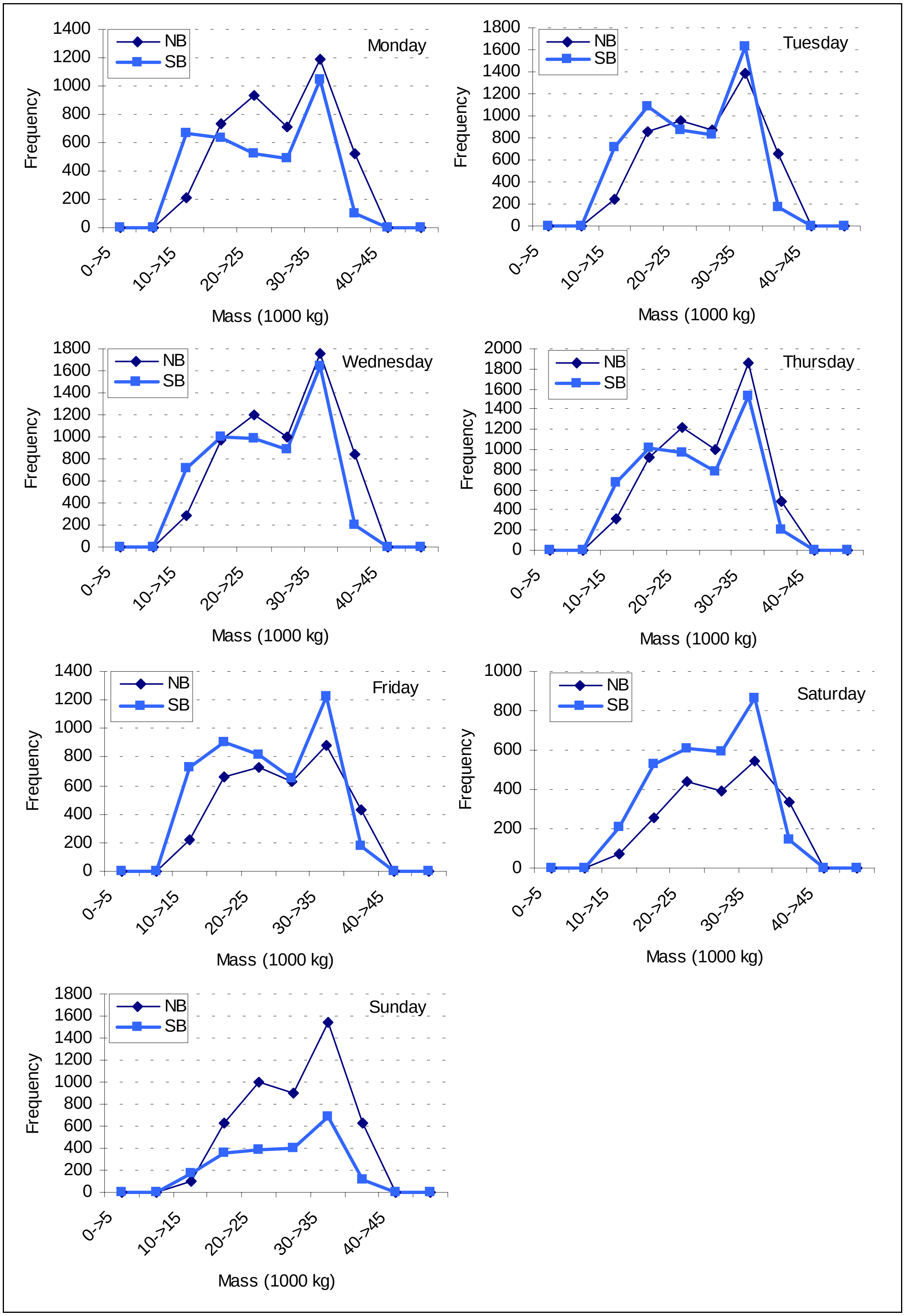


Figure 3.14: Truck weight distributions for vehicle class 9 for September 2000

Vehicle mass on tractive axle has influence on tractive force as it is shown with Equation 3.1 through friction between the tires of the vehicle's tractive axle and the roadway surface. Here will be analyzed AWTA for vehicle class 9, as the most frequent vehicle class on the US highways.

$$F_{max} = 9.8066\, M_{ta}\, \mu \tag{3.1}$$

where

F_{max} maximum tractive force;

M_{ta} mass on tractive axle; and

μ coefficient of friction between tires and pavement

Figure 3.15 shows AWTAs for analyzed years. It is clearly that mass on tractive axle slightly increasing through the years. There are not significant changes in AWTA's over the 3-year period analyzing 6 months for each year. Volumes of AWTAs by month are shown with **Figure** 3.16. **Figure** 3.17 demonstrates that northbound (NB) is heavier than southbound (SB) direction comparing day-of-the-weeks for analyzed months in 2000 year.

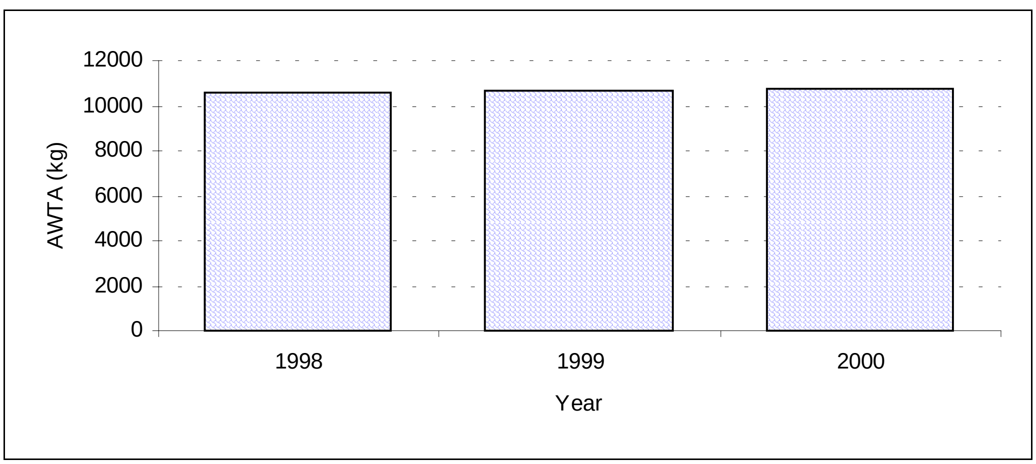


Figure 3.15: Average weight on tractive axle by year

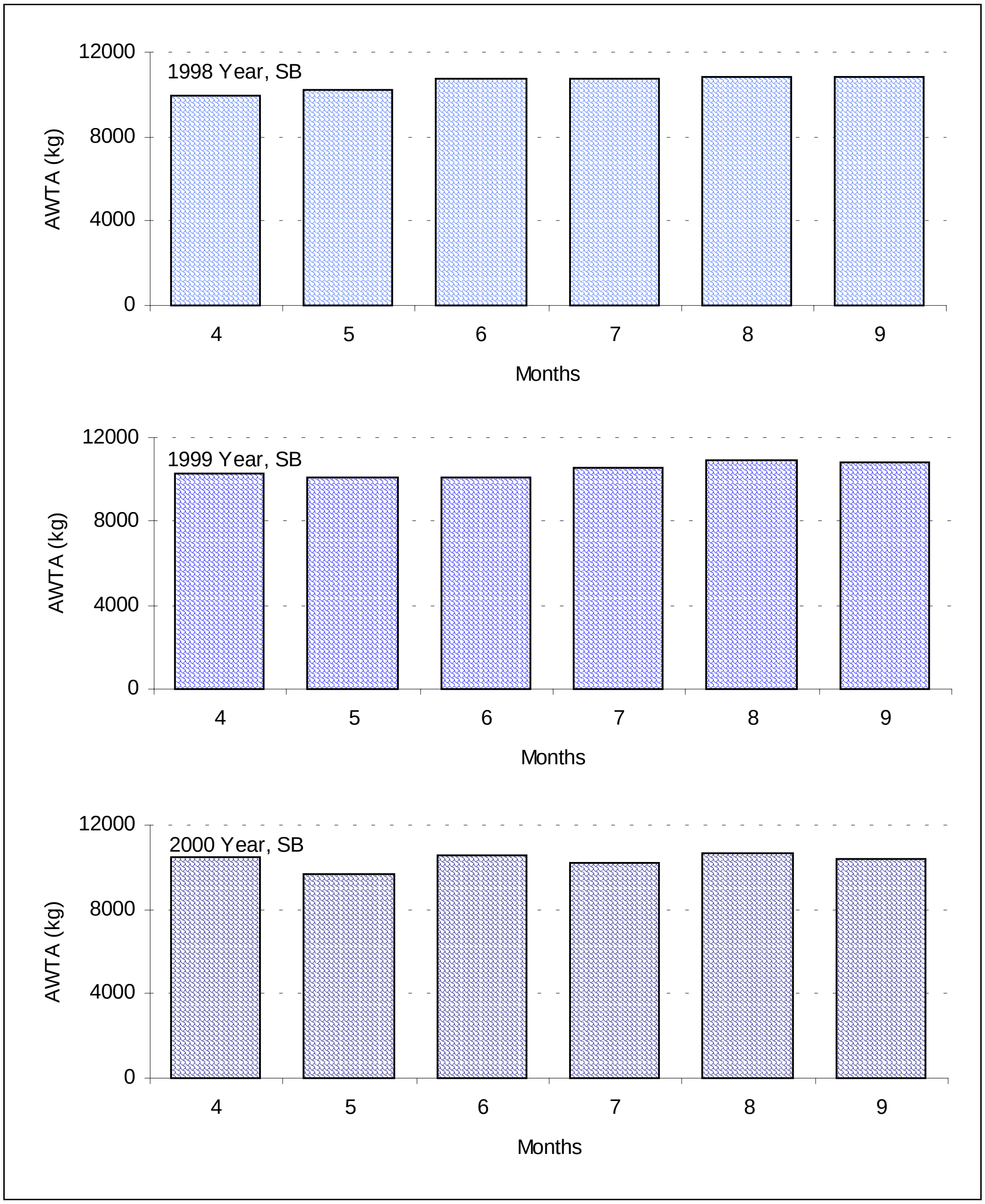


Figure 3.16: Average weight on tractive axle by month

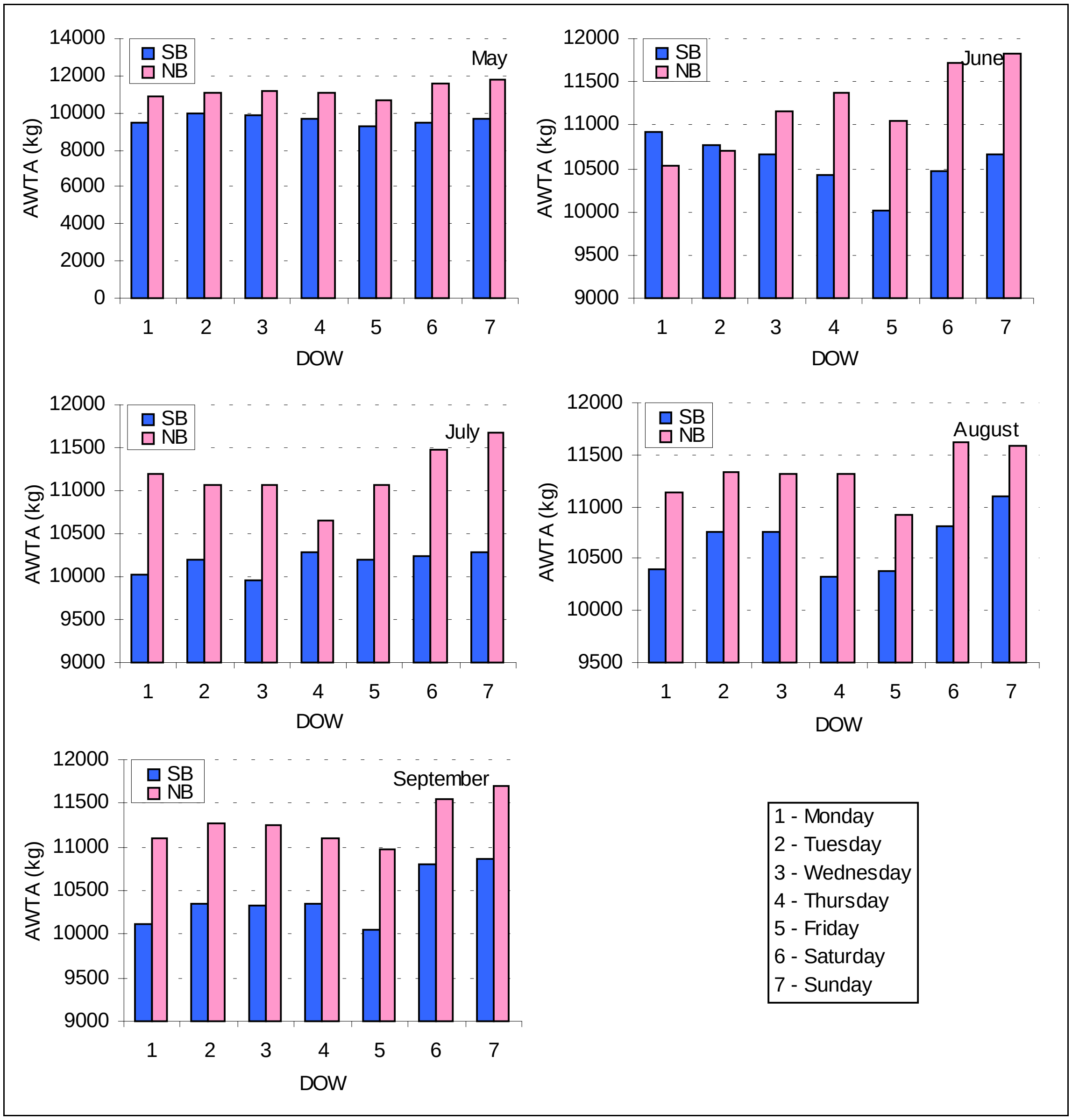


Figure 3.17: Average weight on tractive axle by day-of-the-week

3.2.6 Analysis of Variance (ANOVA)

WIM data that were available for this research were classified into the following: direction, year, season, month, day-of-the-week (DOW), GVW, and AWTA. ANOVA was done using SAS program for nine separate cases, which are the follows:

1. DOW
2. Direction

3. Year
4. Month
5. Season
6. DOW x direction
7. DOW x direction, year
8. DOW x direction, year, month
9. DOW x direction, year, season

Results show that all parameters alone have significance contribution in GVW's distribution with confidence level of 0.01 except parameter year. In previous analysis was shown that there is no big difference in GVWs between years. Results related to analysis of variance for all cases are summarized in Table 3.6. Analysis was done for the following cases:

Table 3.6: Summarized data for ANOVA Test

		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
GVW	**F Value**	8.40	115.42	0.93	5.91	19.20	22.64	27.19	30.68	33.18
	F Cr. Value	2.80	6.63	4.61	3.02	6.63	2.13	2.04	2.05	2.18
	Conf. Level	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Pr > F	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	df	6, 161	1, 166	2, 165	5, 162	1, 166	13, 154	15, 152	20, 147	16, 151
AWTA	**F Value**	5.95	71.08	0.82	6.96	22.45	11.21	5.24	-	4.18
	F Cr. Value	2.80	2.80	4.61	3.02	2.80	2.13	1.66	-	1.66
	Conf. Level	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Pr > F	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	df	6, 161	1, 166	2, 165	5, 162	1, 166	13, 154	34, 133	167, 0	62, 105

Table 3.6 shows that critical value for F with confidence level of 0.01 is lower than calculated F value through SAS for all those cases except for parameter year. Additionally, degrees of freedom are calculated and summarized in the same table. It is noticeable that almost all above stated characteristics have significant impacts on vehicle weight distribution. Additionally, analysis of variance was done for AWTA and data are summarized in Table 3.6. Results are similar with analysis of GVWs and all parameters have significant impacts except parameter year.

Calculated values for mean by day-of-the-week and month for both directions of travel (NB-northbound, SB-southbound) are shown with Table 3.7 and Table 3.8 for GVW and with Table 3.9 and Table 3.10 for AWTA. Results for mean mass variations by day-of-the –week for GVWs and AWTAs show that Saturday and Sunday carry slightly heavier trucks than other days in entire week. Variations in mean mass by the month for both parameters (GVW and AWTA) show that August and September carry heavier trucks than other analyzed months.

Table 3.7: Mean mass variations by day-of-the-week for GVW

	Mean (kg)				
	1998	1999		2000	
DOW	SB	NB	SB	NB	SB
1	24793	26475	24279	26496	24229
2	25634	27266	25080	26775	25026
3	25691	27419	25153	26930	24954
4	25343	27441	24867	26864	24671
5	24903	27447	24369	26265	24104
6	25983	29211	25777	27823	25109
7	27666	28527	26285	28017	25441

Table 3.8: Mean mass variations by month of the year for GVW

	Mean (kg)				
	1998	1999		2000	
Month	SB	NB	SB	NB	SB
April	25002		24704		25123
May	25482		24382	26935	23341
June	25876		24335	27089	25297
July	25793		25510	26929	24547
August	26083		25800	27130	25436
September	26062	27684	25963	27037	25000

Table 3.9: Mean mass variations by day-of-the-week for AWTA

	Mean (kg)				
	1998	1999		2000	
DOW	SB	NB	SB	NB	SB
1	10309	11172	10095	10964	10119
2	10148	11536	10410	11088	10434
3	10704	11705	10482	11188	10371
4	9983	11728	10444	11116	10201
5	10363	11639	10112	10940	10009
6	10844	12373	10648	11589	10440
7	11577	12221	10945	11726	10630

Some of the original output results for all these cases generated from SAS program are given in Appendix D.

Table 3.10: Mean mass variations by month of the year for AWTA

	Mean (kg)				
	1998	1999		2000	
Month	SB	NB	SB	NB	SB
April	9966		10272		10440
May	10225		10096	11184	9632
June	10728		10084	11198	10563
July	10752		10560	11173	10168
August	10879		10881	11320	10649
September	10817	11768	10796	11277	10412

Results show that northbound direction is heavier than southbound, but range is not big and vary between 24000 kg (52800 lb) and 28000 kg (61600 lb). There are no significant differences between years compared in this research. Analysis of variance was done for each year separately using parameters: DOW, direction, month, and season in interaction and original output results from SAS program are summarized with tables in Appendix D.

3.3 SURVEY DATA

Unfortunately, the weigh station data only provides information on truck volumes and weight characteristics, but does not provide information on other important vehicle characteristics like vehicle power and aerodynamic features. Consequently, a survey was conducted at Troutville weigh station on I-81 to gather truck data including information on the truck aerodynamic, tire, transmission, and power characteristics. Appendix A illustrates the Questionnaire that was utilized to collect the data. In total a sample of 182 trucks were included in the survey. This section describes the results of the survey analysis.

3.3.1 Consistency Between Sample and Population Trucks

In order to ensure that the sample of trucks that were surveyed were indeed a random sample, two comparisons were conducted. The first comparison effort involved comparing the distribution of vehicle class types within the sample to the distribution of vehicle classes for the I-81 truck population, as illustrated in **Figure** 3.18. The figure clearly demonstrates a consistency in vehicle classification between the sample and I-81 trucks. Table 3.11 summarizes these data from survey and WIM station comparing vehicle class percentage.

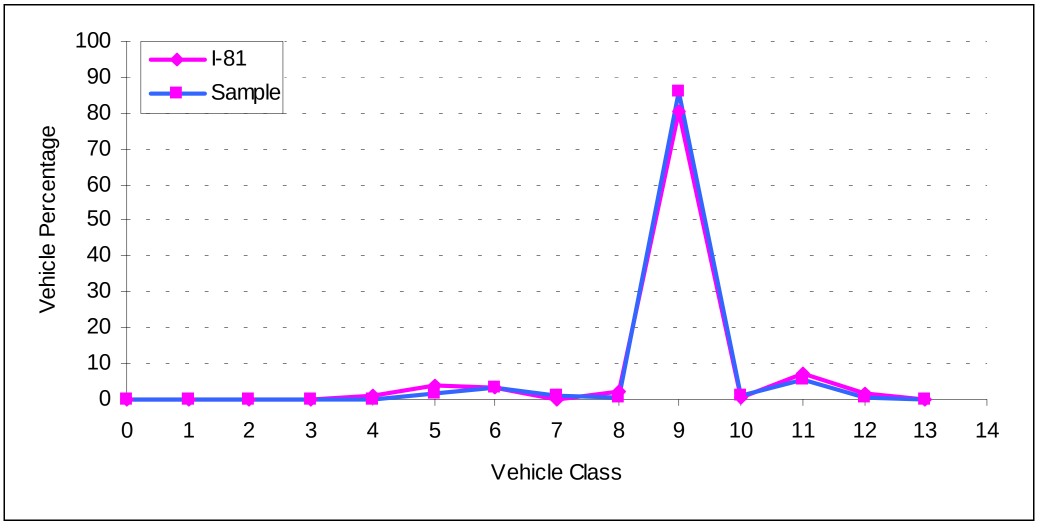


Figure 3.18: Vehicle class percentage comparison of sample and WIM data

A Friday was selected because it was not a busy day and this would cause minimum disruption to the weigh station operation. Trucks were randomly selected from 9am to noon and then from 2pm to 6pm.

Table 3.11: Summarized data for vehicle classification from sample and WIM station

Vehicle class	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	
Vehicle percentage	0.00	0.00	0.00	0.00	0.89	3.75	3.20	0.04	2.27	80.42	0.42	7.18	1.76	0.08	I-81
	0.00	0.00	0.00	0.00	0.00	1.65	3.30	1.10	0.55	86.26	1.10	5.49	0.55	0.00	Sample

The second comparison effort involved comparing the vehicle weight distribution within the sample and I-81 WIM data, as it is illustrated with **Figure** 3.19. The figure evidently demonstrates that uniformity in vehicle weight distribution between compared data.

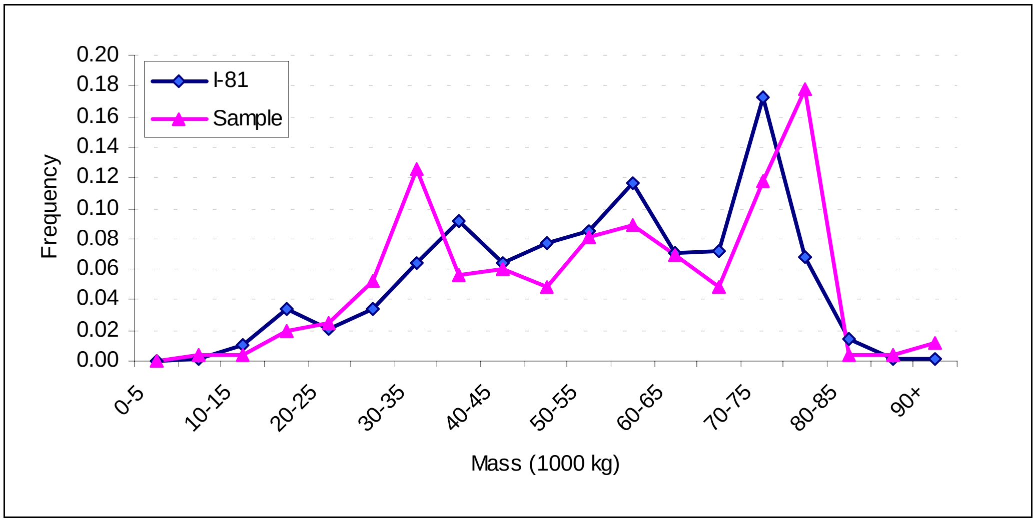


Figure 3.19: Vehicle weight distribution comparison of sample and WIM data

3.3.2 Sample Vehicle Characterization

An analysis of the engine power distribution demonstrated that the majority of trucks that have an engine power that ranges from 335 kW (450 hp) to 375 kW (500 hp), illustrated in **Figure** 3.20. Similar results are found if vehicle class 9 is only considered.

Vehicle class 9, because of its frequency (more than 80%) on the road is analyzed in more detail. Mass distributions were found to vary from 9979 kg (22000 lb) to 38555 kg (85000 lb) as illustrated in **Figure** 3.21.

Using data from mentioned survey, weight-to-power distribution for class 9 is plotted and shown with **Figure** 3.21. The figure demonstrates that weight-to-power ratio is ranged between 39 kg/kW (65 lb/hp) and161 kg/kW (266 lb/hp). Additionally summarized data are given in Appendix A that gives class nine truck's characteristics collected through survey. Some typical characteristics as aerodynamic features, cabin's type, and transmission's type are obvious. For example, conventional type of cabin is representing with more than 90 percent between surveyed vehicles and almost the same is with manual type of transmission. Aerodynamic features are divided into three categories: no aerodynamic aids, partial aerodynamic aids, and full aerodynamic aids with 30, 16, and 54 percent respectively. Although, radial tire had 100 percent of surveyed vehicles.

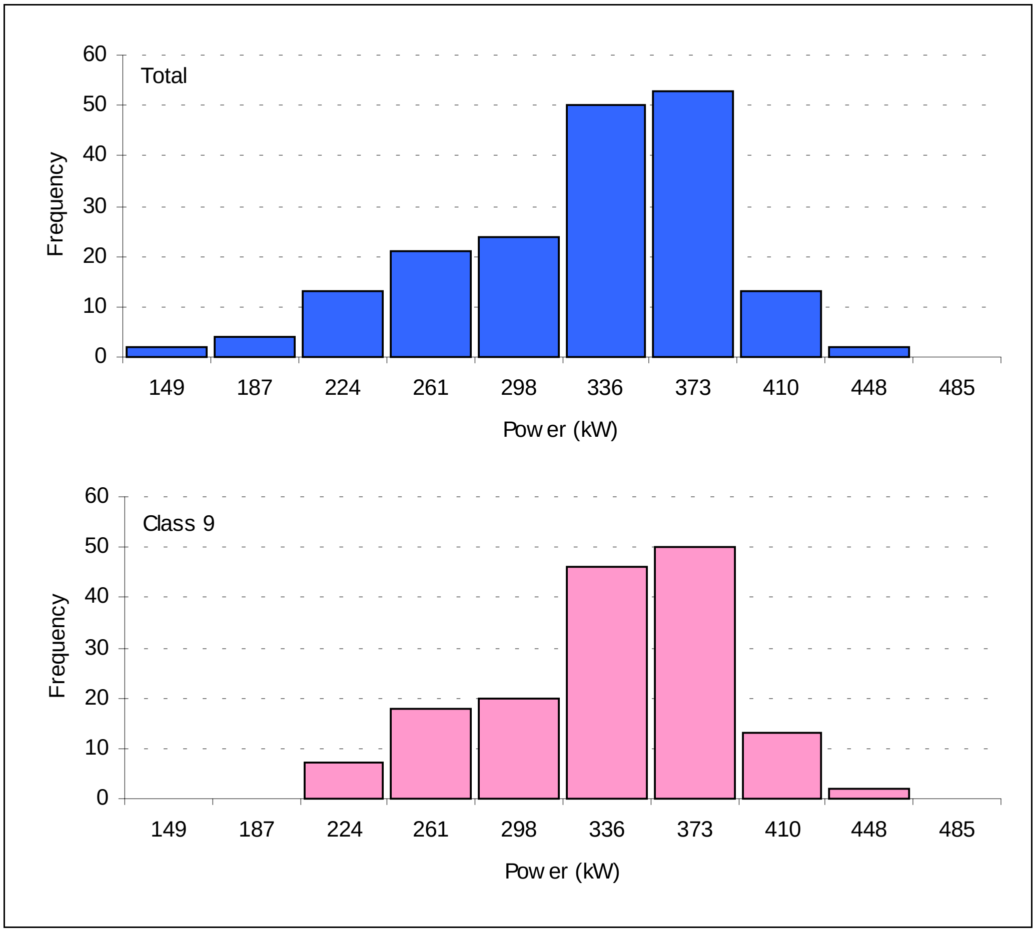


Figure 3.20: Power distribution for all vehicle classes and class 9

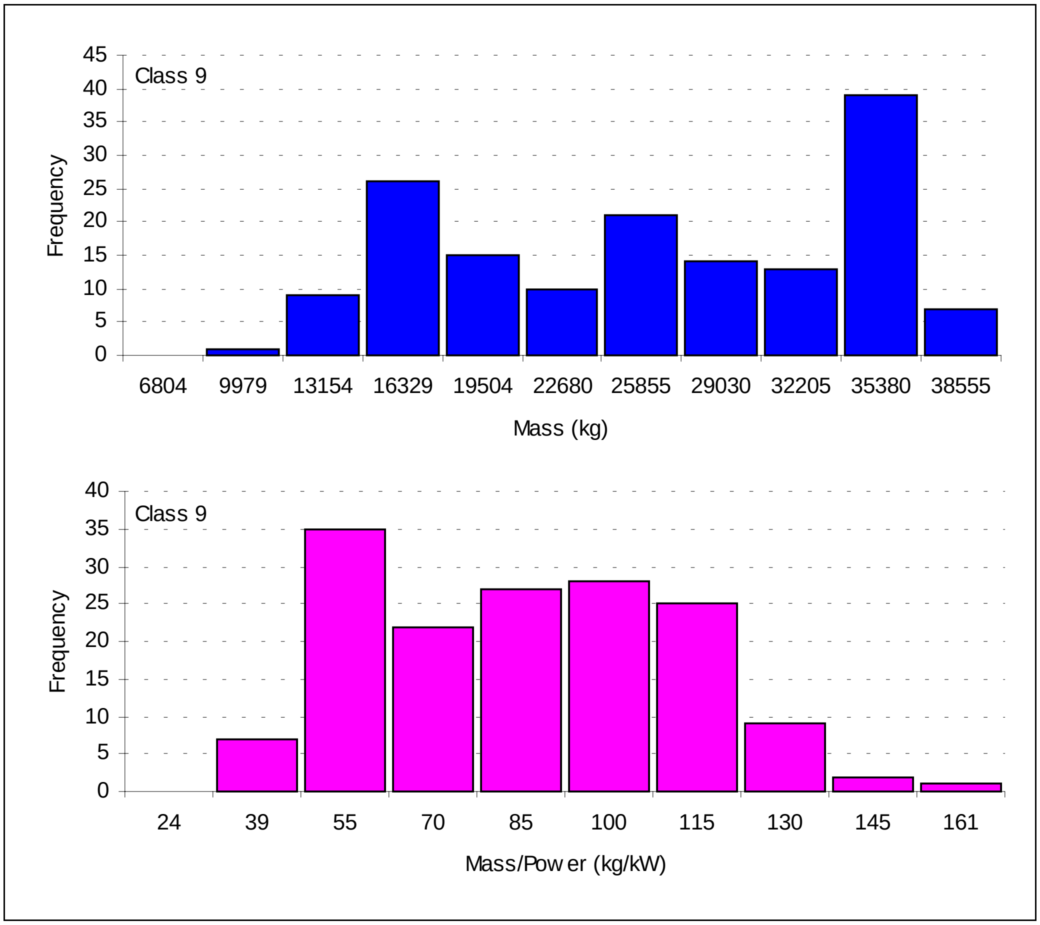


Figure 3.21: Mass distribution (vehicle class nine)

3.4 CONCLUSION

This chapter described characterization and classification of trucks on US highways using particular I-81 road to analyze data. Data are based on WIM system data and data collected from randomly chosen trucks on Troutville WIM station. In summary, as a result from detailed examinations, the following conclusions can be stated:

1. The monthly variation in truck volumes appears to be in the range of 30%.
2. The day-of-the-week variation in truck volumes appears to be significant (70% variability). Sundays and Saturdays appear to carry the lowest SB demand while Fridays and Saturdays carry the lowest NB demand.

3. The daily variations in truck volumes indicate that the truck volumes typically peak between 10 am and 10 pm.
4. Load range for all vehicle classes is from 5000 kg (11000 lb) to 45000 kg (99000 lb).
5. The most frequent vehicle class is class nine.
6. The most frequent truck power range is from 260 kW (350 hp) to 375 kW (500 hp).
7. The most frequent truck weight-to-power ratio is from 55kg/kW (91 lb/hp) to 115kg/ kW (191 lb/hp).
8. There are no significant differences in changing loads through the design years.

These results are very important for continuing the research. Validation/calibration of two studied models for evaluating truck acceleration on various grades is done using trucks with powers that fit with the range of most frequent powers. Additionally, loads for design trucks with trailer are inside above stated range. Further research should be focused on other vehicle classes in details, evaluating percentage of trucks in terms of load violations and comparing weights measured by WIM and static scales.

CHAPTER 4: BASIC VEHICLE DYNAMICS MODEL

Truck performance along grade sections may have significant impacts on roadway throughput depending on the grade level, the truck characteristics, the percentage of trucks, and the level of congestion along the roadway section. Although, the HCM provides curves for predicting vehicle speeds as a function of the distance traveled and the percentage grade along the section (TRB, 1998), these curves were developed over 20 years ago and thus may not be reflective of current trucks. For example, **Figure** 4.1 illustrates that the maximum speed along a level roadway (0 percent grade) barely exceeds 90 km/h (55 mi/h). Furthermore, the curves indicate different equilibrium speeds (crawl speeds) depending on whether a truck is accelerating or decelerating (grades 1%, 2% and 3%). Specifically, differences in equilibrium speed estimates based on a vehicle's acceleration and deceleration behavior contradicts basic vehicle dynamics. It is not clear at this point if this difference in crawl speeds is a result of some flaw in the HCM procedures or that the equilibrium speeds occur outside the 5-km travel range.

This chapter first presents the proposed vehicle dynamics model and recommended parameters for the model. The next will be described how the model was calibrated/validated using field data collected along the Smart Road test facility. In order to demonstrate the applicability of the model, performance curves for a sample 120 kg/kW (200 lb/hp) truck are developed. These performance curves overcome the major shortcomings of the current performance curves in the HCM that were described earlier.

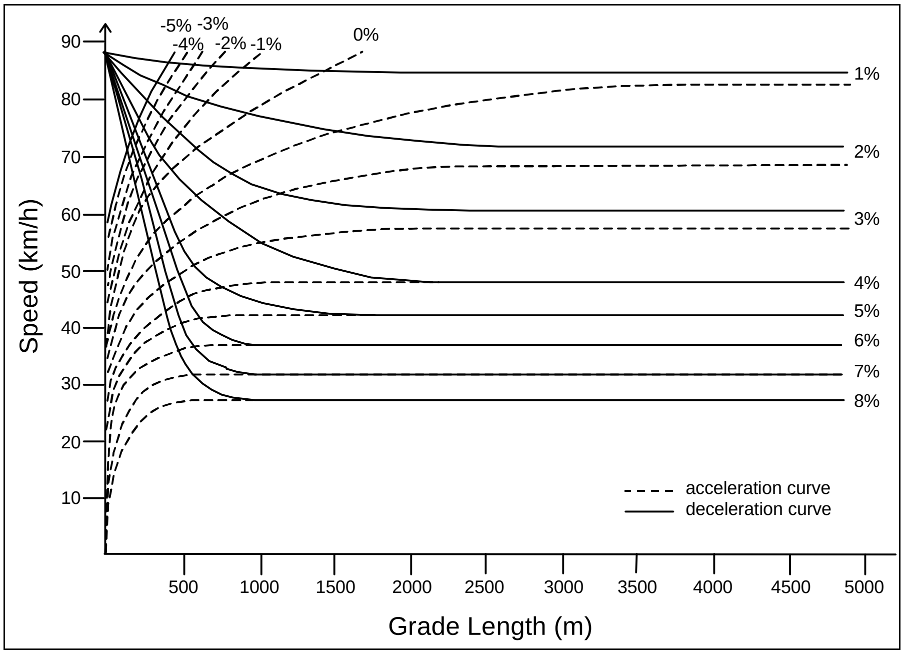


Figure 4.1: Truck performance curves for an average truck (200 lb/hp) (HCM, 1997)

4.1 TRACTIVE EFFORT

The proposed model is similar to models presented by others with an enhancement, which will be demonstrated in the next chapter. A truck's ability to accelerate, decelerate, and negotiate a grade is a function of a number of factors including the truck weight and engine power. The engine power provides the torque that is required to drive the vehicle's axle, which in turns spins the vehicle's wheels and generates a tractive force between the vehicle tires and the road surface. Provide vehicle to accelerate, the tractive force magnitude must exceed all resistance forces. Specifically, the model constrains the maximum tractive force that is computed in Equation 4.1 using Equation 4.2 as demonstrated in Equation 4.3. Equation 4.2 accounts for the friction between the tires of the vehicle's tractive axle and the roadway surface. The use of Equation 4.3 ensures that the tractive effort does not approach infinity at low vehicle speeds. A complete definition of the variables that are used in the model is summarized in Table 4.1.

$$F_t = 3600\eta \frac{P}{V} \tag{4.1}$$

$$F_{max} = 9.8066\, M_{ta}\,\mu \quad (4.2)$$

$$F = \min(F_t, F_{max}) \quad (4.3)$$

where F_t: tractive effort (N);

P: engine power (kW);

V: truck speed (km/h);

η: transmission efficiency;

F_{max}: maximum tractive force (N);

M_{ta}: vehicle mass on tractive axle (kg) such that $M_{ta} = M.perc_{ta}$;

$perc_{ta}$: percent mass acting on tractive axle;

μ: coefficient of friction between tires and pavement; and

F: tractive effort effectively acting on truck (N).

Table 4.1: Model variables and coefficients

Variable	Definition	Units
V	Vehicle speed	km/h
A	Vehicle acceleration	m/s^2
F	Residual force	N
F_t	Tractive force	N
F_{max}	Maximum tractive force	N
P	Engine power	KW
η	Power efficiency	–
M	Vehicle mass	Kg
M_{ta}	Vehicle mass on tractive axle (M x $perc_{ta}$)	Kg
$perc_{ta}$	Percentage of vehicle mass on tractive axle	%
μ	Coefficient of friction	–
R	Total resistance force	N
R_a	Air drag resistance	N
R_r	Rolling resistance	N
R_g	Grade resistance	N
c_1	Constant = 0.047285	–
C_d	Air drag coefficient	–
C_h	Altitude coefficient	–
H	Altitude	M
A	Frontal area	m^2
c_2, c_3	Rolling resistance constants	–
C_r	Rolling coefficient	–
i	Grade magnitude	proportion

Equation 4.1 indicates that the tractive force decays as a function of the vehicle speed assuming that the vehicle power remains constant. The tractive force is limited by the

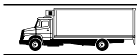
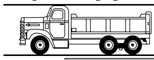
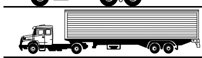
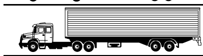
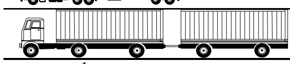
tire-to road adhesion for lower speeds and for higher speeds, it is limited by the force generated by the engine. It should be noted that the engine power curve is degraded as a result of two factors. The first source of power loss is caused by engine accessories including the fan, generator, water pump, magneto, distributor, fuel pump, and compressor. The second source of power loss occurs in the transmission system. Typical transmission efficiencies range from 0.89 to 0.94, as summarized in Table 4.2. While is Fitch (1994) recommended an additional 10 percent reduction caused by accessory losses.

Table 4.2: Transmission efficiency (SAE J2188, 1996)

	Direct (through transmission)	**Indirect (single transmission)**	**Double indirect (auxiliary transmission))**
Single Drive	0.94	0.92	0.90
Tandem Drive	0.93	0.91	0.89

It should be noted that the maximum tractive force is a function of the proportion of the vehicle mass on the tractive axle. A summary of typical axle mass distributions for different truck types is provided in Table 4.3 for use within the proposed model. Axle mass distributions shown in Table 4.3 are in accordance with the limits established in STAA 1982, assuming a maximum mass per single axle of 9000 kg (20000 lb), a maximum mass per tandem axle of 15400 kg (34000 lb), a maximum total mass of 36300 kg (80000 lb), a maximum width of 2.6 m (8.5 ft), a maximum length for a single trailer of 14.6 m (48 ft), and a maximum length for a double trailer of 17.1 m (56 ft).

Table 4.3: Length and mass distribution for typical trucks (Fitch, 1994)

Truck configuration	Length (m)	Mass (10^3 kg) and percent mass per axle[1]						
		Total	Front axle		Tractive axle[2]		Trailer axles	
	6.86	13.6	4.5	33%	9.1	67.0%		
	7.92	19.3	3.9	20%	15.4	80.0%		
	7.92	22.7	8.2	36%	14.5	64.0%		
	15.24	28.6	4.3	15%	8.9	31.0%	15.4	54.0%
	16.07	35.4	4.6	13%	15.4	43.5%	15.4	43.5%
	19.80	36.3	3.5	10%	8.2[3]	22.5%	8.2[3]	22.5%

[1] Limits acording to the STAA 1982 assuming a maximum mass per single axle of 9.0 metric tons (20000 lb), a maximum mass per tandem axle of 15.4 metric tons (34000 lb), a maximum total mass of 36.3 metric tons (80000 lb), a maximum width of 2.6 m (8.5 ft), a maximum length for a single trailer of 14.6 m (48 ft), and a maximum length for a double trailer of 17.1 m (56 ft).
[2] Rear axle is the tractive axle.
[3] For each single axle.

4.2 RESISTANCE FORCES

The model considers three major types of resistance forces, including aerodynamic, rolling, and grade resistance as was proposed in previous models (Mannering and Kilareski, 1990; Fitch, 1994; Archilla and De Cieza, 1996). The total resistance force is computed as the sum of the three resistance components, as summarized in Equation 4.4.

$$R = R_a + R_r + R_g \tag{4.4}$$

The aerodynamic resistance is a function of the vehicle frontal area, the altitude, the truck drag coefficient, and the speed of the truck (second order polynomial), as indicated in Equations 4.5 and 4.6.

$$R_a = c_1 C_d C_h A V^2 \tag{4.5}$$

$$C_h = 1 - 8.5 \times 10^{-5} H \tag{4.6}$$

The constant c_1 accounts for the air density at sea level at a temperature of 15^{o}C (59^{o}F). Typical values of vehicle frontal areas for different truck and bus types are provided in

Table 4.4 while typical drag coefficients are provided in Table 4.5. Equation 4.6 is a linear approximation that derived from a more complex formulation (Watanada *et al*., 1987). The linear approximation was found to provide similar results to the more complex formulation for altitudes in the range of 0 to 5000 m.

Table 4.4: Typical vehicle frontal areas (SAE J2188, 1996)

Vehicle type		Area (m^2)
Truck	Semi-trailer van type (conventional or cab-over engine	10.0
	Semi-trailer van type body (2.60 m wide)	10.7
	Straight truck van type body (rental truck)	8.9
	Tanker and flatbeds (conventional cab)	7.0
	Tanker and flatbeds (cab-over-engine, high tilt)	7.9
	Dump truck, conventional cab	6.8
Bus or coach	Intercity bus	7.9
	City bus	7.4
	School bus	7.0
	Motor home	7.4

Table 4.5: Typical vehicle drag coefficients

Vehicle type		C_d	Source
Passenger car	Ordinary	0.30 - 0.60	Wong [1978]
	Convertible	0.40 - 0.65	Wong [1978]
	Citroen DS19	0.311	Wong [1978]
	Oldsmobile Toronado	0.380	Wong [1978]
	Mercedes 300SE	0.387	Wong [1978]
	Ford Falcon Futura	0.416	Wong [1978]
	VW 1200 (Beetle)	0.458	Wong [1978]
	Ford Mustang	0.475	Wong [1978]
Motorcycle		1.8	Wong [1978]
Bus	Intercity or city/suburban	0.45	SAE J2188
	School bus	0.55	SAE J2188
Truck	Single unit	0.70	Fitch [1994]
	Tractor-semitrailer	0.70	Fitch [1994]
	Car hauler - cattle hauler	0.96 - 1.10	SAE J2188
	Garbage	0.95 - 1.05	SAE J2188
	No aerodynamic aids on roof	0.78	SAE J2188
	Aerodynamic aids on roof	0.64	SAE J2188
	Full aerodynamic treatment	0.58	SAE J2188

The rolling resistance is a linear function of the vehicle speed and the mass on the tractive axle, as indicated in Equation 4.7. Also, it should be noted that the rolling resistance results from the friction between the vehicle tires and the road surface. Typical values for rolling coefficients as a function of the road surface type and condition are provided in Table 4.6. In addition, the rolling resistance coefficients vary as a function of the vehicle's tire type, as summarized in Table 4.7. Generally, radial tires provide a resistance that is 25 percent less than that for Bias Ply tires.

$$R_r = 9.8066 C_r (c_2 V + c_3) \frac{M}{1000} \tag{4.7}$$

Table 4.6: Highway surface coefficients (derived from Fitch, 1994)

Rolling Coefficients			Coefficient of Friction
Pavement Type	**Pavement Condition**	**C_r**	**μ**
Concrete	Excellent	1.00	0.80
	Good	1.50	0.70
	Poor	2.00	0.60
Asphalt	Good	1.25	0.60
	Fair	1.75	0.50
	Poor	2.25	0.40
Macadam	Good	1.50	0.55
	Fair	2.25	0.45
	Poor	3.75	0.35
Cobbles	Ordinary	5.50	0.5
	Poor	8.50	0.40
Snow	2"	2.50	0.20
	4"	3.75	0.15
Dirt	Smooth	2.50	0.30
	Sandy	3.75	0.20
Mud	-	3.75 to 15.0	0.15
Sand	Level soft	6.0 to 0.15.0	0.15
	Dune	16.0 to 30.0	0.10

Table 4.7: Rolling resistance constants

Tire	c_2	c_3	Source
Bias Ply	0.0438	6.100	Derived from Fitch (1994)
Radial	0.0328	4.575	Derived from Fitch (1994)

The grade resistance is the major component of the resistance to movement and as indicated in Equation 4.8, it is a function of the vehicle's mass and the percent grade that the vehicle travels along. The grade resistance accounts for the proportion of the vehicle weight that resists the movement of the vehicle. The value of the grade resistance increases as the level of upgrade increases, because of a large component of the vehicle weight resists the vehicle's motion. The larger grade resistance at higher upgrades results in equilibrium speeds and decrease as a function of the grade magnitude. The equilibrium speeds represent the speed at which the maximum vehicle acceleration is zero.

$$R_g = 9.8066Mi \tag{4.8}$$

4.3 MAXIMUM VEHICLE ACCELERATION

The vehicle acceleration (deceleration) can be expressed as a function of the net force on the vehicle and using Equation 4.9 it should be possible to compute the maximum vehicle acceleration. Given that acceleration is the first derivative of speed with respect to time and that the tractive effort and resistance forces are functions of the vehicle speed, Equation 4.9 can be solved as an ODE. It should be noted, however, that the variation in other independent variables including the roadway grade and/or the vehicle power necessitate solving the ODE numerically.

$$a = \frac{F - R}{M} \tag{4.9}$$

where a: maximum truck acceleration (m/s^2);
F: tractive effort (N);
R: total resistance force (N); and
M: vehicle total mass (kg).

Assuming a constant vehicle power and given that acceleration is the second derivative of distance with respect to time, Equation 4.9 resolves to a second-order ODE of the form indicated in Equation 4.10 The ODE is a function of the first derivative of distance (vehicle speed) because the tractive effort, the rolling resistance, and aerodynamic resistance forces are all functions of the vehicle speed. In addition, the ODE may be a function of the distance traveled if the roadway grade changes along the study section. It should be noted at this point that because the tractive effort includes a minimum operand, the derivative of acceleration becomes a non-continuous function. Consequently, a first-order solution technique is inevitable, as will be described subsequently through thesis.

$$\ddot{x} = f(\dot{x}, x) \tag{4.10}$$

Where: x is the distance traveled

4.4 MODEL VALIDATION

In an effort to validate the proposed model together with the recommended input parameters, a number of field tests were conducted along a test roadway at the VTTI. This section first describes the test truck that was utilized to conduct the validation effort. Second, the study roadway section is described in detail prior to discussing the specifics of the validation effort. Finally, the model validation results are presented and discussed.

4.4.1 Test Truck Characteristics

The test truck that was utilized in the validation effort was a 1990 truck owned by the VDOT. The truck used a Cummins NTC-350 engine with an engine power rating of 261 kW (350 hp) at an engine speed of 2100 rpm. The peak torque of 1627 N.m (1,200 lbf-ft) occurred at an engine speed of 1300 rpm. The engine was fairly large with a piston displacement of 14 liters (850 cu.in); the engine power, however, would be considered fairly low, as typical truck engines currently range from 223 kW to 485 kW (300 hp to 650 hp).

The test vehicle and trailer was composed of a single trailer with a total of 6 axles, and thus would be classified as vehicle class 10 using the FHWA classification. The front axle was a single axle, the tractive axle was a dual axle, and the trailer axle was a triple axle. The truck did not have any aerodynamic fixtures and used radial tires.

4.4.2 Study Section Description

The study section that was considered included a 1.5-km (0.9-mi) section of the Smart Road test facility at the VTTI. Currently, the Smart Road is a 1.5-km (0.9-mi) roadway that will be expanded to a 3.2-km (2-mi) experimental highway in Southwest Virginia that spans varied terrain, from in-town to mountain passes.

The horizontal layout of the test section is fairly straight with some minor horizontal curvature that does not impact vehicle speeds. The vertical layout of the section demonstrates a substantial upgrade that ranges from 6 percent at the leftmost end to 2.8 percent at the rightmost end, as illustrated in **Figure** 4.2. In constructing the vertical profile of the test section the elevation of 35 stations were surveyed, as indicated by the diamond symbols in **Figure** 4.2. The vertical profile of the test section was then generated by interpolating between the station elevations using a cubic spline interpolation procedure at 1-meter (3.28 ft) increments. The cubic spline interpolation ensures that the elevations, the slopes, and the rate of change in slopes are identical at the boundary conditions (in this case every meter). The grade was computed for each 1-meter (3.28 ft) section and found to vary considerably, as illustrated in **Figure** 4.2 (thin line). A polynomial regression relationship was fit to the grade data (R^2 of 0.951) for two reasons. First, to ensure a smooth transition in the roadway grade while maintaining the same vertical profile. Second, to facilitate the solution of the ODE because it ensures that the grade function is continuous. The modified grade and vertical elevation, which are illustrated in **Figure** 4.2 (thick line), demonstrate an almost identical vertical profile with much smoother grade transitions when compared to the direct interpolation.

Apart from a 150-m (492-ft) segment of the roadway that was a rigid pavement, the entire roadway surface was asphalt. Consequently, a rolling resistance coefficient for asphalt pavement was only utilized. In addition, it should also be noted that the quality of the road surface was good when the test runs were conducted. These factors are important in identifying the road surface rolling resistance coefficients, as will be discussed later.

4.4.3 Test Run Execution

In an attempt to validate the dynamics model and the parameters that have been proposed in the literature, a test truck was driven along the Smart Road test facility. This section describes how vehicle speeds were measured and the specifics of the test run execution.

The vehicle was equipped with a Global Positioning System (GPS) unit that measured the vehicle speed to an accuracy of 0.1 m/s (0.305 ft/s). GPS is a worldwide, satellite-based radio-navigation system that can determine with certain accuracy the position and velocity of any object equipped with a GPS receiver.

Typical output data from GPS receivers include latitude, longitude, altitude, speed, heading and time. GPS receivers can also typically update these parameters once every second. Nominal position accuracy is specified with a 25-m (82-ft) spherical error probability, while nominal velocity accuracy is specified with a 0.1 m/s (0.31 ft/s) error probability. These inaccuracies are attributed to a number of sources of error. The majority of the errors are linked to the way the distance between a satellite and a GPS receiver is measured. Within the system, distances are measured by calculating the time it takes for a signal to travel between a satellite and a receiver. Consequently, any delay in the signal transmission then results in distance overestimation and inaccuracies in the estimated position of an object.

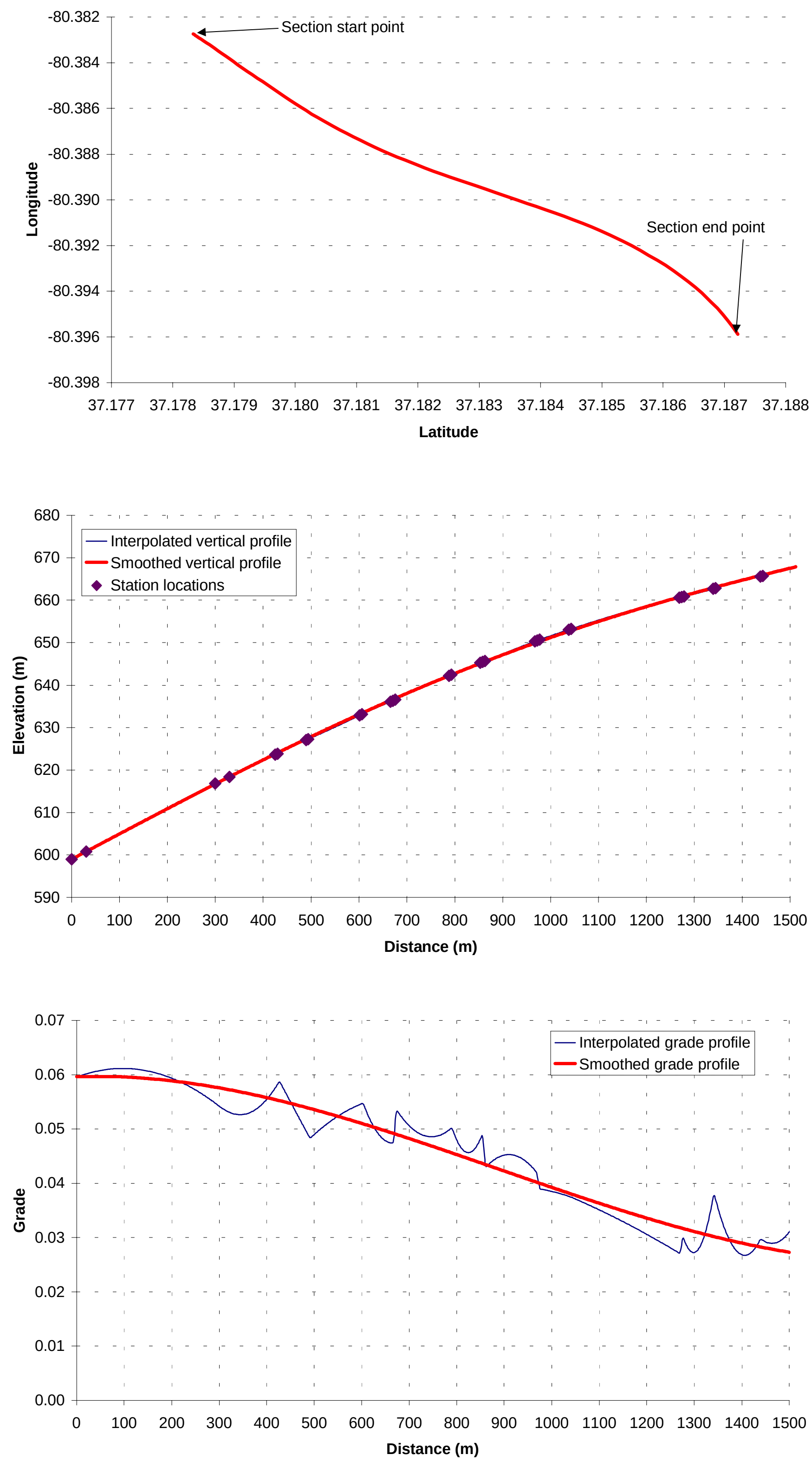


Figure 4.2: Smart road test section layout

4.4.4 Test Run Description

The test runs involved accelerating at the maximum possible acceleration rate from a complete stop at the start of the test section. The acceleration continued until the end of the test section, over the entire 1.5-km (0.9-mi) section.

In an attempt to alter the mass-to-power ratio, a total of ten mass configurations were analyzed using the same test truck. The truck and trailer mass was altered by progressively reducing the number of concrete blocks on the trailer from 9 to 0 blocks, with each block weighing approximately 2400 kg (5300 lb). Axle weights were recorded prior to conducting the test runs using General Electrodynamics Corporation (GEC) weigh scales with an advertised accuracy of 98 percent. In summary, the study involved varying the mass of the truck and trailer from 22600 to 44800 kg (49880 lb to 98880 lb), as summarized in Table 4.8, with the mass-to-power ratio varying from 85 kg/kW to 168 kg/kW (140 lb/hp to 277 lb/hp).

Table 4.8: Truck and trailer axle's mass analyzed

	Load Configuration									
Mass (kg)	0	1	2	3	4	5	6	7	8	9
Axle1	4491	4627	4935	4953	5008	5189	4899	5062	5606	5189
Axle2	4200	5162	5715	6241	6296	6994	7394	8001	8192	8518
Axle3	3865	4672	5352	5842	5869	6523	7040	7575	7865	8083
Axle4	3012	3547	4010	4944	5180	5788	5842	7430	8092	8700
Axle5	3239	3611	3955	4518	4944	5080	4953	5742	6550	7330
Axle6	3856	4336	4518	4817	5126	4790	5080	4935	5625	6985
Total	22661	25954	28485	31316	32423	34364	35208	38746	41930	44806

In conducting the study, a minimum of 10 repetitions was executed for each load configuration in order to provide a sufficient sample size for the validation analysis.

4.4.5 Model Validation Procedures and Results

This section describes how the model and the proposed model parameters were validated and the results of the validation exercise.

The proposed dynamics model was applied by setting the model parameters to reflect the truck, trailer, altitude, tire, and pavement conditions. Values for these parameters were obtained from the manufacturer's specifications or from the literature (SAE J2188, 1996; Fitch, 1994). These parameters included:

a. A horsepower of 261 kW (350 hp), assuming that the engine operates at maximum power over the entire section (to compute maximum acceleration levels).
b. The percentage mass on the tractive axle was computed as the percentage mass on axles 2 and 3 relative to the entire truck and trailer mass, as shown in Table 4.9.
c. The power efficiency (η) was set to 0.94 (single drive) as suggested in the literature.
d. The air drag coefficient (C_d) was set to 0.78 because no aerodynamic aids were on the truck roof.
e. The coefficient of friction (μ) was set to 0.6 and the rolling coefficient (C_r) was set to 1.25 to account for a good asphalt pavement surface.
f. The rolling resistance coefficients were set to 0.04375 and 4.575, respectively to account for radial tires on the truck and trailer.
g. The frontal area was set to 10.7 m^2 (115.2 ft^2) for a semi-trailer van type body whose width is 2.60 m (8.5 ft).

Table 4.9: Model parameters utilized in analysis

	Weight Configuration									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Power (HP)	350	350	350	350	350	350	350	350	350	350
Power (kW)	261.1	261.1	261.1	261.1	261.1	261.1	261.1	261.1	261.1	261.1
Mass (kg)	22,208	24,617	27,029	29,440	31,852	34,263	36,675	39,086	41,498	43,910
W/P Ratio (lb/hp)	140	155	170	185	201	216	231	246	261	277
Percta	0.356	0.379	0.389	0.386	0.375	0.393	0.410	0.402	0.383	0.371
Efficiency	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Coeff fric	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
C_d	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
C_h	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
C_1	0.04728	0.04728	0.04728	0.04728	0.04728	0.04728	0.04728	0.04728	0.04728	0.04728
C_2	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328
C_3	4.58	4.58	4.58	4.58	4.58	4.58	4.58	4.58	4.58	4.58
C_r	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
A (m^2)	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7

Given that the ODE that is presented in Equation 4.11 is a second-order ODE it can be recast as a system of two first-order equations (an n^{th}-order equation reduces to a set of n

1st-order equations), as demonstrated in Equation 4.12. These ODEs are solved using a first-order Euler approximation, as demonstrated in Equations 4.13 and 4.14.

$$a(t_i) = \frac{F(t_i) - R(t_i)}{M} \tag{4.11}$$

$$\text{Where}: \quad t_i = t_0 + i\Delta t \quad \text{for } i = 1,2,...,n$$

$$\begin{Bmatrix} \dot{v}(t_i) \\ \dot{x}(t_i) \end{Bmatrix} = \begin{Bmatrix} a(t_i) \\ v(t_i) \end{Bmatrix} \tag{4.12}$$

$$v(t_i) = v(t_{i-1}) + a(t_{i-1})\Delta t \tag{4.13}$$

$$x(t_i) = x(t_{i-1}) + v(t_{i-1})\Delta t \tag{4.14}$$

where:

Δt = duration of time interval used for solving the ODE (in this case 1-second duration)

$F(t_i)$ = total resistance force at instant t_i

$a(t_i)$ = vehicle acceleration at instant t_i

$v(t_i)$ = vehicle speed at instant t_i

$x(t_i)$ = vehicle location along test section at instant t_i

Table 4.10 summarizes the solution of the ODE system for nine load configuration for the first 10 seconds of the trip where

T time (s)

S distance (m)

V speed (km/h)

A acceleration (m/s^2)

F force (N)

I grade (%)

Ra air drag resistance (N)

Rr rolling resistance (N)

Rg grade resistance (N)

R total resistance (N)

It should be noted at this point that a higher order solution to the ODE was not feasible because the first derivative of the acceleration function was not continuous as explained earlier. The results for all load configurations are given in Appendix B.

Table 4.10: Example solution to ODE (9-Load Configuration)

T	S	V	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	97682	0.0596	0.00	2512.77	26200.14	28712.91
1	0.62	4.98	1.54	97682	0.0596	9.30	2602.56	26201.04	28812.90
2	2.77	10.41	1.25	84854	0.0596	40.61	2700.35	26204.05	28945.02
3	6.20	13.97	0.76	63266	0.0596	73.05	2764.36	26208.54	29045.95
4	10.43	16.34	0.56	54069	0.0597	100.02	2807.16	26213.53	29120.71
5	15.23	18.13	0.44	48723	0.0597	123.17	2839.46	26218.49	29181.12
6	20.47	19.57	0.36	45160	0.0597	143.38	2865.23	26223.04	29231.66
7	26.07	20.75	0.30	42591	0.0597	161.20	2886.50	26226.92	29274.62
8	31.98	21.74	0.25	40642	0.0597	177.03	2904.42	26229.91	29311.35
9	38.14	22.59	0.22	39110	0.0597	191.16	2919.76	26231.83	29342.76
10	44.52	23.33	0.19	37874	0.0597	203.85	2933.04	26232.55	29369.44

The procedures for solving the ODE are best described by illustrating how the various parameters were computed for the first two seconds of a test run. Using the initial condition of speed equal to zero ($v(t_0) = 0$), the tractive force, aerodynamic resistance, and rolling resistance were estimated using Equations 4.1, 4.5, and 4.7. Using the initial condition of distance equal to zero ($x(t_0) = 0$) the grade was estimated using the polynomial grade function that was described earlier and the grade resistance was computed using Equation 4.8. The maximum acceleration was then computed using Equation 4.9.

At i=1, the speed of the vehicle and location of the vehicle were estimated using Equations 4.13 and 4.14, respectively using the acceleration at i=0 ($t = t_0$). Again as was the case at i=0, the tractive force, aerodynamic resistance, rolling resistance, and grade resistance forces were computed based on: the speed and location after 1 second of travel. The acceleration at i=1 was then estimated using Equation 4.11.

The final speed profile from the model was superimposed on the field collected GPS second-by-second speed measurements, as illustrated in **Figure** 4.3, which illustrates the variation in vehicle speed as a function of traveled distance for load configuration 9, which corresponds to a gross vehicle mass of 44806 kg (98896 lb). The fit indicates a maximum error in the range of 5 km/h (3.1 mi/h) for the first 200 m (656 ft) with an error within the variability of the data for 200 m (656 ft) onwards. Figures with generated curves for all load configurations are given in Appendix B.

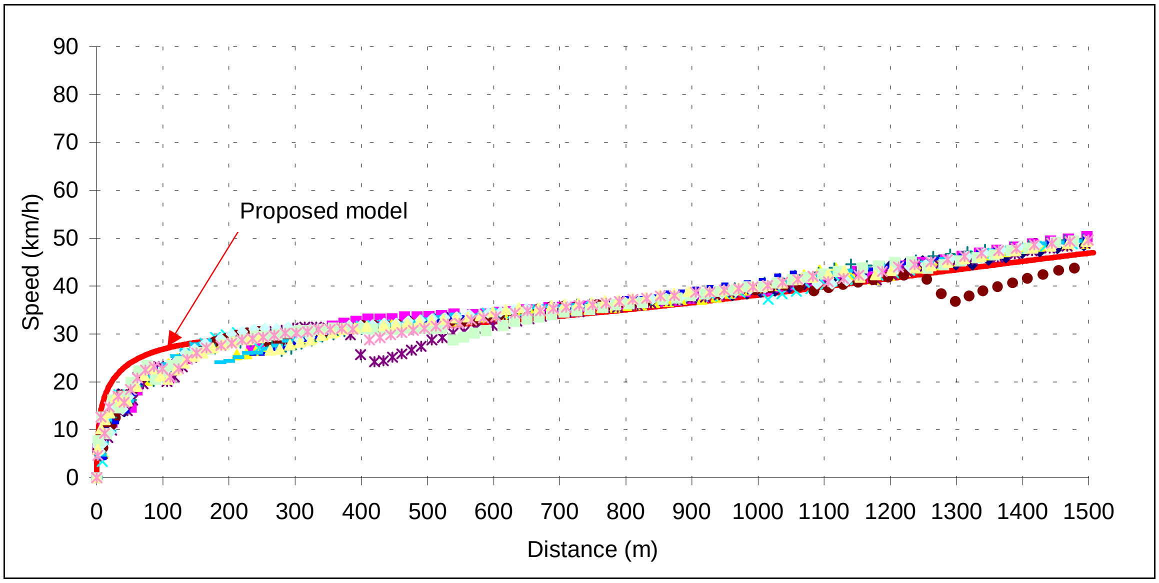


Figure 4.3: Predicted and observed speed profile (9-Load Configuration)

The initial error as the truck accelerates from a speed of zero can be explained by the fact that while the truck initially accelerates the gear shifting behavior results in the vehicle operating at a power that is less than the maximum power of 261 kW (350 hp). The analytical model, on the other hand, assumes a constant power of 261 kW (350 hp) over the entire trip. The dips observed in the measured speed curves are also due to the shifting of gears, as there is virtually no power transmission to the tractive axles while the clutch is activated. Further enhancements to the model are being considered to capture the buildup of power as a vehicle accelerates from a complete stop and to include the effects of gear shifting that will be described later.

Similar results are observed for other load configurations. However, only the results for the configuration 5 and 1 are presented due to lack of space. As illustrated in the other two graphs shown in **Figure** 4.4 and **Figure** 4.5, the error in the estimated speed versus the measured speed was found to be less than 10 percent at the conclusion of the 1.5-km (0.9-mi) section. These findings were consistent across the various load configuration tests and these figures for other load configurations are given in appendix.

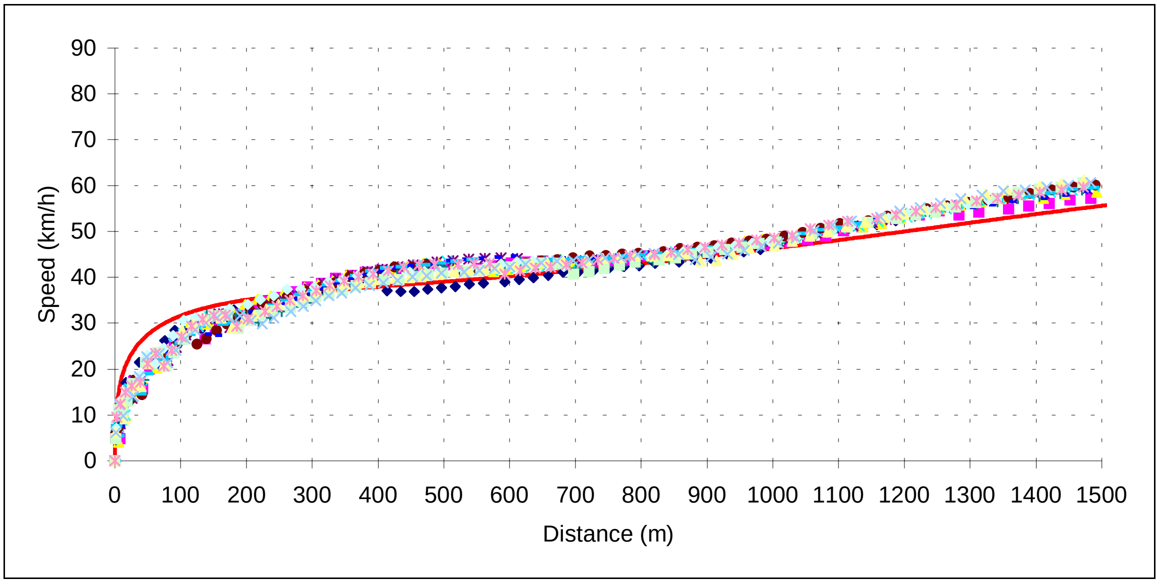


Figure 4.4: Predicted and observed speed profile (5-Load Configuration)

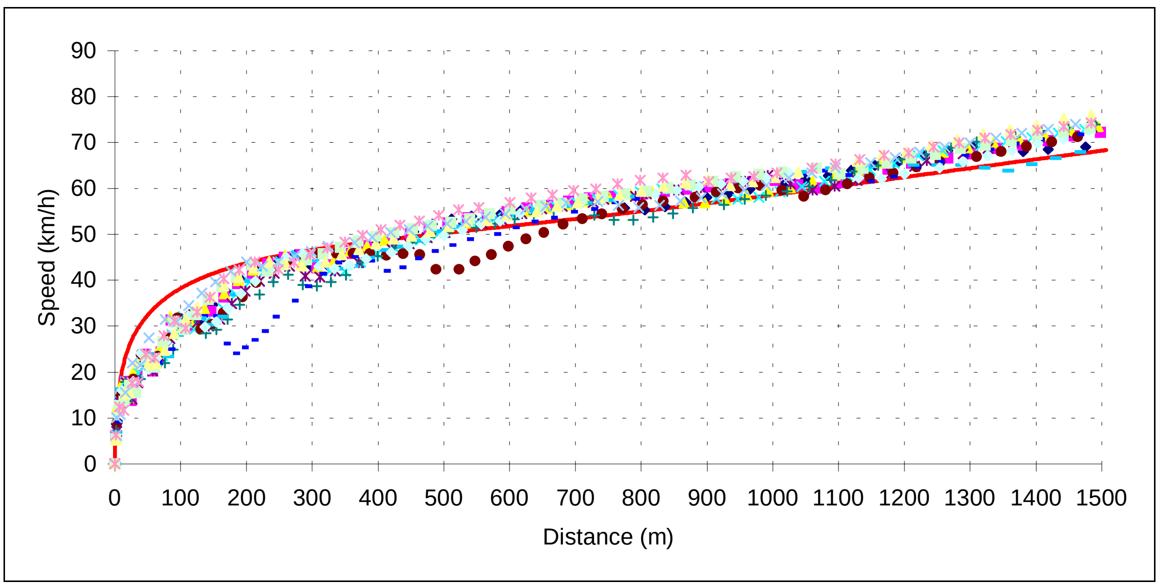


Figure 4.5: Predicted and observed speed profile (1-Load Configuration)

4.5 UPDATED SAMPLE PERFORMANCE CURVES FOR DESIGN TRUCK

Having validated the proposed dynamics model, this section demonstrates the model applicability by developing performance curves for a 120 kg/kW (200 lb/hp) truck along grades ranging from 0% to 6%, as illustrated in **Figure** 4.6. These curves can be used to update the truck performance curves currently used in the geometric design of highways, among other uses. It should be noted that the performance curves reflect a truck with no aerodynamic treatments using radial tires driving along a good surfaced asphalt pavement. Further research is to develop performance curves for different truck and roadway characteristics and it is done and demonstrated with improvements in the next chapter.

Figure 4.6 demonstrates that the equilibrium speed for this design truck on a 0% grade is 112 km/h (70 mi/h). Furthermore, the equilibrium speed is very similar for both acceleration and deceleration curves along a 5-km (16000 ft) section, and identical for longer sections when the equilibrium speed can be attained. Consequently, these curves overcome the first shortcoming of the HCM curves, namely the difference in equilibrium speeds depending on whether the vehicle is accelerating or decelerating. Identical equilibrium speeds is expected given that the equilibrium speed represents the speed at which the tractive effort equals the total resistance force, the equilibrium speed is independent of how the vehicle approaches the equilibrium speed (either accelerating or decelerating). The updated curves also provide higher equilibrium speeds than proposed by the HCM curves. For example, the 120 kg/kW (200 lb/hp) test truck has an equilibrium speed along a 1 percent upgrade slope of 98 km/h (61 mi/h) versus 88 km/h (55 mi/h) in the HCM. These higher equilibrium speeds are more reflective of the trucks in North America.

Finally, the model demonstrates a reduction in the equilibrium speed as the vehicle mass-to-power ratio increases and as the roadway grade increases, as illustrated in **Figure** 4.7. Specifically, the equilibrium speed ranges from a high of 120 km/h (70 mi/h) to a low of only 30 km/h (19 mi/h) depending on the truck weight-to-power ratio and the roadway grade.

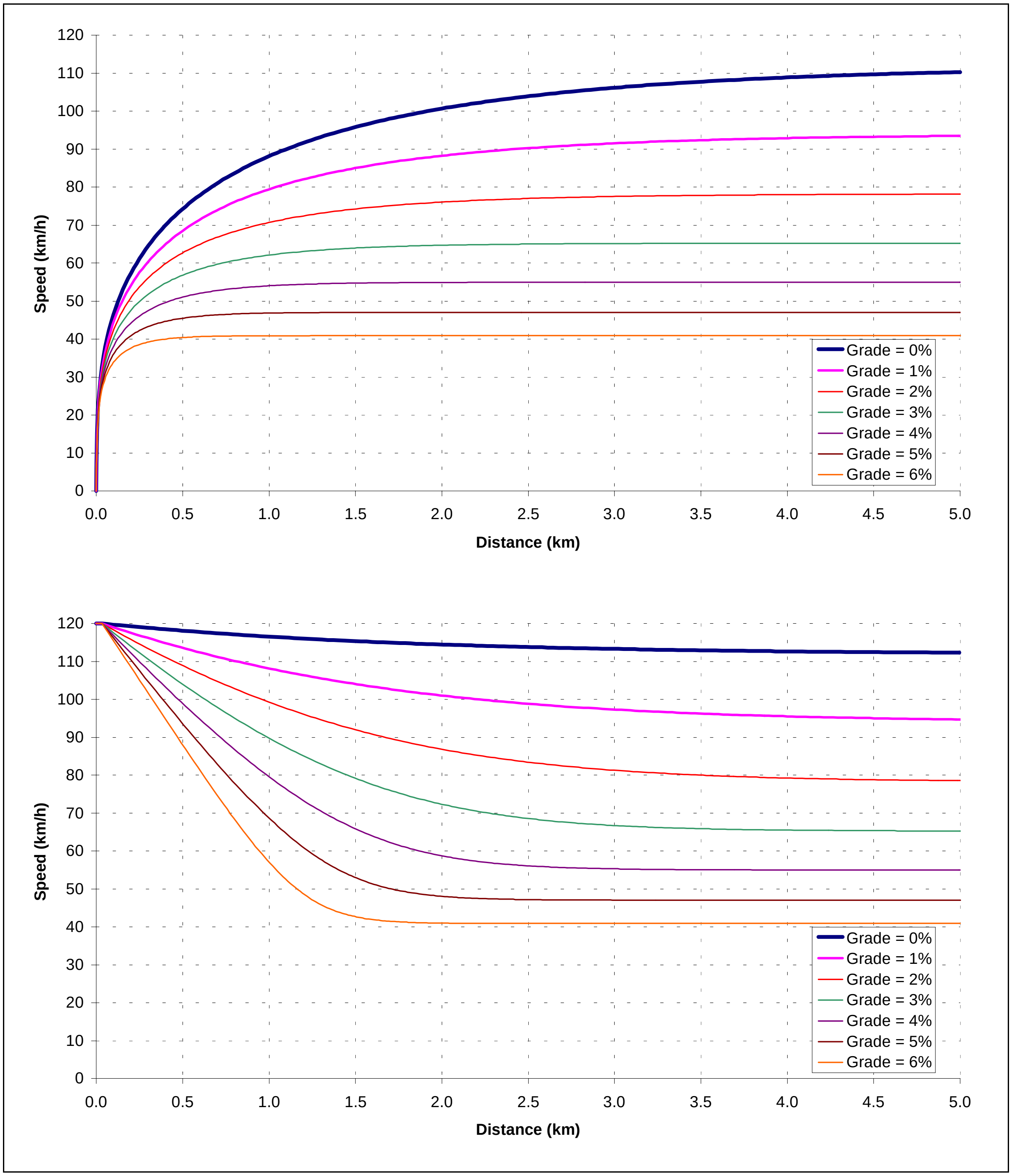


Figure 4.6: Truck performance curves for NTC-350 engine (200 lb/hp)

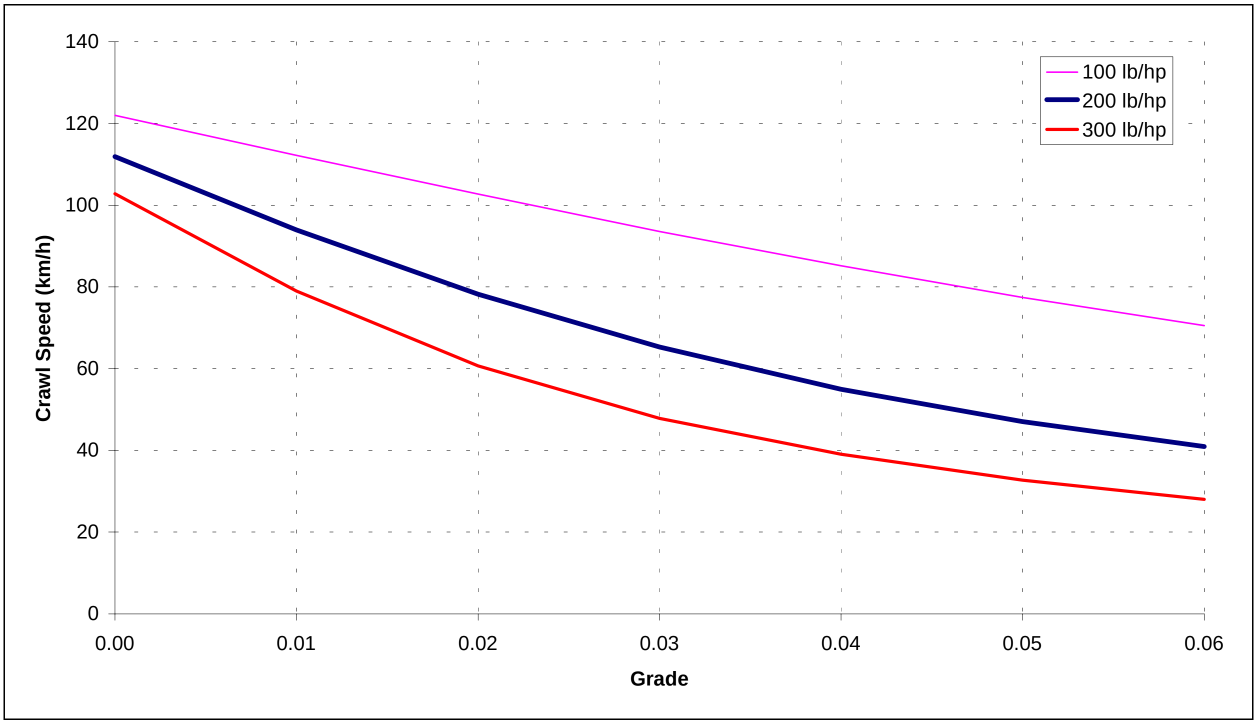


Figure 4.7: Variation in crawl speed as a function of roadway grade for NTC-350 engine

4.6 CONCLUSION

Based on the field tests that were conducted on the Smart Road test facility it can be concluded that the proposed model and proposed model input parameters provide results that are consistent with field observations, presenting errors less than 10% and within 5 km/h (3.1 mi/h). The new performance curves could be used to update the curves that are currently used for the geometric design of highways and climbing lanes.

As in any research effort, further investigations are required to better establish the accuracy of the proposed models. These investigations will include similar field tests with alternative trucks to investigate differences in vehicle performance as a function of engine and truck characteristics as it will be demonstrated in the next chapter. Although, model will be improved using variable power vehicle dynamic model to give better results in first 200 m (656 ft) of test field section, where was the maximum error in comparing model with raw data. The next chapter will provide description, validation, and calibration of gearshift model where power is not constant as it was with basic vehicle dynamics model. Four trucks different performances were used to validate/calibrate this model.

CHAPTER 5: VARIABLE POWER VEHICLE DYNAMICS MODEL

The chapter five presented the state–of–the-art vehicle dynamics models that can be utilized to estimate truck speeds. Typical model parameters were introduced and model speed predictions were compared to field data in an effort to validate the proposed parameters. Chapter four demonstrated that the constant power assumption that is inherent results in an overestimation of vehicle speeds at low speed and an under-estimation at high speeds.

Consequently, this research effort introduces the concept of variable power in order to enhance current state-of-the-art vehicle dynamics models and capture the build-up of power as a vehicle engages in gearshifts at low travel speeds. The proposed enhancement to the current state-of-practice vehicle dynamics model allows the model to reflect typical vehicle acceleration behavior more accurately. Subsequently, the model parameters are calibrated using field measurements along a test roadway facility.

5.1 PROPOSED MODEL ENHANCEMENT

This section describes the proposed enhancement to the vehicle dynamics model in order to capture the buildup of power as a vehicle engages in gearshifts. Initially, vehicle engine characteristics are presented in order to provide a background before describing the proposed enhancement.

Although a complete description of engine design is beyond the scope of the thesis, an understanding of how engine output is measured and applied is important to the study of vehicle performance, which relates to the proposed enhancement to state-of-practice vehicle dynamics models. The two most commonly used measures of engine output are torque and power (Mannering and Kilareski, 1990). Specifically, Mannering and

Kilareski (1990) define torque as "*the work generated by the engine (the twisting movement) and is expressed in units of newton-meters (Nm).*" In addition, they define power as "*the rate of engine work, usually expressed in kilowatts (kW) for engines*," and is related to the engine's torque by Equation 5.1.

$$P = \frac{2\pi T n}{1000} \quad (5.1)$$

Where:

P	Engine power (kW)
T	Engine torque (Nm)
N	Engine speed or speed of the crankshaft (revolutions per second)

Figure 5.1 illustrates a sample torque-power diagram for a typical gasoline vehicle (Oldsmobile Aurora) and a typical diesel engine truck (NTC-350 engine). The figure clearly demonstrates the differences between an automobile and truck engine. The first difference is the higher power and torque curves that are associated with truck versus automobile engines. The second difference is the smaller range of engine speeds for truck versus automobile engines. Specifically, the engine speed for the Oldsmobile Aurora extends up to 6200 rpm while the engine speed for the truck extends to 2100 rpm. This difference signifies the fact that the larger the engine the slower the engine speed of operation, in order to reduce the significant stresses that build up in the reciprocating engine parts at high engine speeds. Therefore, most large engines (i.e. engines having a large bore and stroke) are governed or restricted to a lower engine speed than smaller bore engines. The third observation from the engine performance curves is that truck engine curves are typically reported to begin at an engine speed of 1000 to 1200 rpm. The slowest engine speed at which the engine will operate without stalling or fouling up averages about 500 to 800 rpm (Fitch, 1994). Typically, an idling engine operates in the 500 to 800 rpm speed range, at which the engine power is zero. Noteworthy from the figure is that the idle engine speed for the Oldsmobile is approximately 700 rpm with a power that is approximately 1 percent the maximum power.

The literature also indicates that gear shifting may occur during high idling, which is illustrated in the figure. The high idling typically occurs at an engine speed that is 100 to 200 rpm above the rated speed and results in an engine power of zero.

Because tractive effort for acceptable vehicle performance is typically higher at lower vehicle speeds, and because maximum engine torque is developed at fairly high engine speeds, the use of gasoline-powered engines requires some form of gear reduction. This gear reduction provides the mechanical advantage necessary for acceptable vehicle acceleration. With gear reductions, two factors determine the amount of tractive effort reaching the driving wheels. First, the mechanical efficiency of the driveline (i.e. the gear reduction devices including the transmission and differential) must be considered, which typically range between 5 and 25 percent. Second, the overall gear reduction ratio that refers to the relationship between the revolutions of the engine's crankshaft and the revolutions of the road wheels. For example, an overall gear ratio of 4 to 1 means that the engine's crankshaft turns four revolutions for every one turn of the road wheel. In order to illustrate the concept of gear shifting, **Figure** 5.1 illustrates the torque and power relationships for the four gears of the Oldsmobile Aurora. Gear shifting typically occurs at maximum torque, which does not coincide with the maximum power, as demonstrated in **Figure** 5.2. Consequently, during gearshifts the vehicle operates at sub-optimal power.

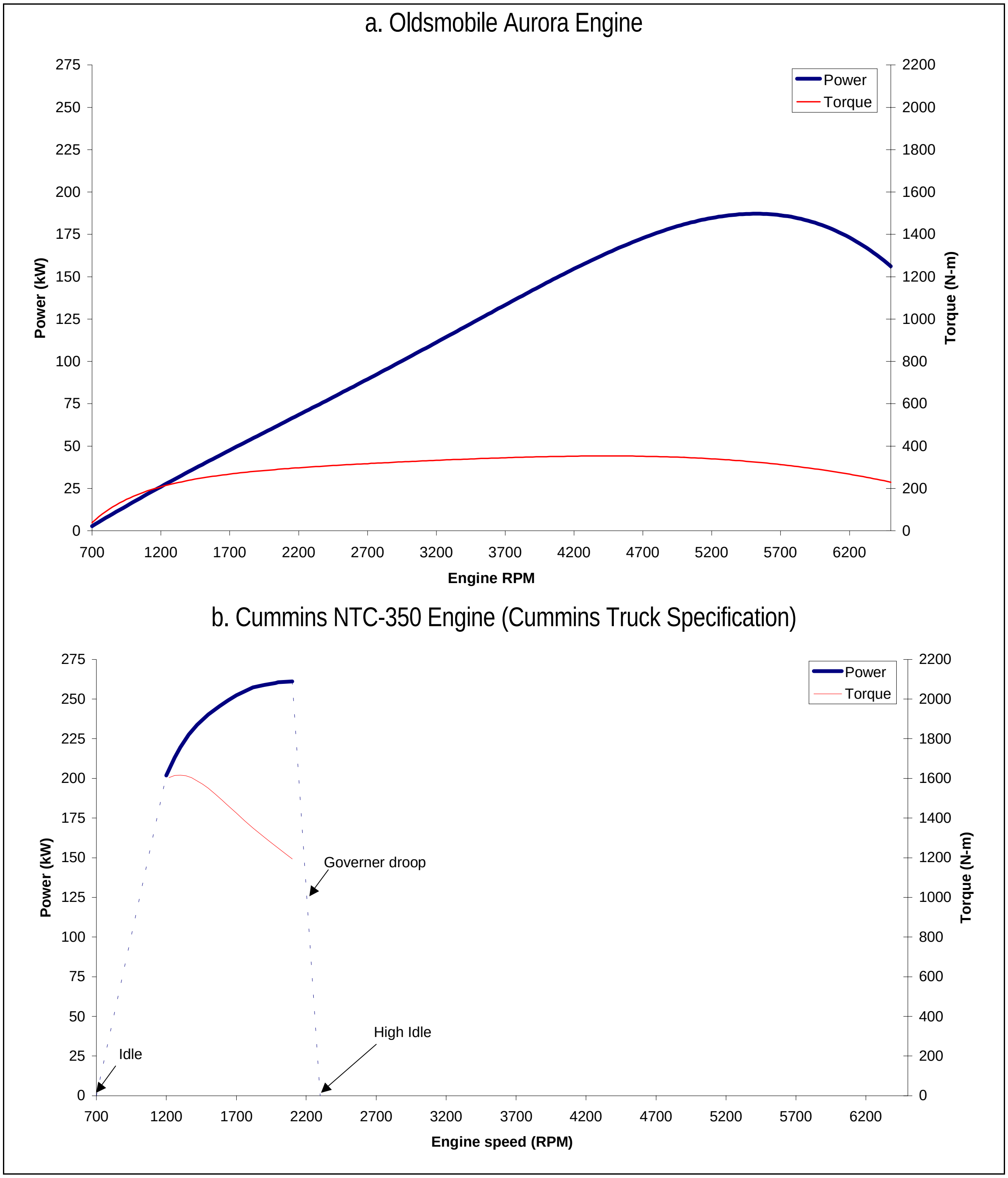


Figure 5.1: Sample torque-power curves for a gasoline powered vehicle and a truck

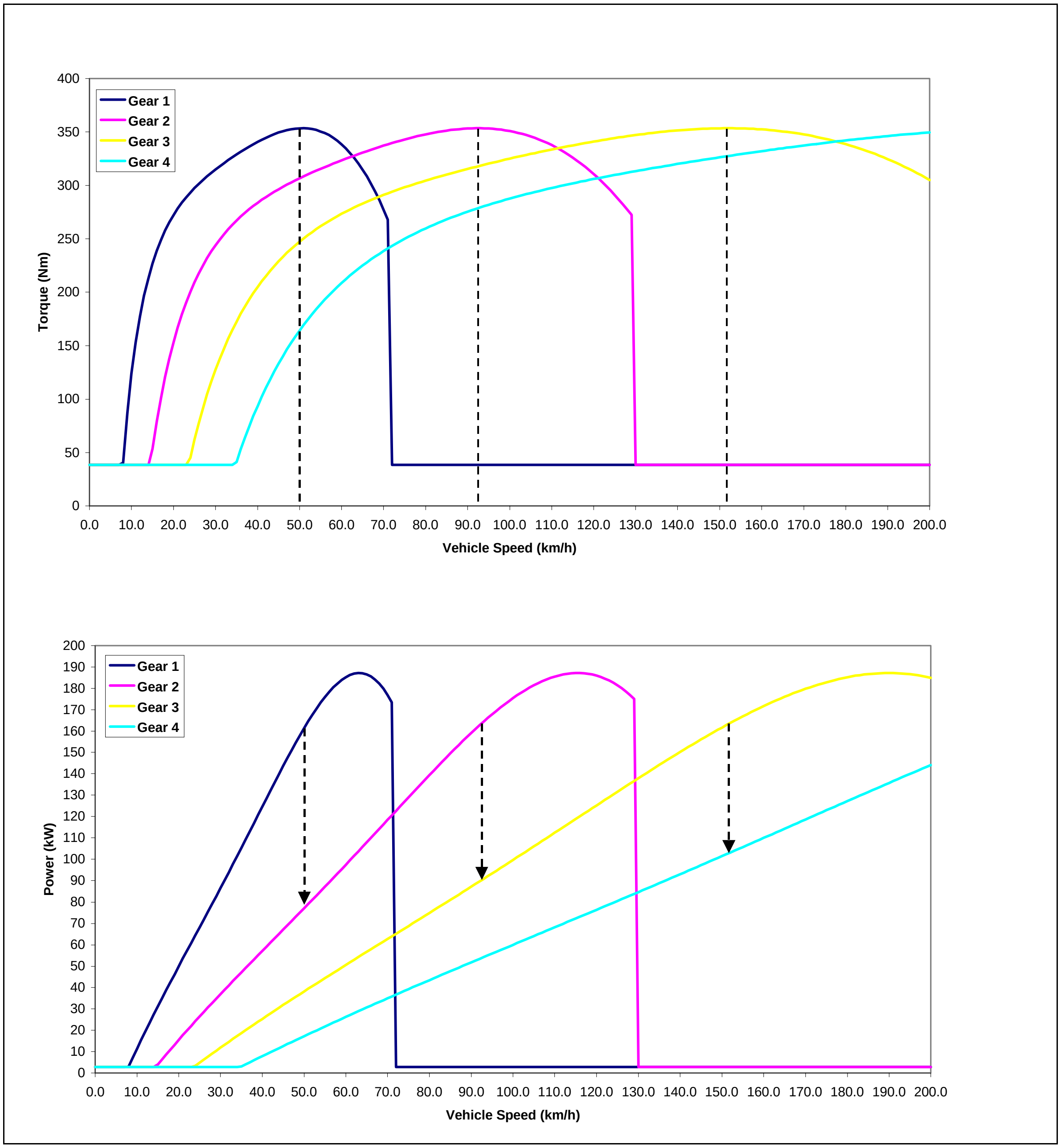


Figure 5.2: Sample torque and power curves for different gears (Oldsmobile Aurora)

5.2 VARIABLE POWER ADJUSTMENT FACTOR

While the proposed basic vehicle dynamics model does not involve gear shifting, it does account for the major behavioral characteristics that result from gear shifting, namely the reductions of power as gearshifts are being engaged. Specifically, the approach uses a simple vehicle dynamics model that captures the more complicated gear shifting behavior while accounting for the buildup of power as a vehicle accelerates from a complete stop.

The modification that is proposed uses a variable power efficiency factor that is dependent on the vehicle speed, as opposed to the constant factor that is currently utilized in the model. The factor is a linear relation of vehicle speed with an intercept of zero and a maximum value of 1.0 at a speed v_0, as demonstrated in Equation 5.2. In order to ensure that the vehicle has sufficient power to accelerate from a speed of zero a vehicle power lower bound is computed using a speed of 1 km/h, as demonstrated in Equation 5.2. The adjustment factor is then multiplied by the vehicle power and incorporated in Equation 4.1 to compute the tractive force, as demonstrated in Equation 5.3.

The estimation of the variable power factor "β"requires the calibration of two parameters, namely, the minimum power and the speed at optimum power. The proposed model assumes the minimum power to be a function of the optimum speed, as demonstrated in Equation 5.1. As will be demonstrated in a forthcoming section of the chapter, these parameters were calibrated using four trucks with vehicle rated powers ranging from 260 to 375 kW (350 to 500 hp) each involving 10 weight configurations. The calibration demonstrated that higher weight-to-power ratios required a lower optimum speed and a higher minimum power. The proposed power lower bound addresses this need for a variable parameter while maintaining a single calibration parameter.

Figure 5.3 illustrates the variation in the vehicle power and the resulting vehicle acceleration by incorporating the power adjustment factor that is presented in Equation

5.1. As illustrated in the figure the modification reduces the vehicle acceleration levels at the lower speeds while altering acceleration behavior at higher speeds slightly.

The calibration of the variable power factor involves calibrating the speed at which the vehicle power reaches its maximum (termed the optimum speed). The optimum speed was found to vary as a function of the weight-to-power ratio, as demonstrated in **Figure** 5.4. The details of how this relationship was derived is discussed in the model calibration section, however, it is sufficient to note at this point that the relationship is a power relationship, as demonstrated by Equation 5.4.

$$\beta = \begin{cases} \frac{1}{v_0} & v < 1 \\ \frac{v}{v_0} & 1 \le v \le v_0 \\ 1.0 & v > v_0 \end{cases} \tag{5.2}$$

$$F_t = 3600\ \beta\ \frac{P}{v} \tag{5.3}$$

$$v_0 = 1164 w^{-0.7499} \tag{5.4}$$

Where:

β	Variable power factor
v	Vehicle speed (km/h)
a	Calibrated parameter that tends to zero (recommended value 0.01)
v_0	Speed at which vehicle attains maximum power (km/h)
w	Vehicle weight-to-power ratio (kg/kW)

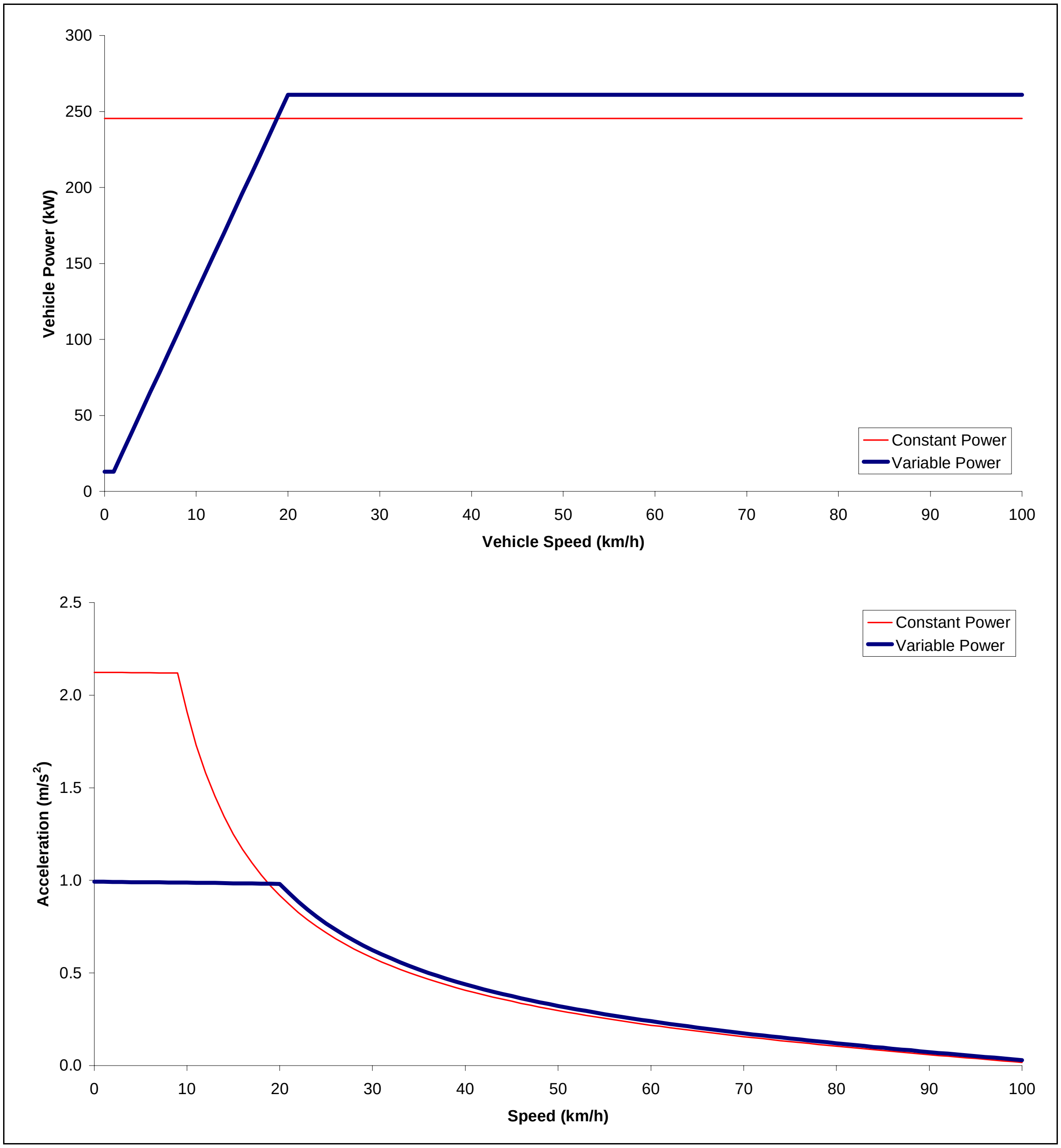


Figure 5.3: Variation in vehicle power and acceleration as a function of speed

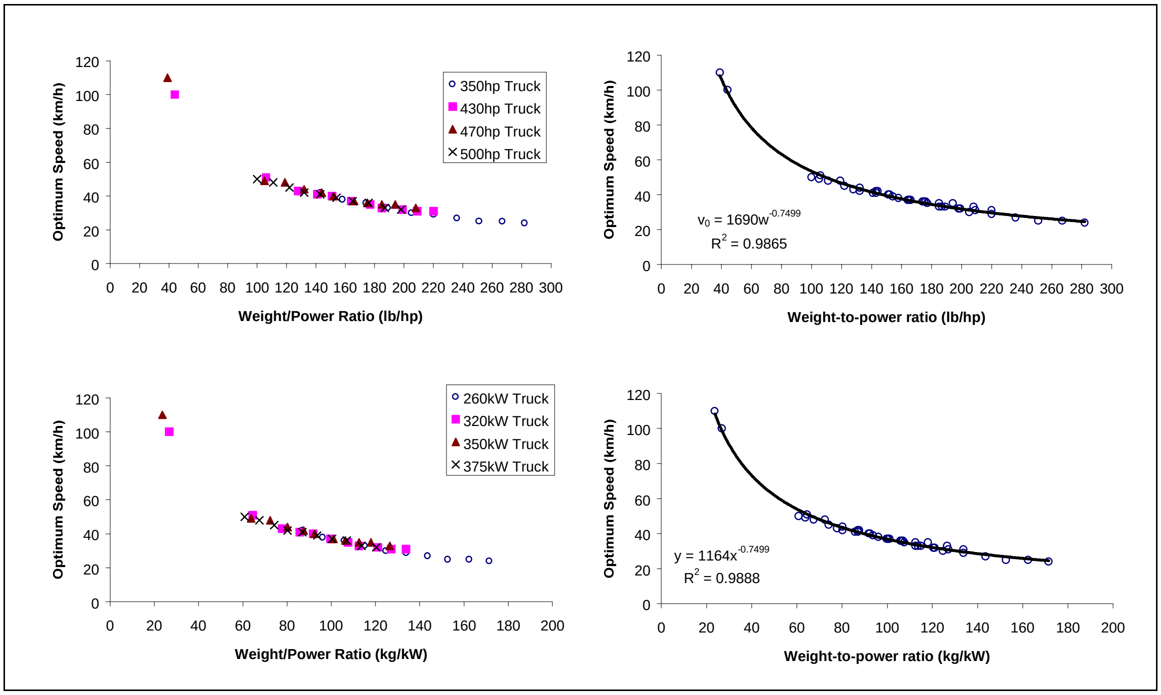


Figure 5.4: Relationships between speed at optimum power and weight-to-power ratios

The linearly increasing power as a function of vehicle speed in a constant acceleration as a function of vehicle speed given that force (mass and acceleration) is the first derivative of power with respect to speed.

Figure 5.5 illustrates the field observed and model predicted vehicle acceleration for the two load configurations that were illustrated earlier. The figure clearly demonstrates fluctuations in vehicle accelerations between positive and negative values as the vehicle engages in initial gearshifts. The trend, however, involves less fluctuations as the vehicle speed increases. The model predictions appear to reflect the average acceleration behavior during the initial gear shifting and after the vehicle attains its maximum power.

The acceleration profile as a function of distance also demonstrates consistency between field data and model predictions, as illustrated in **Figure** 5.6. The figure also illustrates that the vehicle attains maximum power within the initial 200 m (656 ft) of travel.

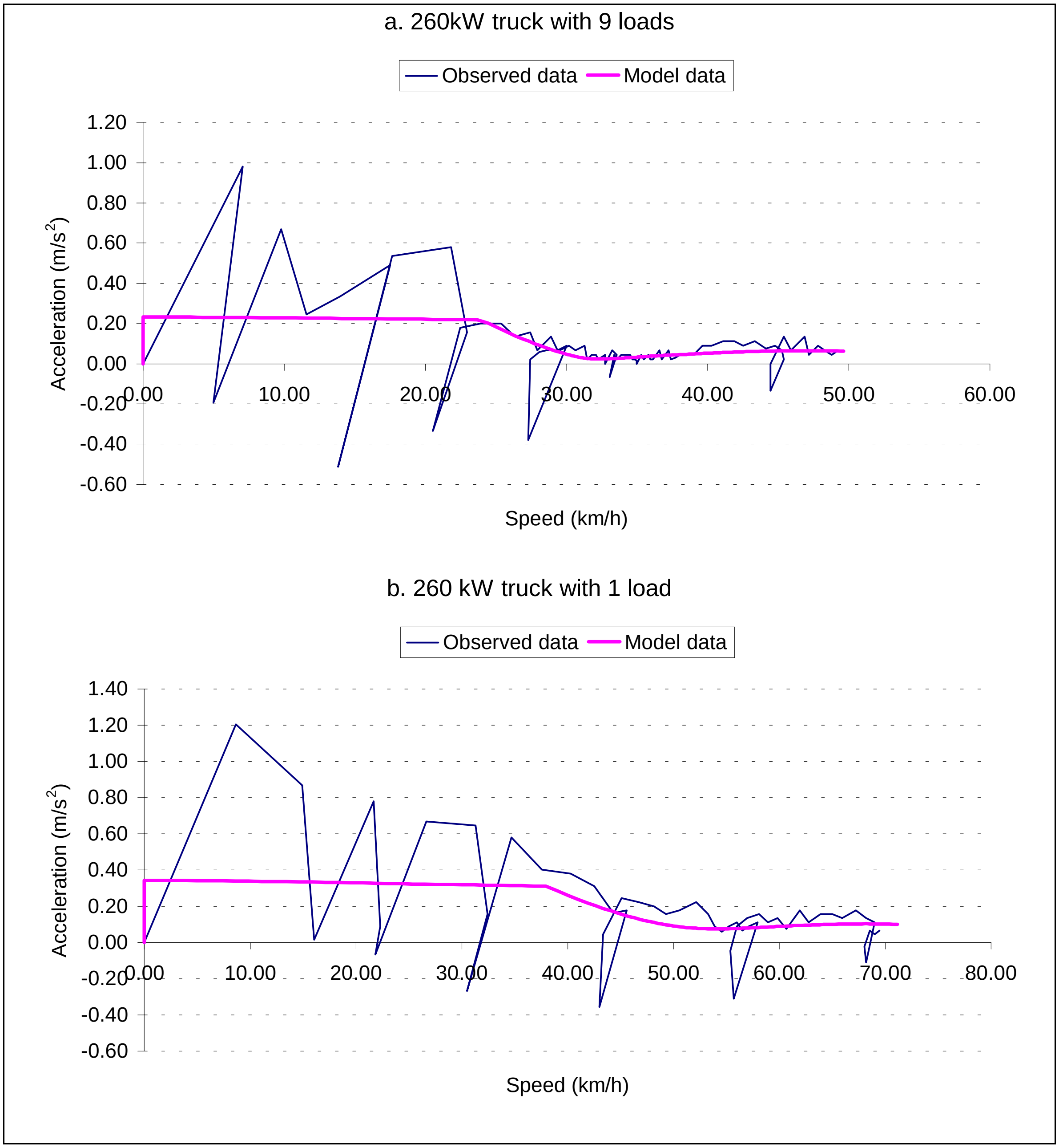


Figure 5.5: Sample acceleration versus speed profile for 260 kW (350 hp) truck

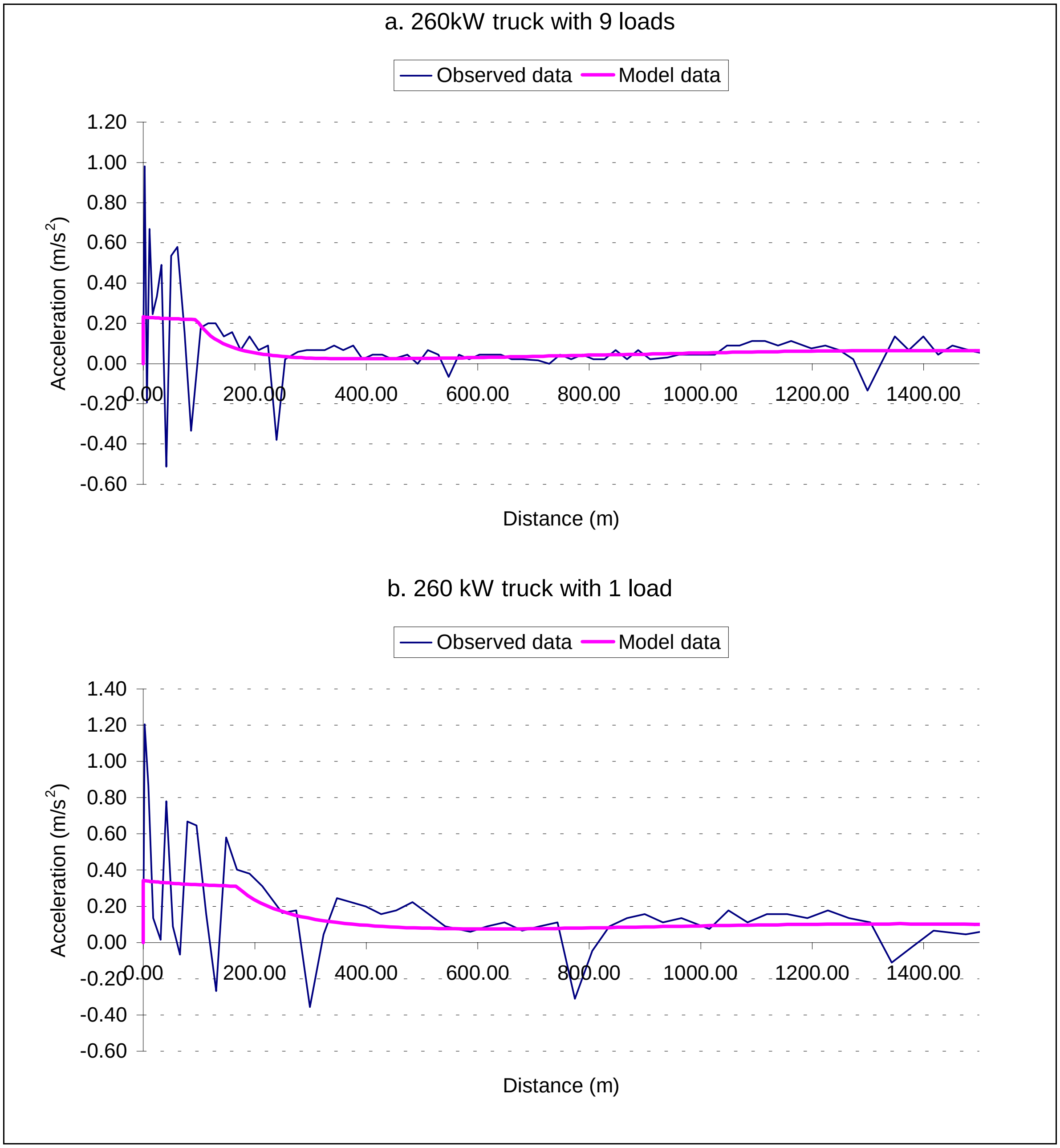


Figure 5.6: Sample acceleration versus distance profile for 260 kW (350 hp) truck

5.3 CHARACTERIZATION OF TRUCKS ON US INTERSTATE HIGHWAYS

In order to test the proposed enhanced vehicle dynamics model it was necessary to calibrate the optimum speed parameter using trucks that cover a typical range of weight-to-power ratios that are observed in the field. This section describes the characterization of in-field trucks that was necessary for the calibration effort.

The characterization of trucks along interstate highways was achieved by conducting a one-day survey at the Troutville weigh station along Interstate 81 was described in Chapter 3. Specifically, a random sample of about 200 trucks was included in the survey, of which 157 were classified as vehicle class 9. **Figure** 5.7 clearly demonstrates that the distribution of truck weights for the sample that was included in the survey was very similar to typical truck weight distributions along I-81.

In conducting the survey, the weights of the sample trucks were obtained from the static scales at the weigh station. In addition, information on the engine power, type of tires, aerodynamic features, and type of transmission were obtained through a questionnaire that was conducted with the truck drivers as was explained in Chapter 3.

The weight of the trucks ranged from 6800 kg (10000 lbs) to 38000kg (90000 lbs), as illustrated in **Figure** 5.7. The truck powers ranged from a minimum of 150 kW (200 hp) to a maximum of 450 kW (600 hp) with the majority of trucks falling in the 260 kW (350 hp) to 415 kW (550 hp) range (82 percent of the truck sample). The average truck power was 325 kW (435 hp) with a standard deviation of 55 kW (70 hp). Consequently, the 95% confidence limits ranged from 225 kW (300hp) to a 430 kW (575hp). The weight-to-power ratio for the sample ranged from a minimum of 25 kg/kW (44 lb/hp) to a maximum of 150 kg/kW (240 lb/hp) with a mean of 80 kg/kW (130 lb/hp) and a standard deviation of 25 kg/kW (45 lb/hp). Consequently, the 95% confidence limits ranged from approximately 30 to 130 kg/kW (40 to 220 lb/hp).

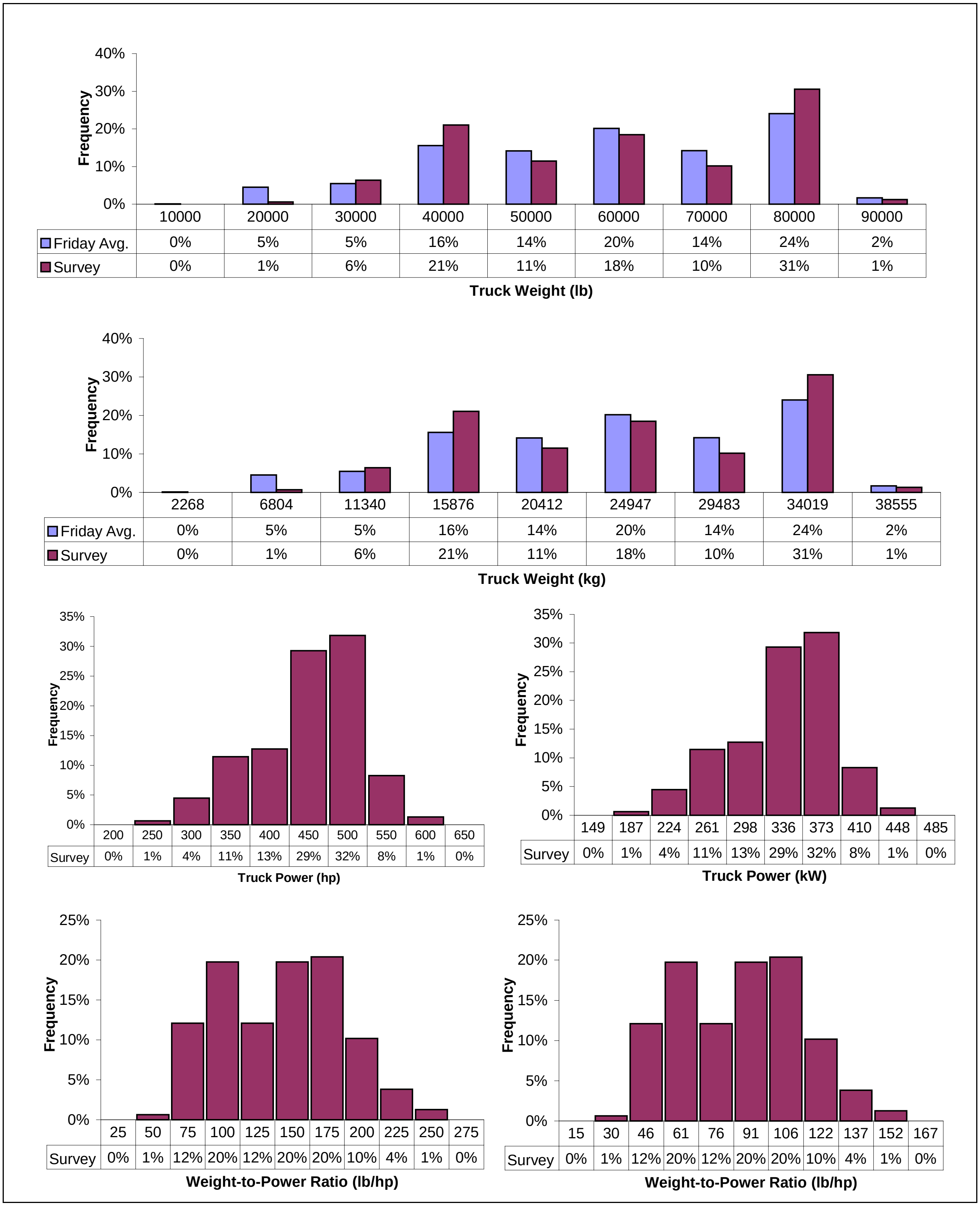


Figure 5:7: Truck characterization at I-81 Troutville weigh station

5.4 MODEL CALIBRATION

Having characterized the trucks along typical I-81, the next step was to calibrate the proposed enhanced model parameters for trucks that travel along US highways. This section describes how the optimum speed was calibrated using four trucks with different weight configurations. The characteristics of the trucks are summarized in Table 5.1. Each of these four trucks was tested for at least 10 weight configurations along the Smart Road test facility, as summarized in Table 5.2. In addition, two of the trucks were tested without a trailer in order to cover the fairly low weight-to-power ratios that were observed in the field. The test scenarios covered a range of weight-to-power ratios from 24 kg/kW to 171 kg/kW (39 lb/hp to 282 lb/hp), weight ratios from 8373 kg (18460 lb) to 44806 kg (98780 lb), and both ranges cover data that were observed in the field. The truck powers ranged from a minimum of 260 kW (350 hp) to a maximum of 375 kW (500 hp), which does not cover the full range of the sample that was observed in the field but does cover a substantial range (85 percent of the field observations). It should also be noted that the trucks included engines that were developed by different engine manufacturers for different model years. All trucks were equipped with radial tires and all trucks were manual, which is consistent with the survey data that were gathered.

Table 5.1: Test truck characteristics

	260-kW (350-hp)	**320-kW (430-hp)**	**350-kW (470-hp)**	**375-kW (500-hp)**
Vehicle year	1990	1998	1997	1997
Engine manufacturer	Cummins	Detroit Diesel	Detroit Diesel	Detroit Diesel
Engine power	260	320	350	375
Engine RPM	2100	1800	2100	2100
Number of gears	9	10	10	10
Aerodynamic features	None	Full	Full	Full

The execution of the test runs was identical to what was described previously in Chapter 4 where drivers accelerated from a full stop at the maximum possible rate as they traveled along the test roadway. The model parameters were selected based on recommendations in Chapter 4 to reflect the characteristics of the trucks. Multiple repetitions were made for each weight-to-power ratio combination in order to ensure that the runs were not biased by a single observation. The test scenarios included a total of 42 weight-to-power combinations, as summarized in Table 5.1. For each scenario the system of two first-order ODEs was solved using a first-order Euler approximation that was presented earlier in Equations 4.13 and 4.14.

Table 5.2: Truck weight-to-power experimental design (kg/kW)

Load Configuration	Test Truck Breaking Power			
	260-kW (350-hp)	320-kW (430-hp)	350-kW (470-hp)	375-kW (500-hp)
No Trailer		27	24	
Trailer no load	87	64	64	61
Trailer 1 load	96	78	72	67
Trailer 2 loads	106	86	80	74
Trailer 3 loads	115	92	88	80
Trailer 4 loads	125	100	92	87
Trailer 5 loads	134	108	101	94
Trailer 6 loads	143	112	106	100
Trailer 7 loads	153	121	112	107
Trailer 8 loads	162	127	118	114
Trailer 9 loads	171	134	126	120

The estimation of the optimum speed for each weight-to-power scenario was computed by solving a constrained non-linear optimization problem, as demonstrated in Equation 5.5. The objective function is to minimize the sum of squared error between the estimated and observed speeds for each observation j. The constraints ensure that the estimated speeds and distances traveled satisfy the system of first-order ODEs in addition to the non-negativity constraints.

$$\begin{aligned} \min \quad & E = \sum_{j=1}^{n} \left(\tilde{v}_{x_j} - v_{x_j} \right)^2 \\ \text{S.T.} \quad & \tilde{v}(t_i) = \tilde{v}(t_{i-1}) + \tilde{a}(t_{i-1})\Delta t \\ & \tilde{x}(t_i) = \tilde{x}(t_{i-1}) + \tilde{v}(t_{i-1})\Delta t \\ & \tilde{x}(t_i), \tilde{v}(t_i) \geq 0 \end{aligned} \qquad (5.5)$$

Where:

v_{x_j} Observed speed at the distance location of observation j

$\tilde{v}_{x_j}$ Estimated speed at the distance location of observation j

The calibrated optimum speed was found to decrease as a function of the weight-to-power ratio in a consistent fashion for the various trucks, as illustrated in **Figure** 5.4. A regression model was fit to the 42 observations to generate the relationship between the optimum speed and the weight-to-power ratio, as indicated in Equation 5.4.

Figure 5.8 and **Figure** 5.9 illustrate for the same sample runs the model predicted truck speed profile based on the constant power and variable power vehicle dynamic models. In addition, Table 5.3 and Table 5.4 summarize the solution of the ODE system for the sample nine and single load configurations by applying the variable vehicle dynamic model for the first 10 seconds of the trip.

Solutions for the same truck using the constant power vehicle dynamics model was provided earlier in Chapter 4. The results for both models for all load configurations and all trucks are given in Appendix B.

Comparing **Figure** 5.8 and **Figure** 5.9 clearly demonstrates an improvement in vehicle speed predictions as a result of introducing the variable power concept. Findings are observed for the other 40 weight-to-power combinations that were tested, as illustrated in Appendix B.

Table 5.3: Example solution to ODE (9-Load Configuration)

T	S	V	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	39165	0.0596	0.0	2512.8	26200.1	28712.9
1	0.00	0.00	0.23	39165	0.0596	0.0	2512.8	26200.1	28712.9
2	0.00	0.84	0.23	39165	0.0596	0.3	2527.9	26200.1	28728.3
3	0.23	1.68	0.23	39165	0.0596	1.1	2543.0	26200.5	28744.5
4	0.70	2.52	0.23	39165	0.0596	2.4	2558.1	26201.2	28761.6
5	1.40	3.35	0.23	39165	0.0596	4.2	2573.1	26202.1	28779.5
6	2.33	4.19	0.23	39165	0.0596	6.6	2588.2	26203.4	28798.2
7	3.49	5.02	0.23	39165	0.0596	9.4	2603.2	26205.0	28817.6
8	4.89	5.85	0.23	39165	0.0596	12.8	2618.2	26206.9	28837.8
9	6.51	6.68	0.23	39165	0.0596	16.7	2633.1	26208.9	28858.7
10	8.37	7.51	0.23	39165	0.0597	21.1	2648.0	26211.2	28880.3

Table 5.4: Example solution to ODE (1-Load Configuration)

T	S	V	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	24736	0.0596	0.0	1408.8	14688.8	16097.6
1	0.00	0.00	0.34	24736	0.0596	0.0	1408.8	14688.8	16097.6
2	0.00	1.24	0.34	24736	0.0596	0.6	1421.3	14688.8	16110.7
3	0.34	2.47	0.34	24736	0.0596	2.3	1433.7	14689.1	16125.2
4	1.03	3.71	0.34	24736	0.0596	5.1	1446.2	14689.7	16141.0
5	2.06	4.94	0.34	24736	0.0596	9.1	1458.6	14690.5	16158.3
6	3.43	6.17	0.34	24736	0.0596	14.3	1471.1	14691.5	16176.9
7	5.15	7.40	0.34	24736	0.0596	20.5	1483.5	14692.8	16196.7
8	7.20	8.62	0.34	24736	0.0597	27.8	1495.8	14694.2	16217.9
9	9.60	9.84	0.34	24736	0.0597	36.3	1508.1	14695.8	16240.2
10	12.33	11.06	0.34	24736	0.0597	45.8	1520.4	14697.5	16263.7

Additionally, a Matlab computer program was used to estimate optimum vehicle speeds and the error in speed along the test section traveled for both models that are already demonstrated. Program makes best fit for observed data using polynomial function and Figures for sample speed profiles are given with **Figure** 5.10. Error in speed difference along test section was computed for each meter and curves for sample speed profiles for observed data and both models are shown with **Figure** 5.11. Optimum vehicle speeds are summarized in Table 5.5 and code for a sample 260 kW (350 hp) truck with no loads is given in Appendix C. **Figure** 5.12 illustrates comparison of error in speeds versus distance traveled for both models and for sample runs already mentioned. Figures with error curves for all load configurations are shown in Appendix C. Mean square errors were computed and summarized for both models in Table 5.6 and Table 5.7. These tables show that variable power vehicle dynamic model gives much better results than using constant power vehicle dynamic model.

Figure 5.13 and **Figure** 5.14 illustrate for the truck runs without trailer estimating the truck speed profile using both models constant power vehicle dynamic model and variable power vehicle dynamic model and for truck with 350 kW (470 hp). Computed mean square errors for these two cases and for both models are bigger comparing with other load configurations. Reason for that problem for constant vehicle dynamics model lie in the first 200 m (656 ft) where gearshift was problem to accelerate more in order to produce higher speed and looking at curves generated from both models. The last 300 m

(984 ft) shows overestimating and reason for that is safety. At the end of the test section there is a loop and trucks produced very high speed that was not possible to stop safely. Drivers reduced the speed before the end of the section.

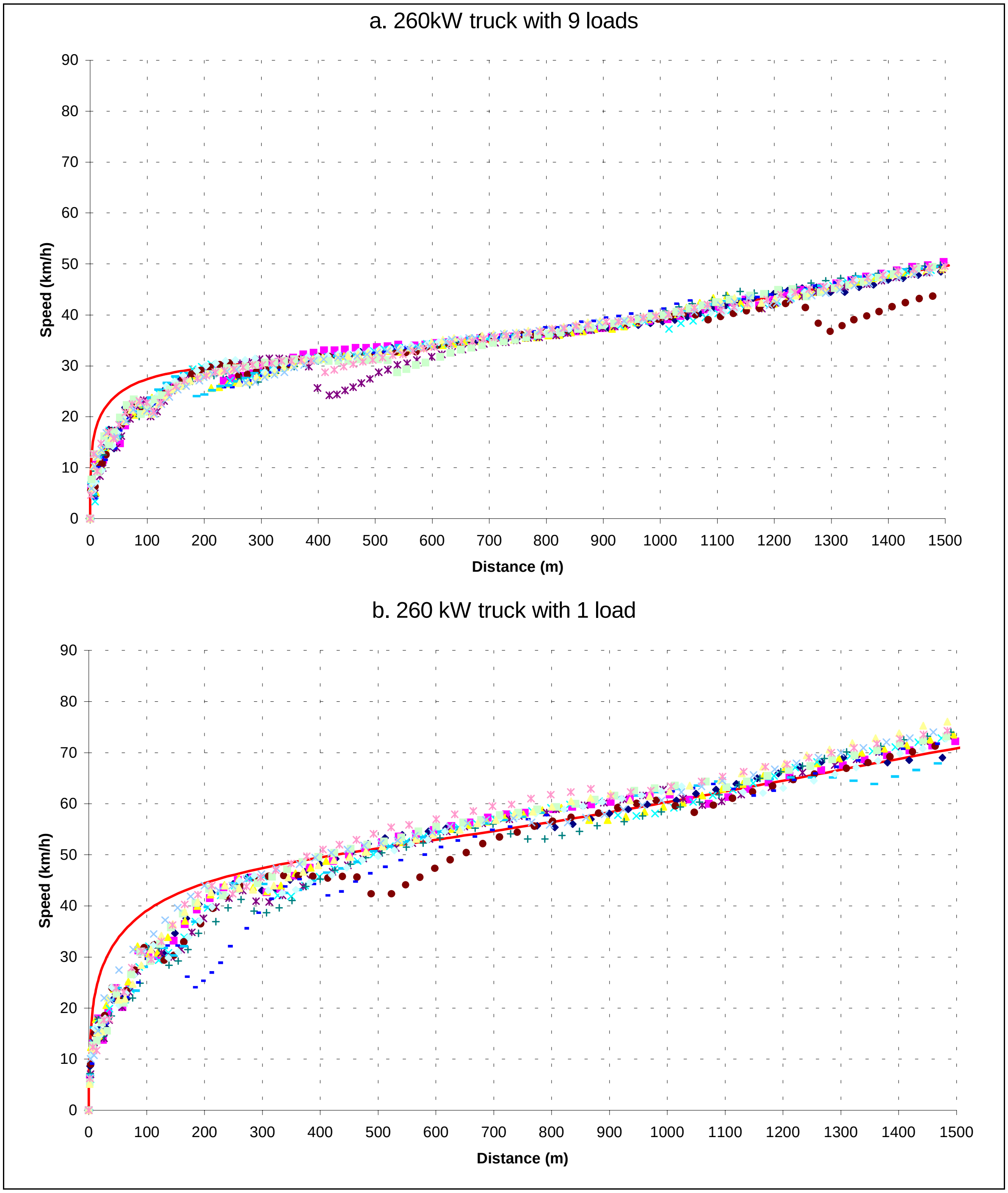


Figure 5.8: Sample speed profile validation using the constant power model (NTC-350 engine)

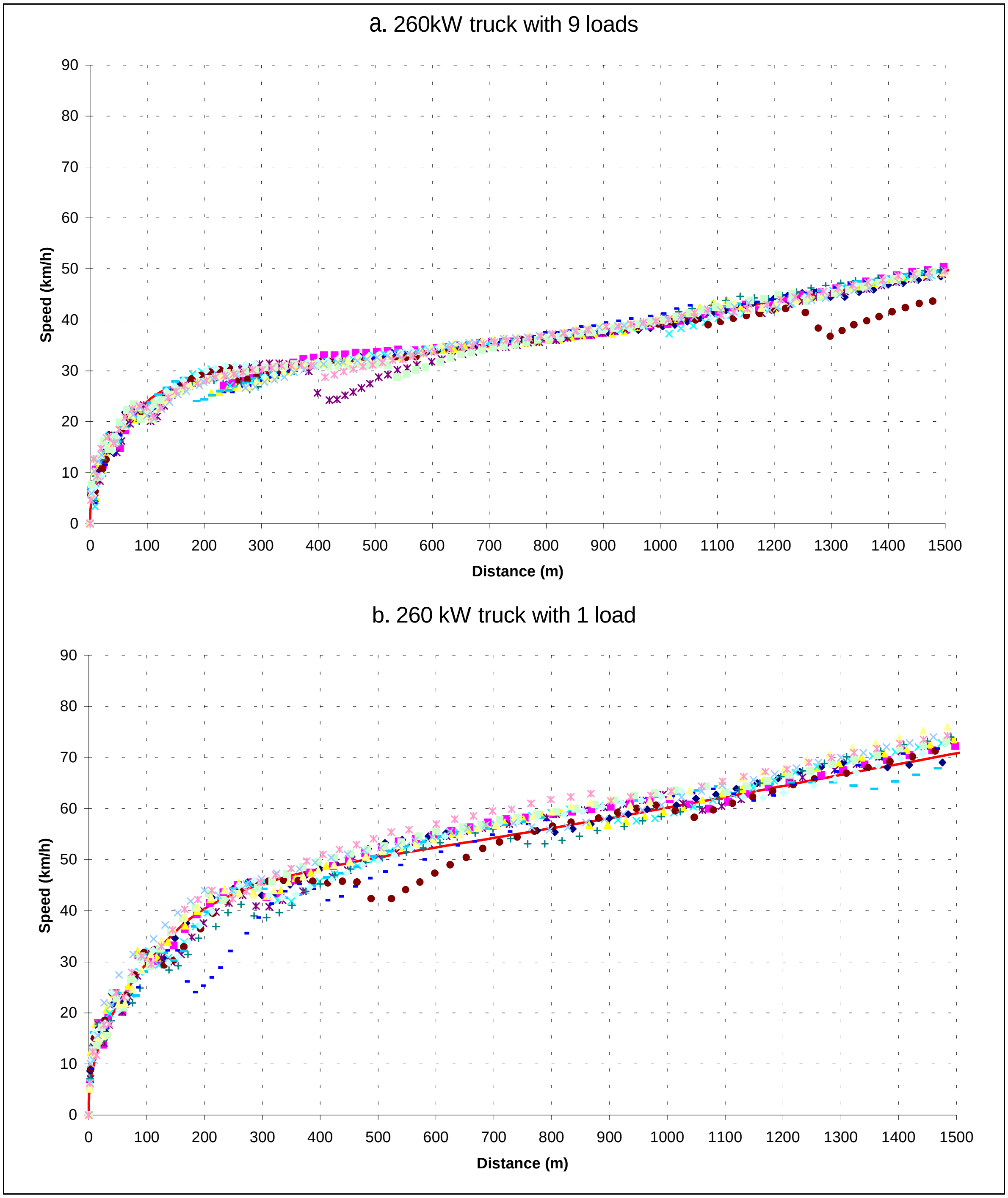


Figure 5.9: Sample speed profile validation using the variable power model (NTC-350 engine)

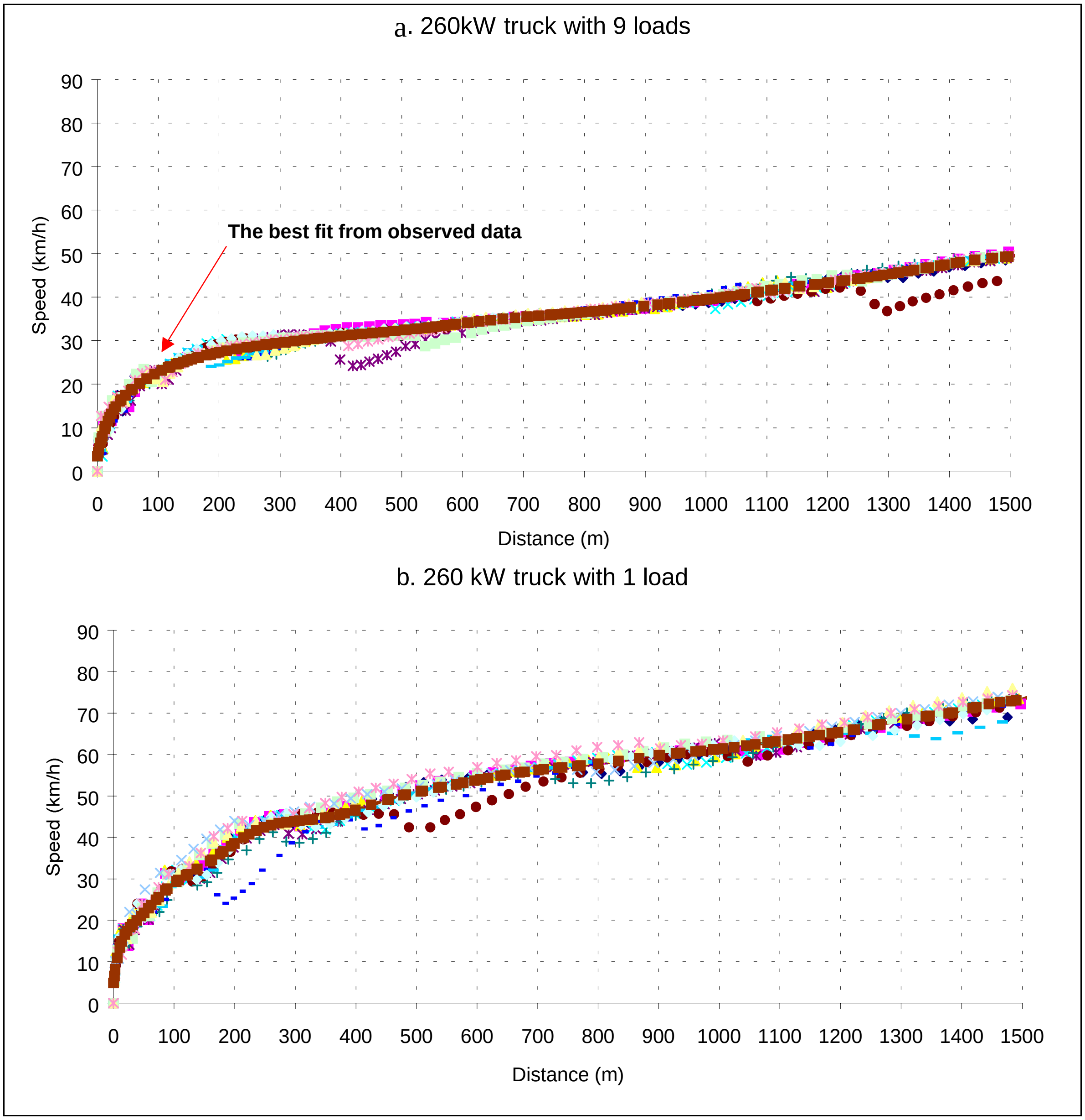


Figure 5.10: Sample speed profile with the best fit used for error computing (NTC-350 engine)

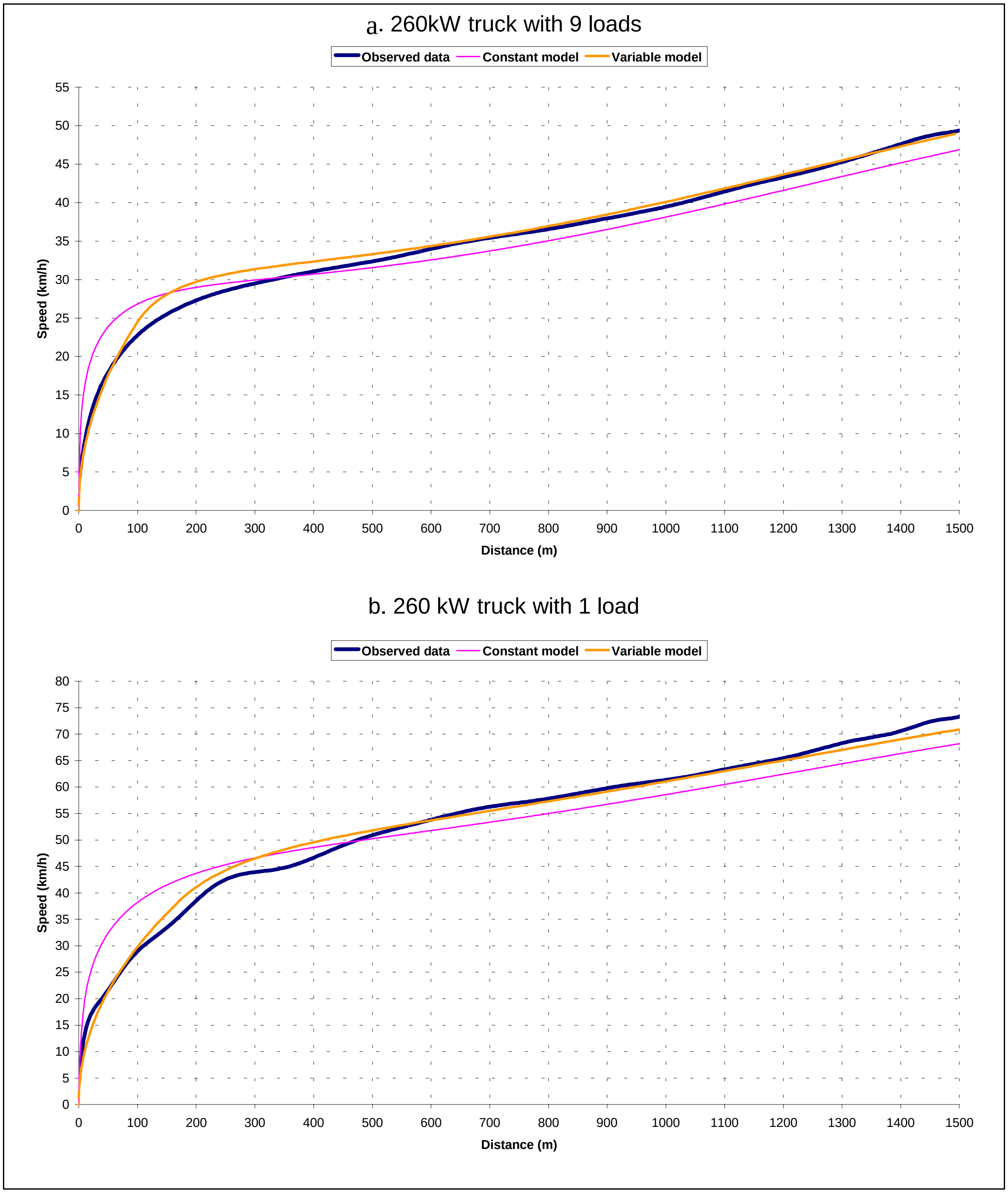


Figure 5.11: Sample speed profile comparing observed data with both models (NTC-350 engine)

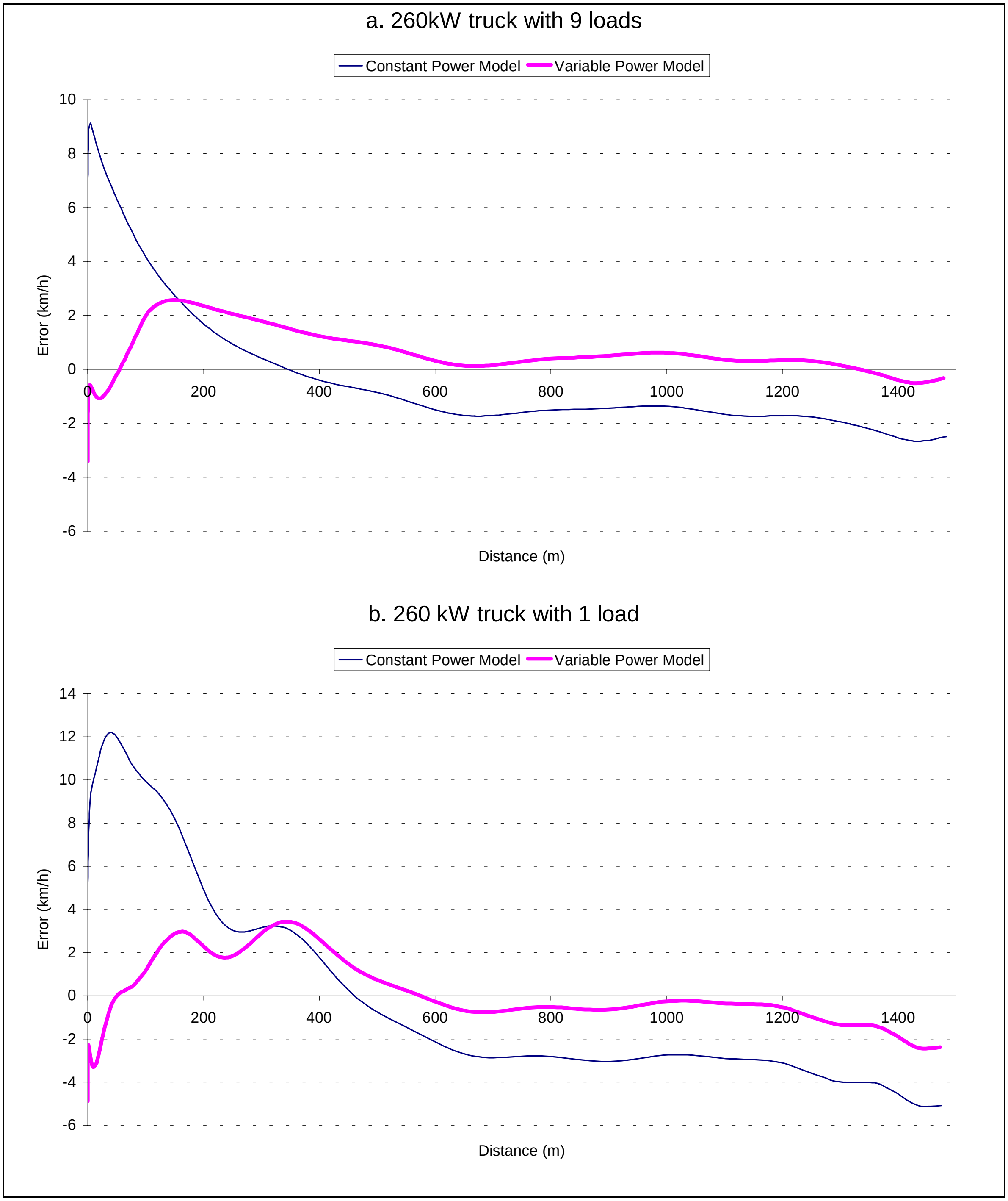


Figure 5.12: Comparison of error versus distance traveled for constant and variable power vehicle dynamic models

Table 5.5: Computed optimum speeds for different trucks and load configurations

Load	260 kW (350hp) Truck		320 kW (430hp) Truck		350 kW (470hp) Truck		375 kW (500hp) Truck	
	W/P (kg/kW)	u0 (km/h)	W/P (kg/kW)	u0 (km/h)	W/P (kg/kW)	u0 (km/h)	W/P (kg/kW)	u0 (km/h)
	-	-	44	100	39	110	-	-
0	143	42	106	51	105	49	100	50
1	158	38	128	43	119	48	111	48
2	174	36	141	41	132	44	122	45
3	189	33	151	40	144	42	132	42
4	205	30	164	37	152	40	143	41
5	220	29	177	35	166	37	154	39
6	236	27	185	33	175	36	165	37
7	251	25	199	32	185	35	176	36
8	267	25	209	31	194	35	187	33
9	282	24	220	31	208	33	198	32

Table 5.6: Mean square errors for constant vehicle dynamic model

Load Configuration	Mean Square Error (km/h)			
	260-kW (350-hp)	320-kW (430-hp)	350-kW (470-hp)	375-kW (500-hp)
No Trailer	-	329.1	266.7	-
Trailer no load	35.3	52.1	43.8	46.6
Trailer 1 load	26.4	34.9	41.5	47.0
Trailer 2 loads	30.6	31.0	30.9	37.7
Trailer 3 loads	20.6	30.1	32.2	31.8
Trailer 4 loads	13.8	24.9	28.0	31.9
Trailer 5 loads	14.7	25.2	21.8	36.7
Trailer 6 loads	8.4	16.2	19.7	28.8
Trailer 7 loads	8.3	14.8	19.7	22.3
Trailer 8 loads	9.2	43.3	24.0	20.5
Trailer 9 loads	7.8	17.3	21.1	20.1

Table 5.7: Mean square errors for variable vehicle dynamic model

Load Configuration	Mean Square Error (km/h)			
	260-kW (350-hp)	320-kW (430-hp)	350-kW (470-hp)	375-kW (500-hp)
No Trailer	-	42.5	25.3	-
Trailer no load	4.4	8.7	7.4	5.0
Trailer 1 load	3.3	3.5	5.7	4.2
Trailer 2 loads	4.8	3.0	6.8	2.9
Trailer 3 loads	2.0	2.6	5.8	3.1
Trailer 4 loads	1.5	2.4	8.4	3.5
Trailer 5 loads	1.7	2.1	6.6	2.9
Trailer 6 loads	2.6	1.6	13.1	2.9
Trailer 7 loads	2.5	2.9	10.6	1.6
Trailer 8 loads	1.0	25.4	34.4	4.3
Trailer 9 loads	1.4	7.6	25.3	3.5

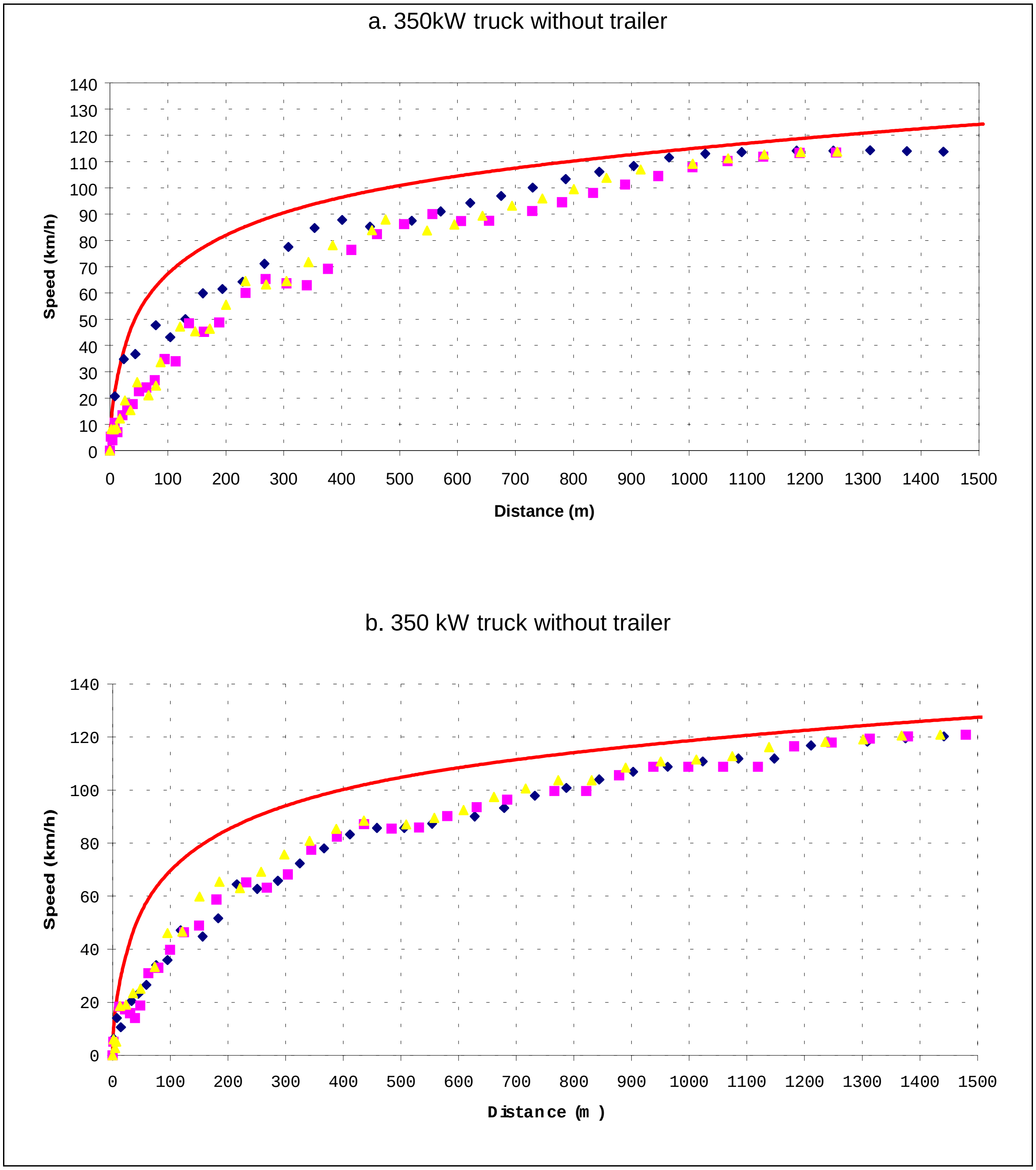
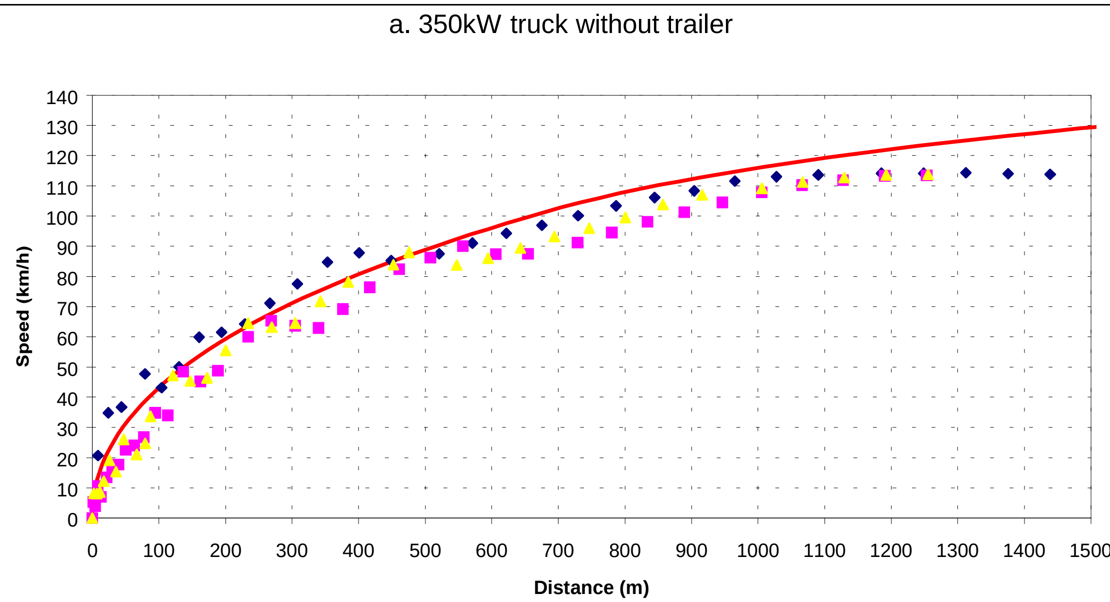


Figure 5.13: Sample speed profile validation using the constant power model (470 hp engine)



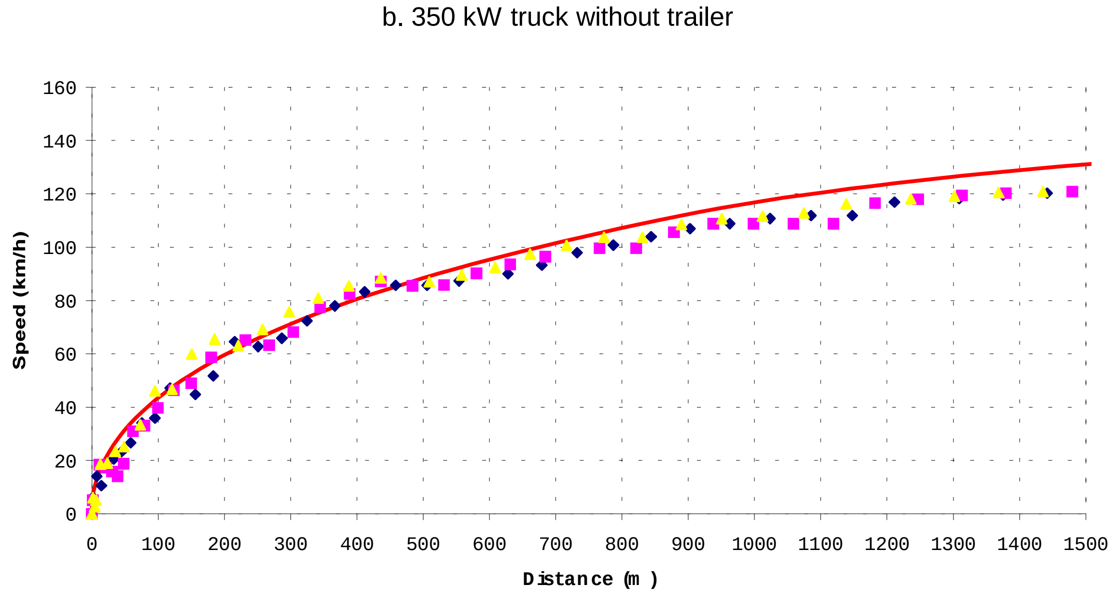


Figure 5.14: Sample speed profile validation using the variable power model (470 hp engine)

Variable power vehicle dynamics model has better results than basic vehicle dynamics model and performance curves for sample 261 kW (350 hp) truck should be updated. **Figure** 5.15 illustrates acceleration and deceleration performance curves for design truck with weight-to-power ratio of 120 kg/kW (200 lb/hp) comparing HCM curves and those generated from the model. Figure clearly demonstrates difference between HCM curves and curves from the model. Differences in equilibrium speeds are in a range of 12 km/h.

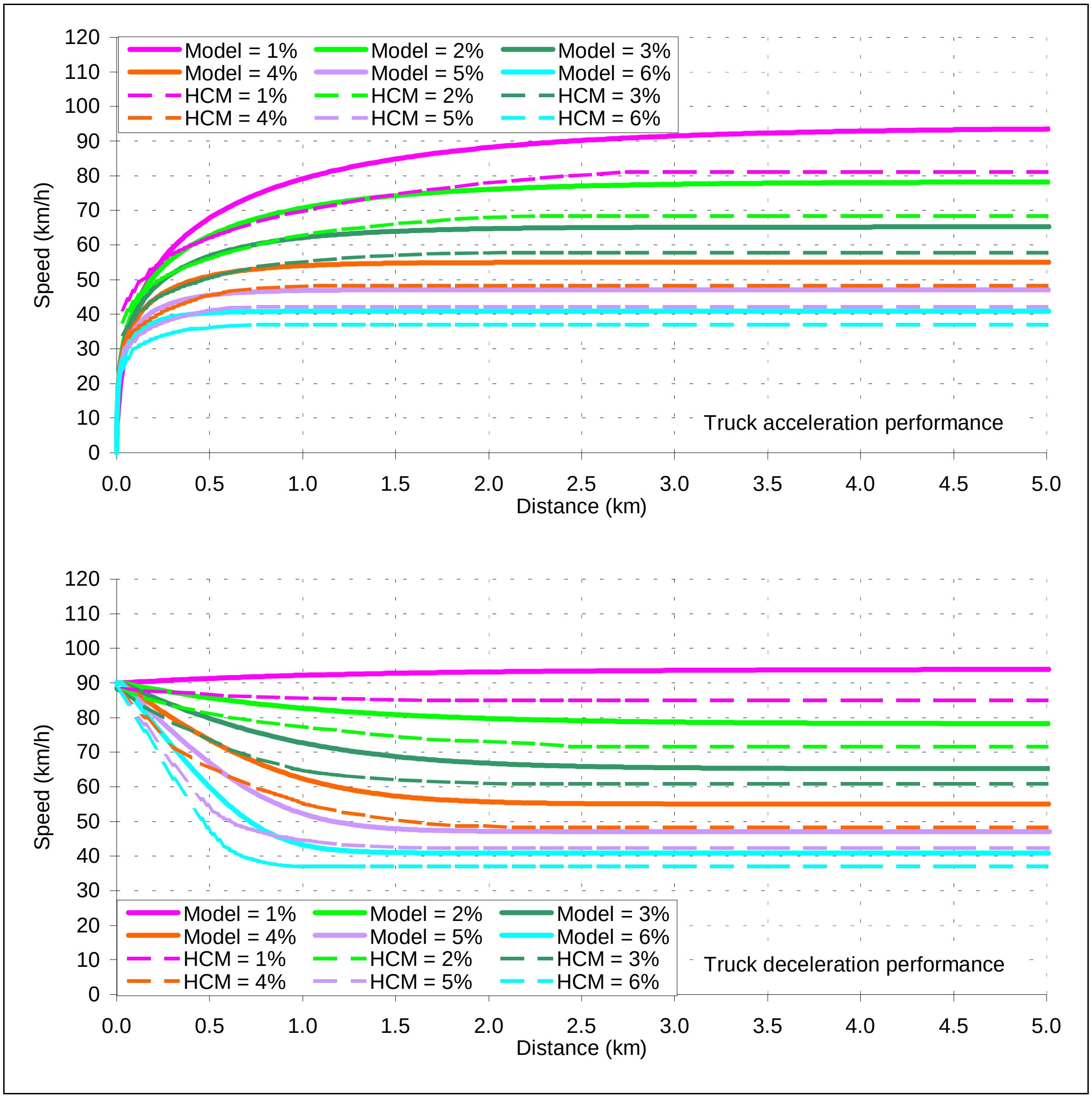


Figure 5.15: Truck performance curves for NTC-350 engine (200 lb/hp)

5.5 CONCLUSION

In summary, the chapter introduced the concept of a linearly increasing variable power to the basic vehicle dynamics model. The chapter also presented calibration of the model to typical trucks that travel along interstate highways in the US. The proposed enhancement resulted in significant improvements in vehicle performance curves especially at low speeds when vehicles are engaged in gearshifts. Computed errors for both presented models show that variable power vehicle dynamics model has much better results. Table 5.8 summarizes percentage in error difference for these two models. The truck power of 350 kW (470 hp) had general problem with gearshift and that is reason for lower difference than for other trucks. The biggest problem was utilizing truck with 8 and 9 load configurations.

Table 5.8: Difference in error computed for both models

Load Configuration	**Error difference in percent**			
	260-kW (350-hp)	**320-kW (430-hp)**	**350-kW (470-hp)**	**375-kW (500-hp)**
No Trailer	-	87.1	90.5	-
Trailer no load	87.5	83.3	83.1	89.3
Trailer 1 load	87.5	90.0	86.3	91.1
Trailer 2 loads	84.3	90.3	78.0	92.3
Trailer 3 loads	90.3	91.4	82.0	90.3
Trailer 4 loads	89.1	90.4	70.0	89.0
Trailer 5 loads	88.4	91.7	69.7	92.1
Trailer 6 loads	69.0	90.1	33.5	89.9
Trailer 7 loads	69.9	80.4	46.2	92.8
Trailer 8 loads	89.1	41.3	-43.3	79.0
Trailer 9 loads	82.1	56.1	-19.9	82.6

CHAPTER 6: CONCLUSIONS AND RECCOMENDATION

The thesis attempted to develop models that can be utilized to quantify the impact of trucks on roadway operations. A first step in developing these models was to characterize the trucks that travel on US interstate highways. Next, the thesis introduced the concept of a linearly increasing power to the basic vehicle dynamics model that has been proposed in the literature. The proposed enhancement was found to produce significant improvements in the state-of-the-art vehicle dynamic model especially at low speeds when vehicles engage in gearshifts. This chapter summarizes the main contributions, findings, and conclusions of the thesis. In addition, recommendations for further research are presented.

6.1 PROBLEM OVERVIEW

Heavy vehicles play an important role in ground transportation in the US. They have significant impacts on traffic, because of their characteristics, size, weights, and ability to accelerate/decelerate. The percentage of trucks on US interstate highways is significant. For example, on I–81 approximately 40% of the average daily traffic are trucks. Truck performance along grade sections may have significant impacts on roadway throughput depending on the grade level, the truck characteristics, the percentage of trucks, and the level of congestion along the roadway section. Every year truck technology has some innovations and their characterization and classification on US roads is essential.

The HCM provides curves for predicting vehicle speeds as a function of the distance traveled and the percentage grade along the section (TRB, 1997), these curves were developed several decades ago and thus may not be representative of current trucks. Furthermore, the curves do not capture the effect of other factors on vehicle performance like for example the availability of aerodynamic aids and the type of pavement

6.2 THESIS SUMMARY

State-of-the-art vehicle dynamics models were validated along the Smart Road test facility for typical truck characteristics. It was found that these models overestimated vehicle speeds at low speeds and typically under-estimated the vehicle speeds at the high speeds. The test runs involved accelerating at the maximum possible acceleration rate from a complete stop at the start of the test section. The acceleration continued until the end of the test section, over the entire 1.5-km (0.9-mi) section. Four trucks were utilized with a trailer for 10 weight-to-power configurations. The proposed dynamics model was applied by setting the model parameters to reflect the truck, trailer, altitude, tire, and pavement conditions. Values for these parameters were obtained from the manufacturer's specifications or from the literature (SAE J2188, 1996; Fitch, 1994).

The calibration of the model require calibrating a single parameter which was conducted using four trucks with ten weight configurations resulting in a total of 42 weigh-to-power configurations.

6.3 THESIS CONTRIBUTIONS

The thesis makes four significant contributions, which are the follows:

1. The thesis attempts to characterize trucks traveling along US highways by analyzing data from Interstate 81. I-81 is a typical of US highways and thus can provide some insight into typical truck characteristics. These truck characteristics are important for the development of an exhaustive vehicle performance procedure.

2. The thesis collects a database of systematic field data that can be utilized for the validation of vehicle performance models. This database is unique because it was conducted in a controlled field environment where the vehicle is only constrained by its dynamics.

3. The thesis validates a state-of-the-art constant power vehicle dynamics model that has been presented in the literature using field data that were collected along the Smart Road test facility. In addition the thesis identifies typical input parameters and validates these parameters against field measurements.

4. The thesis extends the vehicle dynamics model by introducing the concept of variable power in order to capture the buildup of power as the vehicle engages in gearshifts. The proposed enhancement results in a significant enhancement to the current state-of-the-art vehicle dynamics model.

6.4 THESIS CONCLUSIONS

Data analysis of the truck data on the I-81 corridor indicated that the majority of trucks could be classified as vehicle class 9 (84.3% in 1998, 91.2% in 1999, and 86.6% in 2000 year). The heaviest day-of-week demand occurred on Thursdays and Wednesdays for both directions of travel (between 12% and 20% of total demand). The frequency distribution of weights was not found to follow either a normal or log-normal distribution.

The single day survey indicated that the average vehicle mass was 35380 kg (77836 lb), the most frequent engine power ranged from 335 kW (450 hp) to 375 kW (500 hp), and the weight-to-power ration ranged from 55 kW/kg (90 lb/hp) to 115 kW/kg (190 lb/hp).

In terms of validating the vehicle dynamic model, the following conclusions can be made:

1. The model parameters that are suggested in the literature and summarized in Chapter 4 are consistent with field measurements.
2. The use of a constant transmission efficiency results in an over-estimation of vehicle speeds at low speeds and an under-estimation at high speeds.

3. The proposed linear power relationship provides a good fit to field data over the full range of vehicle speeds (error less than 10%).

6.5 FUTURE RESEARCH

It is recommended that further research be conducted in calibrating similar power relationships for other vehicle classes including automobiles, buses, and smaller trucks. As in any research effort, further investigations are required to better establish the accuracy of the proposed models. These investigations will include:

1. Conduct similar field tests to establish the sensitivity of truck performance to type of pavement, to pavement condition, to type of vehicle tires, and to percentage weight on the tractive axle;
2. It is recommended that further research be conducted in calibrating similar power relationships for other vehicle classes including automobiles, buses, and smaller trucks;
3. Develop curves similar to the HCM curves that reflect grade, truck, pavement, and tire conditions; and
4. Incorporate the proposed model within a microscopic simulation software to evaluate the impact of trucks on system throughput for different roadway, traffic, and pavement characteristics.

REFERENCES

1. Archilla A. R. and De Cieza A. O. F., ‘Truck Performance on Argentinean Highways’, Transportation Research Record, n 1555, Nov 1996, p 114-123
2. A.M. Khan, J. Y. Wong, and M. Rastogi, ‘Heavy Vehicle Performance on Grade and Climbing Lane Criteria’, Final Report of Research and Development Project
3. A.T. Papagiannakis, W. A. Phang, J. H. F. Woodrooffe, A. T. Bergan, and R. C. G. Hass, ‘Accuracy of Weigh-in-motion Scales and Piezoelectric Cables’, Transportation Research Record 1215, 1989
4. Bahman Izadmehr and Clyde E. Lee, ‘On-Site Calibration of Weigh-in-motion Systems’, Transportation Research Record n 1123, 1989, pp 136-144
5. Bahman Izadmehr and Clyde E. Lee, ‘Accuracy and Tolerances of Weigh-in-motion Systems’, Transportation Research Record 1123, 1989, pp 127-135
6. Barton, Raymond A. Morrall, John, ‘Study of long combination vehicles on two-lane highways’, Transportation Research Record. n 1613 Aug 1998. p 43-49
7. Bruce G. Hutchinson, ‘Large-Truck Properties and Highway Design Criteria’, Journal of Transportation Engineering, Vol. 116, No. 1, January, 1990
8. Chia-pei J. Chou and Chung-piau Ching, ‘Truck Load Distribution and Its Impacts on Vehicle Weight Regulations in Taiwan’, Transportation Research Record 1501, 1995
9. D. W. Lear, M. Bettison, and G. Kent, ‘Advances in Piezoelectric Axle Sensor Design’, Transport and Road Research Laboratory, V. 30, n. 1, Jan 1989
10. Edward S. K. Fekpe, ‘Characteristics of Heavy Vehicle Weight Distributions and Pavement Loading’, PhD Thesis, Department of Civil Engineering, University of Manitoba, Winnipeg, Canada, 1993
11. Edward S. K. Fekpe and A. M. Clayton, ‘Vehicle Clasification from Weigh-in-motion Data: The Progressive Sieving algorithm’, Canadian Journal of Civil Engineers 21, 1994, pp 195-206
12. Edward S. K. Fekpe, ‘Utilisation of five- and six-axle Tractor Semitrailers in Western Canada’, Heavy Vehicle Systems, Vol. 4, No. 1, 1997.

13. Edward S. K. Fekpe, Alan M. Clayton, and Attahiru Sule Alfa, 'Aspects of Performance of Truck Weigh Stations', Canadian Journal of Civil Engineering 20, 1993, pp 380-385
14. Edward S. K. Fekpe and Alan Clayton, 'Prediction of Heavy-Vehicle Weight Distributions', Journal of Transportation Engineering, v121, n2, Mar-Apr 1995, pp 158-168
15. ERES Consultants and Fugro-Bre, 'Determination of Traffic Information and Data for Pavement Structural Design and Evaluation', National Cooperative Highway Research program, Transportation research Board, National Research Council, December, 1999
16. ERES Consultants and Fugro-Bre, 'Traffic Input Guide', National Cooperative Highway Research program, Transportation research Board, National Research Council, January, 2000
17. Fitch J. W., 'Motor Truck Engineering Handbook', Society of Automotive Engineers, 4th Edition, 1994
18. Highway Capacity Manual, Special Report 209, National Research Council, Transportation Research Board, Washington, D. C., 3rd Edition, Revised, 1997
19. James York and Tom Maze, 'Applicability Of Performance-Based Standards To Truck Size and Weight Regulation in The United States', Road Transport Technology, 4: Proceedings of the Fourth International Symposium on Heavy Vehicle Weights and Dimensions, Ann Arbor, 1995, pp 137-142
20. Jose Reynaldo Setti and Sergio Henrique Demarchi, 'Assessing Heavy Vehicle Impacts on Operation of Rural At-Grade Intersections in Brazil', Transportation Research Record 1555, pp 114-123, 1996
21. Koniditsiotis Chris, Buckmaster Rodney, and Fraser Peter, 'Australian High Speed Weigh-in-motion an Overview', Road Transport Technology, 4: Proceedings of the Fourth International Symposium on Heavy Vehicle Weights and Dimensions, Ann Arbor, 1995, pp 143-151
22. Lily Elefteriadou, Darren Torbic, and Nathan Webster, 'Development of Passenger Car Equivalents for Freeways, Two-Lane Highways, and Arterials', Transportation Research Record 1572, Nov 1996.

23. Mannering F. L. and Kilareski W. P., ‘Principles of Highway Engineering and Traffic Analysis’, John Wiley & Sons, 1990
24. Nicholas J. Garber and Lester A. Hoel, ‘Traffic and Highway Engineering’, PWS Publishing Company, Second Edition, 1997
25. OECD Road Research Group, report, ‘Impacts of Heavy Freight Vehicles’, Road Research, Organization for Economic Co-Operation and Development, December, 1982
26. Paul S. Fancher, Jr. and Thomas D. Gillespie, Ph.D., ‘Truck Operating Characteristics‘, Transportation Research Board, 1997.
27. Peter Davies and Fraser Sommerville, ‘Calibration and Accuracy Testing of Weigh-in-motion Systems’, Transportation Research Record 1123, 1987, pp 122-126
28. Raymond A. Barton and John Morrall, ‘Study of Long Combination Vehicles on Two-Lane Highways’, Transportation Research Board n 1613
29. R. C. Moore, B. G. Stoneman, and J. Prudhoe, ‘Vehicle Weight Measurements: Weigh-in-Motion Equipment Trials’, Transport and Road Research Laboratory, V. 30, n. 1, Jan 1989
30. Rob Harrison, Luis A. Sanchez-Ruiz, and Clyde E. Lee, ‘Truck Traffic Crossing Texas-Mexico Border’, Transportation Research Record 1643, 1998
31. Roess, R.P.; Messer, C.J. (1984) ‘Passenger Car Equivalents for Uninterrupted Flow: Revision of Circular 212 Values’. Transportation Research Record 971, p. 7-13.
32. SAE Procedure J2188, ‘Commercial Truck and Bus SAE Recommended Procedure for Vehicle Performance Prediction and Charting’, Society of Automotive Engineers, Warrendale, PA, 1996
33. St. John, A.D.; Kobett, D.R., ‘Grade Effects on Traffic Flow Stability and Capacity NCHRP 185’, Midwest Research Institute, Kansas City, Missouri. Transportation Research Board, Washington, D.C., 1978
34. S. M. Karamihas and T. D. Gillespie, ‘Characterizing Trucks for Dynamic Load Prediction’, Heavy Vehicle Systems, Vol. 1, No. 1, 1993.

35. S. Demarchi, H. Rakha, M. Van Aerde, and J. R. Setti, ‘Modeling Truck Dynamics Using a Second-Order Motion Model’, unpublished paper, 1996
36. T. F. Fwa and S. Li, ‘Estimation of Lane Distribution of Truck Traffic for Pavement Design’, Journal of Transportation Engineering, Vol. 121, No. 3, May/June, 1995.
37. T. F. Fwa, B. W. Ang, and T. N. Goh, ‘Characteristics of Truck Traffic in Singapore’, Journal of Advanced Transportation, Vol. 30, No. 2, pp. 25-46, September, 1994.
38. Trimble, Placer TM GPS 450/455, ‘Instalation and Operations Manual’, Trimble, Navigation Limited, Sunnyvale, CA, December, 1996
39. Shie-Shin Wu, ‘Procedure to Estimate Loading From Weigh-in-motion Data’, Transportation Research Record 1536, 1996, pp 19-24
40. Satish C. Sharma, George Stamatinos, and John Wyatt, ‘Evaluation of IRD-WIM-5000 – a Canadian weigh-in-motion system’, Canadian Journal of Civil Engineers 17, 1990, pp 514-520
41. Xun Zhi, Ahmed Shalaby, Dan Middleton, and Alan Clayton, ‘Evaluation of Weigh-in-motion in Manitoba’, Canadian Journal of Civil Engineering 26, 1999, pp 655-666
42. Watanada T. et al., ‘The Highway Design and Maintenance Standard Model’, v1, Description of the HDM-III Model, John Hopkins University, Baltimore, 1987

APPENDIX A

Figure A.1: Survey questioner

Survey

Surveyor __________ Day ______________

Time __________

Direction ☐ NB ☐ SB

Truck Information:

Make ☐ Volvo ☐ Kenworth ☐ Mack ☐ PeterBilt ☐ International

Cab location ☐ Over Engine ☐ Conventional

Model ______________ Year _____________

License Plate Information:

State ______________ Number _____________

Engine Information:

Manufacturer ☐ Cummins ☐ Detroit Diesel ☐ Volvo ☐ Other

HP ______________ RPM _____________

Model ______________ Serial # _____________

Transmission Information:

Number of gears _______________ ☐ Manual

Direct (through transmission) ☐ ☐ Automatic

Indirect (single transmission) ☐

Double Indirect (auxiliary transmission) ☐

Tire Information:

☐ Bias Ply ☐ Radial

Observations:

____

____

____

____

____

____

Aerodynamic Feature:

No aerodynamic aids ☐

Aerodynamic aids ☐

Full aerodynamic aids ☐

Table A.1: Survey data

		Static Mass (lb)				Truck Information					Engine Information				Transmission Information		Tire Information	
Truck	**Class**	**Total**	**Axle 1**	**Axle 2**	**Axle 3**	**Make**	**Cab**	**Year**	**State**	**Plate #**	**Manufacturer**	**HP**	**RPM**	**# gears**	**M/A**	**D/I/DI**	**B/R**	**AF**
1	9	54900	11320	20300	23280	Volvo	Conventional	1998	IL	P343321	Detroit Diesel	500	2100	super 10	M	DI	R	FA
2	9	32520	8440	14080	10000	Mack	Conventional	1989	VA	15375	Mack	350	1800	9	M	D	R	NA
3	9	65780	10520	28280	26980	Freightliner	Conventional	2000	MO	79517	Detroit Diesel	500	3000	10	M		R	FA
4	9	76760	12020	30800	33940	Ford	Conventional	1998	OK	INZ625	Cat	400	2000	10	M	D	R	FA
5	9	50240	10840	22680	16720	Kenworth	Conventional	1992	NJ	AC705M		450	1800	13	M		R	NA
6	9	38740	11180	15500	12060	Freightliner	Conventional	1997	IL	P325050		430	1800	10	M	D	R	FA
7	11	70180	11380	18560	40240	Freightliner	Conventional	1997	IL	P201998		280	1750	7	M	D	R	FA
8	9	49520	11560	19880	18080	Kenworth	Conventional	1996	NY	PR7392	Cummins	435	1950	10	M	D	R	FA
9	5	20460	8160	12300	0	Freightliner	Conventional		VA	20398P	Cummins	280	3000	6	M	I	R	NA
10	9	75640	11660	32520	31460	Mack	Conventional		OK	IVB561	Mack	460	2100	13	M	D	R	FA
11	9	34000	10580	12940	10480	Freightliner	Conventional		MD	377F23	Detroit Diesel	500	2500	9	M	I	R	FA
12	6	50640	15580	35060	0	Ford	Conventional		VA	11951	Cummins	250	3500	8	M	D	R	NA
13	9	39840	10800	17080	11960	Mack	Conventional	2001	ID	AF1459	Mack	470	2200	10	A		R	FA
14	9	34560	11660	13000	9900	Kenworth	Conventional	2000	TN	45244HY	Cat	500	2100	10	M		R	FA
15	9	71300	11300	28780	31220	Western Star	Conventional		PA	AE26719	Cat	435	1650	9	M	D	R	PA
16	11	51680	10620	12360	28700	International	Conventional	1999	OK	TX110	Cummins	370	1600	10	M	D	R	PA
17	8	33060	9300	12140	11620	Freightliner	Over Engine	1989	NC	LC1074	Detroit Diesel	350	2100	9	M	D	R	PA
18	9	57460	11060	22340	24060	Freightliner	Conventional	1996	OR	PGH832	Cat	425	1500	10	M	D	R	PA
19	9	74660	11440	32460	30760	Freightliner	Conventional	1998	MO	50652	Detroit Diesel	470	1500	10	M	split	R	FA
20	11	79040	10640	32500	35900	Volvo	Conventional	1998	Brunswick	PRS175	Cummins	500	1750	13	M	DI	R	NA
21	9	37900	10240	17300	10360	Peterbilt	Conventional	2000	SC	P731278	Detroit Diesel	470	1900	10	M	DI	R	NA
22	9	39400	11300	17040	11060	Kenworth	Conventional	2000	NJ	AE322K	Cat	550	2120	18	M	DI	R	NA
23	9	78880	13220	33360	32300	Kenworth	Conventional	1997	PA	AE43644	Cat	550	1800	15	M	D	R	PA
24	9	27020	9720	9920	7380	Whitegmc	Conventional	1988	VA	72209	Cat	350	2100	9	M	D		NA
25	9	56820	11160	23640	22020	Freightliner	Over Engine	1994	IA	PS9707	Cummins	350	1600	10	M	I	R	NA
26	9	78600	10880	32060	35660	Peterbilt	Conventional	1999	NY	8203PB	Cat	425	1700	10	M	D	R	NA
27	9	75320	11200	31880	32240	International	Conventional		OR	PCX595	Cummins	370	1600	10	M			FA
28	9	32980	9580	14000	9400	Peterbilt	Conventional	2000	OR	PJP258	Cat	450	2000	10	M	D	R	NA
29	9	76860	11600	32580	32680	Kenworth	Conventional	1995	MD	234121		435	1800	15	M	DI	R	NA

Table A.1: Survey data (Continued)

30	9	75860	11920	31400	32540	Freightliner	Conventional	1999	OR	NWS621	Detroit Diesel	435	1800	10	M	D	R	FA
31	9	32380	11000	12700	8680	Kenworth	Conventional	1993	VA	87850	Cat	400		10	M	D	R	NA
32	11	61540	9460	14620	37460		Conventional	1993	IL	P230347	Mack	300	1500	9	M	DI	R	PA
33	11	69960	10920	17760	41280	International	Conventional	1999	OK	IRE218	Cummins	370	1600	10	M	D	R	PA
34	9	30840	10220	13360	7260	Kenworth	Conventional	1995	VA	12525	Cat	435	2000	15	M	DI	R	NA
35	5	32280	8760	13660	9860	International	Conventional	2000	GA	2859JS		195	2500	4	A		R	NA
36	9	53660	11480	21580	20600	Volvo	Conventional	1996	GA	C21587	Detroit Diesel	470	1700	8	M	D	R	PA
37	9	69740	11000	27920	30820	Volvo	Conventional	2000	VA	26185	Volvo	375	1550	10	M		R	PA
38	9	24680	8400	9260	7020	International	Conventional		IL	P47742		380	2000	10	M		R	NA
39	9	43920	9420	17960	16540	International	Conventional	1995	NC	LE1482	Detroit Diesel	300	1750	9	M	D	R	PA
40	9	77820	11420	34080	32320	Eagle	Conventional	1999	QC	L149951	Cummins	470	1750	18	M	D	R	NA
41	9	32000	9960	12140	9900	Freightliner	Over Engine	2000	OK	IPL983		400	3000	10	M	DI	R	NA
42	9	77520	12380	33620	31520	Kenworth	Conventional	1999	West VA	B69920	Cat	550	2100	10	M	D	R	NA
43	10	99620	11180	40160	48280	Peterbilt	Conventional	2000	IL	P346279	Cat	475	1800	18	M	D	R	NA
44	9	79360	12440	33360	33560	Kenworth	Conventional	1999	TX	R93011	Cat	550	1500	18	M	I	R	NA
45	9	30980	12180	17600	1200	International	Conventional	1999	VA	WT8007		300	2300	6	M	D	R	NA
46	9	51240	10760	24420	16060	Freightliner	Conventional	1998	NE	5820	Detroit Diesel	500	1700	10	M	D	R	FA
47	9	41980	11040	17520	13420	Freightliner	Conventional	1999	OR	PPL307	Detroit Diesel	335	1800	10	M	D	R	FA
48	9	74940	13380	28220	33340	Peterbilt	Conventional	1997	PA	AE82767	Cat	550	1850	18	M	D	R	NA
49	9	46680	11200	19120	16360	Freightliner	Conventional		TN	11165HY	Detroit Diesel	430	1800	super 10	M		R	FA
50	6	55820	19100	36720	0		Over Engine	2000	VA	66742	Cummins	350		8	M	DI	R	NA
51	9	30620	10840	12240	7540	Kenworth	Conventional	1995	MD	253F47	Cummins	460	2200	10	M	D	R	NA
52	9	28600	7960	12680	7960	Kenworth	Conventional	2000	MD	402F98	Cummins	500	2000	13	M	D	R	NA
53	9	61980	10240	24860	26880	Eagle	Conventional	1998	Oversize		Cummins	460	1800	13	M	I	R	PA
54	9	45120	10960	20060	14100	Freightliner	Conventional	2000	IL	P246243	Detroit Diesel	470	1800	10	M	D	R	FA
55	9	34420	10560	14260	9600	Freightliner	Conventional	1997	TX	R1DT47	Detroit Diesel	430	1900	10	M	D	R	FA
56	9	72020	11280	28440	32300	Freightliner	Conventional	1999	OK	1RE674	Cummins	400		10	M	D	R	FA
57	9	46560	8400	19900	18260	Mack	Conventional	1989	VA	89510	Mack	300	1900	8	M	D	R	NA
58	9	74940	10860	31560	32520	Freightliner	Conventional	1998	IL	P312989	Detroit Diesel	430	2500	10	M	D	R	FA
59	9	25020	8580	9580	6860	International	Conventional	1995	IL	P143069	Cummins	300	2400	10	M	D	R	NA
60	11	63480	10600	15280	37600	Volvo	Conventional	1999	IL	P296929	Detroit Diesel	440	1600	9	M	D	R	NA

Table A.1: Survey data (Continued)

61	9	28540	11220	13420	3900	International	Over Engine	1993	VA	90759	Cummins	430	1950	10	M	D	R	PA
62	9	44960	10920	18020	16020	Freightliner	Conventional	1999	OR	P5P684	Detroit Diesel	500	2100	10	M	D	R	FA
63	9	56520	10300	27060	19160	Freightliner	Conventional	1997	OK	IVE039	Detroit Diesel	500	2200	10	M	D	R	FA
64	9	45140	10540	17080	17520	Kenworth	Conventional	1998	IL	P247421	Detroit Diesel	470	1800	10	M		R	FA
65	9	55440	10560	22400	22480	Kenworth	Over Engine	1991	SC	P729662	Cat	425	2250	9	M		R	NA
66	9	26500	10100	9860	6540	Ford	Conventional	1993	VA	64532	Cummins	300	1700	8	M	D	R	NA
67	9	33120	10380	13800	8940	International	Conventional	1998	VA	96164	Detroit Diesel	470	1800	10	M	D	R	FA
68	9	58920	11400	22380	25140	Freightliner	Conventional	2000	OK	1SZ611	Detroit Diesel	390	1500	10	M		R	FA
69	9	62980	11160	26160	25660	Freightliner	Conventional	1999	NJ	AD609L	Detroit Diesel	430	1700	10	M	D	R	FA
70	9	18880	9840	9040	0	Peterbilt	Conventional	1988	TN	03113HY	Cat	425	3000	15	M	DI	R	NA
71	9	33900	11360	13600	8940	Freightliner	Conventional	1999	UT	97331	Detroit Diesel	400	1500	10	A		R	FA
72	9	74660	11620	34440	28600	Freightliner	Over Engine	1984	NC	LJ7696	Cummins	400	2100	15	M	DI	R	NA
73	11	65300	10720	17900	36680	S	Conventional	1999	IL	P89706	Cummins	280	1650	10	M	DI	R	FA
74	9	32700	10420	12400	9880	Freightliner	Conventional	2001	NY	424117	Detroit Diesel	500	2000	10	M	DI	R	FA
75	9	70880	11020	28060	31800	Freightliner	Conventional	2000	PA	AE05658	Detroit Diesel	460	1200	9	M	D	R	FA
76	9	42740	10620	20920	11200	Freightliner	Conventional	2000	TN	10154HY	Detroit Diesel	460	1550	10	M	D	R	FA
77	9	72820	12820	30000	30000	Peterbilt	Conventional	1994	NJ	AC2058	Detroit Diesel	430	1800	9	M		R	NA
78	9	54320	9660	20100	24560	Freightliner	Conventional	1999	VA	85467	Detroit Diesel	400	1800	10	M	D	R	PA
79	9	30640	10640	11980	8020	Freightliner	Conventional	1998	NC	LE7553	Detroit Diesel	470	1800	10	M	D	R	NA
80	9	34500	10980	13020	10500	Volvo	Conventional		MI	RN7825	Detroit Diesel	500	2300	super 10	M		R	FA
81	9	53640	10240	20480	22920	Western Star	Conventional	1996	OK	1SP848	Cat	455	2100	15	M	DI	R	NA
82	9	28860	9780	12640	6440	Kenworth	Conventional	1998	WV	B66 696	Cat	550	2100	13	M	D	R	FA
83	9	61424	11420	25520	24484	Freightliner	Conventional	1999	IL	P20715	Detroit Diesel	370	1500	10	M		R	FA
84	9	38440	9340	17060	12040	Volvo	Conventional	2000	MD	403F61	Volvo	285	2200	12	M	D	R	FA
85	9	56060	11400	24240	20420	Peterbilt	Conventional	1997	IA	PU2708	Cat	500	2300	13	M	DI	R	NA
86	9	64620	11920	22860	29840	Kenworth	Conventional	1996	IN	151263	Cat	425	1900	13	M	DI	R	FA
87	9	70100	11280	28660	30160	Volvo	Conventional	2000	OK	1UZ770	Detroit Diesel	500	2200	13	M		R	FA
88	9	42920	9800	17220	15900	Freightliner	Conventional	1996	QC	LC75521	Cummins	330	2000	10	M		R	FA
89	9	75860	11640	31040	33180	Kenworth	Conventional	1999	TX	R1BR45	Cummins	525	2100	13	M	DI	R	PA
90	9	28300	9880	10720	7700	Freightliner	Conventional	1995	VA	80753	Cummins	350	1800	9	M	D	R	NA
91	9	74840	10800	29340	34700	Freightliner	Conventional	2000	IA	PR6260	Detroit Diesel	460	2000	10	M	D	R	FA

Table A.1: Survey data (Continued)

92	9	34560	10960	13540	10060	Kenworth	Conventional	1998	TN	10152HY	Cat	550	2100	18	M	DI	R	NA
93	12	39060	10160	11760	17140	Freightliner	Conventional	1999	IL	P298442	Detroit Diesel	430	1500	10	M	D	R	FA
94	6	27540	13940	13600	0	Mack	Conventional	1999	VA	146469	Mack	380		18	M	D	R	NA
95	6	25360	12540	12820		Mack	Conventional	1998	VA	145983	Mack	400	2100	9	M	D	R	NA
96	9	40220	9700	17520	13000	Freightliner	Over Engine	1991	AL	X8 48572	Detroit Diesel	500	2100	9	M	D	R	PA
97	9	50340	10680	18100	21560	Freightliner	Conventional	2000	OK	IUE005	Cummins	500	2000	10	M		R	FA
98	9	64880	11480	23560	29840	Freightliner	Conventional	1997	IL	P330503	Detroit Diesel	430	1600	13	M	DI	R	FA
99	9	58940	10960	26180	21800	Volvo	Conventional	1999	VA	26158	Cummins	350	1000	10	M	DI	R	FA
100	9	51120	10600	19460	21060	Freightliner	Conventional	2000	OK	IUA556	Detroit Diesel	430	1500	10	M	D	R	FA
101	9	54620	10600	22220	21800	Freightliner	Conventional	2000	TN	06120HY	Detroit Diesel	430	1700	10	M	DI	R	FA
102	9	56140	11040	23040	22060	Freightliner	Conventional	1999	NJ	AD6102	Detroit Diesel	430	1800	10	M	D	R	FA
103	11	48960	9900	12400	26660	Volvo	Conventional	1999	TN	36962HY	Cummins	350	1700	10	M	I	R	PA
104	9	75340	11180	31420	32740	Freightliner	Conventional	1993	IN	189554	Cat	350		8	M	D	R	FA
105	9	65400	11320	26500	27580	Freightliner	Conventional	1996	OR	1JA143	Cummins	370	2000	super 10	M		R	FA
106	9	33080	11120	12420	9540	Kenworth	Conventional	1993	VA	28584	Cat	425	2000	8	M	D	R	FA
107	9	58200	11020	29460	17720	Peterbilt	Conventional	2000	MD	393F02	Cat	600	2100	18	M	overdrive	R	NA
108	9	73380	10580	31020	31780	Freightliner	Conventional	2000	IA	PP2351	Detroit Diesel	475	1900	super 10	M		R	FA
109	9	41000	10700	14040	16260	Peterbilt	Conventional	2000	NY	4239PB	Cat	350	2000	8	M	DI ????	R	NA
110	9	74840	10660	28760	35420	Kenworth	Over Engine	1988	AR	K753209	Cat	310	2300	9	M	overdrive	R	NA
111	9	58500	11040	28920	18540	Freightliner	Conventional		GA	C1913	Cummins	435	1800	super 10	M		R	FA
112	7	26800	7400	9960	9440	Freightliner	Conventional	2000	MS	A33346	Cummins	260		6	M	D	R	NA
113	9	77180	11080	32580	33520	Freightliner	Conventional	1992	PA	AE50362	Cat	425	2000	9	M	D	R	FA
114	9	34800	10660	15300	8840	Peterbilt	Conventional	1999	ND	10121	Cummins	525	2100	18	M	DI	R	NA
115	7	41080	10060	14440	16580	Freightliner	Conventional	2000	IN	177237	Detroit Diesel	430	1425	10	M	D	R	FA
116	9	31020	10180	12640	8200	Mack	Conventional	1995	VA	27828	Mack	350	2500	10	M	Eaton Ruller	R	FA
117	9	77400	11620	33280	32500	Freightliner	Conventional	1998	QC	L163878	Cat	455	1625	18	M	DI	R	NA
118	9	52380	11200	26740	14440	Volvo	Conventional	2001	ME	913783	Volvo	425	1600	super 10	M	split	R	FA
119	9	74200	9980	33320	30900	Freightliner	Conventional	1995	NY	PZ6286	Detroit Diesel	375	1950	10	M		R	FA
120	9	59320	10540	27520	21260	Peterbilt	Conventional		TN	00704HY	Cat	425	1800	10	A		R	PA
121	9	79120	12180	33220	33720	Freightliner	Conventional	2000	IN	154667	Cummins	350	1500	10	M	I	R	FA
122	11	61800	10360	14740	36700	S	Conventional	2000	IL	8336302	Detroit Diesel	240	1800	7	M	D	R	PA

Table A.1: Survey data (Continued)

123	9	26980	9360	10240	7380	Kenworth	Conventional	1995	VA	31586	Cummins	425	2000	8	M	DI	R	NA
124	9	54920	11180	20540	23200	Freightliner	Conventional	1995	OK	1UV658	Detroit Diesel	430	1800	9	M	DI	R	FA
125	9	60620	10860	25020	24740	Freightliner	Conventional	1999	OK	1NR661	Detroit Diesel	435	1600	10	A		R	FA
126	9	33400	9880	14060	9460	International	Over Engine	1996	IA	PN3931	Detroit Diesel	330	1800	8	M	D	R	PA
127	9	38080	10500	16600	10980	Freightliner	Conventional	1999	OK	1NR560	Detroit Diesel	435	1600	10	A		R	FA
128	9	79400	12300	33680	33420	Freightliner	Conventional	2000	TX	R97849	Cummins	500	1800	13	M	D	R	FA
129	9	66380	10600	28160	27620	International	Conventional	1992	IL	P286566	GM	350	2100	7	M	D	R	NA
130	11	35600	10320	13100	12180	Peterbilt	Conventional	1995	MD	607675G	Cummins	500	2100	18	M	DI	R	NA
131	9	74400	11520	28020	34860	Volvo	Conventional	1999	PA	AE61156	Cat	435	1700	13	M		R	PA
132	9	35500	10820	14380	10300	Kenworth	Over Engine	1987	QC	LA32028	Cat	425	2100	8	M	D	R	NA
133	9	71480	10980	28660	31840	Peterbilt	Conventional	1999	MO	74519	Cat	550	2300	13	M	DI	R	NA
134	9	67100	9840	28900	28360	Kenworth	Conventional	2000	VA	SHOEY KW	Cat	475	2100	18	M	overdrive	R	PA
135	9	52180	11420	19280	21480	Freightliner	Conventional	2000	IL	P364775	Detroit Diesel	325	2100	10	M	D	R	FA
136	6	24300	10460	13840	0	Peterbilt	Conventional	1994	VA	P129355	Cummins	300	1500	9	M	DI	R	PA
137	9	65860	11860	27060	26940	Peterbilt	Conventional	1995	VA	86456	Cummins	480	2150	13	M	deep reduction	R	FA
138	10	90400	9120	37800	43480	Peterbilt	Conventional	1994	VA	59567	Cummins	430	2100	9	M	D	R	NA
139	9	50740	10940	20840	18960	Western Star	Conventional	2000	Ontario	PL2945	Detroit Diesel	260	2000	13	M	D	R	PA
140	9	77234	10940	33140	33154	Peterbilt	Conventional	1995	Ontario	PN5952	Detroit Diesel	430	1900	13	M	D	R	FA
141	9	75200	11540	31240	32420	Mack	Conventional	1999	MD	257F19	Mack	350	2100	10	M	D	R	FA
142	9	50100	10700	22520	16880	Freightliner	Conventional	2000	MD	377731	Detroit Diesel	500	1750	10	M	D	R	FA
143	9	68440	11020	28840	28580	Freightliner	Conventional	2001	OK	1VK985	Detroit Diesel	500	1500	13	M	overdrive	R	FA
144	9	58380	11620	22880	23880	Freightliner	Conventional	1999	PA	P203579	Detroit Diesel	500	1800	10	M	D	R	FA
145	9	34820	11300	13540	9980	Volvo	Conventional	1994	NE	23625	Cat	425	2200	8	M	straight 8	R	PA
146	9	73600	11080	30140	32380	Freightliner	Conventional	1999	OK	1UH386	Detroit Diesel	470	1800	10	M	D	R	FA
147	6	26960	8160	11580	7220	Peterbilt	Conventional	1992	VA	12456		215	1700	9	M	D	R	NA
148	9	74680	11040	30800	32840	International	Conventional	1995	Ontario	PN7590	Cummins	350	1700	super 10	M		R	NA
149	9	76900	11680	32540	32680	Peterbilt	Conventional	1999	OK	1NS013	Cat	550	2100	10	M	I	R	PA
150	9	75320	11620	33400	30300	Kenworth	Conventional	1999	VA	22455	Cat	435	1700	9	M	D	R	FA
151	9	69840	10780	30940	28120	Kenworth	Conventional	1996	VA	112814	Cummins	435	2300	super 10	M		R	PA
152	9	42980	10980	16420	15580	Freightliner	Conventional	1999	NJ	AC792X	Detroit Diesel	470	1800	10	M		R	FA
153	9	57040	9840	26200	21000	Freightliner	Conventional	1996	NC	LH6579	Detroit Diesel	470	1800	10	M	D	R	FA

Table A.1: Survey data (Continued)

154	9	70740	11460	30600	28680	Freightliner	Conventional	2000	QC	L69998	Cat	430	1900	13	M	overdrive	R	PA
155	9	34200	10520	13260	10420	Eagle	Conventional	1999	IN	111174	Cummins	435	1700	9	M	D	R	PA
156	9	75640	11560	31860	32220	Freightliner	Conventional	1994	MI	RQ1748	Detroit Diesel	430	1800	13	M	I	R	FA
157	9	46440	10120	21780	14540	Eagle	Conventional		VA	112346	Cummins	550	1800	10	M		R	NA
158	9	76580	11280	35360	29940	Peterbilt	Conventional	2000	FL	A8774X	Cat	500	2200	18	M		R	PA
159	9	76780	11300	33860	31620	Freightliner	Conventional	1996	PA	AE64277	Detroit Diesel	430	1700	9	M		R	PA
160	9	75240	11680	33420	30140	Freightliner	Conventional		PA	AE49315	Detroit Diesel	370	1600	10	M		R	FA
161	9	62400	10720	22560	29120	Kenworth	Conventional	1985	MN	B2612	Cat	400	2100	13	M	D	R	NA
162	9	75480	11240	32140	32100	Freightliner	Conventional	2001	IL	T2224138	Cat	365	1525	10	M	D	R	FA
163	5	17480	6680	10800	0	International	Conventional	1993	TN	26161		195		4	A		R	NA
164	9	41240	10360	15520	15360	Freightliner	Conventional	2000	IN	146335	Cat	430	1550	10	M	D	R	FA
165	9	39800	10860	15580	13360	Freightliner	Conventional	1999	IN	178821	Detroit Diesel	470	2100	10	M	D	R	FA
166	9	76480	11880	31380	33220	Freightliner	Conventional	2000	TN	06753HY	Detroit Diesel	430	1700	10	M	Hi/Lo	R	FA
167	9	78320	12000	33220	33100	Freightliner	Conventional	1999	IL	P300073	Detroit Diesel	470	1600	10	M		R	FA
168	9	76580	11700	32380	32500	Volvo	Conventional	2000	PA	AE73545	Detroit Diesel	460	2000	10	M	D	R	PA
169	9	80120	12380	33880	33860	Peterbilt	Conventional	2000	TN	02015HY	Cat	475	1600	10	M	DI	R	NA
170	9	85320	11020	39980	34320	Kenworth	Conventional	1993	VA	18336	Cat	435	1800	10	M	D	R	PA
171	8	29260	7360	10220	11680	Peterbilt	Conventional	1991	West VA	B56 901	Cummins	220	2100	9	M		R	NA
172	9	47420	10280	18080	19060	Freightliner	Conventional	1998	NE	6036	Detroit Diesel	500		10	M	D	R	FA
173	9	43900	10540	20060	13300	Kenworth	Conventional	1997	SC	P734478	Detroit Diesel	500	2150	13	M	DI	R	NA
174	9	32760	10060	12400	10300	Freightliner	Conventional	1998	IL	P275875	Detroit Diesel	375	2200	10	M	D	R	FA
175	9	60080	11480	27080	21520	Freightliner	Conventional	2000	OK	1UV493	Detroit Diesel	475		10	M	D	R	FA
176	9	56660	11960	22740	21960	Kenworth	Conventional	1999	MO	72997	Cummins	350		10	A			FA
177	9	71620	10660	32260	28700	Peterbilt	Conventional		OH	P6D80D	Cat	425	2200	18	M	D	R	FA
178	9	52260	11460	21280	19520	Kenworth	Conventional	1997	OK	1SU113	Detroit Diesel	355			A		R	FA
179	9	32260	10020	12920	9320	Freightliner	Conventional	2000	TN	46175HY	Cat	475	1700	10	M	D	R	FA
180	9	34900	10700	14700	9500	Kenworth	Conventional	1996	IL	P379238	Cat	579	1800	super 10	M		R	FA
181	9	42840	11160	19060	12620	Freightliner	Conventional	1998	MN	1C5682	Cummins	400	1550	10	M	D	R	FA
182	9	76120	11660	32340	32120	Peterbilt	Conventional	2000	TX	R1NC11	Cat	550	1850	18	M	D	R	NA

Direction - North Bound (Friday, 9/29/2000)

Table A.2: Data Legend

Transmission Information	Tire Information	Aerodynamic Feature (AF)
M = Manual	B = Bias Ply	NA = No Aerodynamic Aids
A = Automatic	R = Radial	PA = Partial Aerodynamic Aids
D = Direct		FA = Full Aerodynamic
I = Indirect		
DI = Double Indirect		

Table A.3: Summarized data from survey for vehicle class nine

	Mass (lb)								
Truck #	**Total**	**Axle1**	**Axle 2**	**Axle 3**	**Make**	**Type**	**Engine**	**Power (hp)**	**Mass/Power (lb/hp)**
1	54900	11320	20300	23280	Volvo	Conventional	Detroit Diesel	500	110
2	32520	8440	14080	10000	Mack	Conventional	Mack	350	93
3	65780	10520	28280	26980	Freightliner	Conventional	Detroit Diesel	500	132
4	76760	12020	30800	33940	Ford	Conventional	Cat	400	192
5	50240	10840	22680	16720	Kenworth	Conventional		450	112
6	38740	11180	15500	12060	Freightliner	Conventional		430	90
7	49520	11560	19880	18080	Kenworth	Conventional	Cummins	435	114
8	75640	11660	32520	31460	Mack	Conventional	Mack	460	164
9	34000	10580	12940	10480	Freightliner	Conventional	Detroit Diesel	500	68
10	39840	10800	17080	11960	Mack	Conventional	Mack	470	85
11	34560	11660	13000	9900	Kenworth	Conventional	Cat	500	69
12	71300	11300	28780	31220	Western Star	Conventional	Cat	435	164
13	57460	11060	22340	24060	Freightliner	Conventional	Cat	425	135
14	74660	11440	32460	30760	Freightliner	Conventional	Detroit Diesel	470	159
15	37900	10240	17300	10360	Peterbilt	Conventional	Detroit Diesel	470	81
16	39400	11300	17040	11060	Kenworth	Conventional	Cat	550	72
17	78880	13220	33360	32300	Kenworth	Conventional	Cat	550	143
18	27020	9720	9920	7380	Whitegmc	Conventional	Cat	350	77
19	56820	11160	23640	22020	Freightliner	Over Engine	Cummins	350	162
20	78600	10880	32060	35660	Peterbilt	Conventional	Cat	425	185
21	75320	11200	31880	32240	International	Conventional	Cummins	370	204
22	32980	9580	14000	9400	Peterbilt	Conventional	Cat	450	73
23	76860	11600	32580	32680	Kenworth	Conventional		435	177
24	75860	11920	31400	32540	Freightliner	Conventional	Detroit Diesel	435	174
25	32380	11000	12700	8680	Kenworth	Conventional	Cat	400	81
26	30840	10220	13360	7260	Kenworth	Conventional	Cat	435	71
27	53660	11480	21580	20600	Volvo	Conventional	Detroit Diesel	470	114
28	69740	11000	27920	30820	Volvo	Conventional	Volvo	375	186
29	24680	8400	9260	7020	International	Conventional		380	65
30	43920	9420	17960	16540	International	Conventional	Detroit Diesel	300	146
31	77820	11420	34080	32320	Eagle	Conventional	Cummins	470	166
32	32000	9960	12140	9900	Freightliner	Over Engine		400	80
33	77520	12380	33620	31520	Kenworth	Conventional	Cat	550	141
34	79360	12440	33360	33560	Kenworth	Conventional	Cat	550	144
35	30980	12180	17600	1200	International	Conventional		300	103
36	51240	10760	24420	16060	Freightliner	Conventional	Detroit Diesel	500	102
37	41980	11040	17520	13420	Freightliner	Conventional	Detroit Diesel	335	125
38	74940	13380	28220	33340	Peterbilt	Conventional	Cat	550	136
39	46680	11200	19120	16360	Freightliner	Conventional	Detroit Diesel	430	109
40	30620	10840	12240	7540	Kenworth	Conventional	Cummins	460	67
41	28600	7960	12680	7960	Kenworth	Conventional	Cummins	500	57
42	61980	10240	24860	26880	Eagle	Conventional	Cummins	460	135
43	45120	10960	20060	14100	Freightliner	Conventional	Detroit Diesel	470	96
44	34420	10560	14260	9600	Freightliner	Conventional	Detroit Diesel	430	80
45	72020	11280	28440	32300	Freightliner	Conventional	Cummins	400	180

Table A.3: Summarized data from survey for vehicle class nine (Continued)

46	46560	8400	19900	18260	Mack	Conventional	Mack	300	155
47	74940	10860	31560	32520	Freightliner	Conventional	Detroit Diesel	430	174
48	25020	8580	9580	6860	International	Conventional	Cummins	300	83
49	28540	11220	13420	3900	International	Over Engine	Cummins	430	66
50	44960	10920	18020	16020	Freightliner	Conventional	Detroit Diesel	500	90
51	56520	10300	27060	19160	Freightliner	Conventional	Detroit Diesel	500	113
52	45140	10540	17080	17520	Kenworth	Conventional	Detroit Diesel	470	96
53	55440	10560	22400	22480	Kenworth	Over Engine	Cat	425	130
54	26500	10100	9860	6540	Ford	Conventional	Cummins	300	88
55	33120	10380	13800	8940	International	Conventional	Detroit Diesel	470	70
56	58920	11400	22380	25140	Freightliner	Conventional	Detroit Diesel	390	151
57	62980	11160	26160	25660	Freightliner	Conventional	Detroit Diesel	430	146
58	18880	9840	9040	0	Peterbilt	Conventional	Cat	425	44
59	33900	11360	13600	8940	Freightliner	Conventional	Detroit Diesel	400	85
60	74660	11620	34440	28600	Freightliner	Over Engine	Cummins	400	187
61	32700	10420	12400	9880	Freightliner	Conventional	Detroit Diesel	500	65
62	70880	11020	28060	31800	Freightliner	Conventional	Detroit Diesel	460	154
63	42740	10620	20920	11200	Freightliner	Conventional	Detroit Diesel	460	93
64	72820	12820	30000	30000	Peterbilt	Conventional	Detroit Diesel	430	169
65	54320	9660	20100	24560	Freightliner	Conventional	Detroit Diesel	400	136
66	30640	10640	11980	8020	Freightliner	Conventional	Detroit Diesel	470	65
67	34500	10980	13020	10500	Volvo	Conventional	Detroit Diesel	500	69
68	53640	10240	20480	22920	Western Star	Conventional	Cat	455	118
69	28860	9780	12640	6440	Kenworth	Conventional	Cat	550	52
70	61424	11420	25520	24484	Freightliner	Conventional	Detroit Diesel	370	166
71	38440	9340	17060	12040	Volvo	Conventional	Volvo	285	135
72	56060	11400	24240	20420	Peterbilt	Conventional	Cat	500	112
73	64620	11920	22860	29840	Kenworth	Conventional	Cat	425	152
74	70100	11280	28660	30160	Volvo	Conventional	Detroit Diesel	500	140
75	42920	9800	17220	15900	Freightliner	Conventional	Cummins	330	130
76	75860	11640	31040	33180	Kenworth	Conventional	Cummins	525	144
77	28300	9880	10720	7700	Freightliner	Conventional	Cummins	350	81
78	74840	10800	29340	34700	Freightliner	Conventional	Detroit Diesel	460	163
79	34560	10960	13540	10060	Kenworth	Conventional	Cat	550	63
80	40220	9700	17520	13000	Freightliner	Over Engine	Detroit Diesel	500	80
81	50340	10680	18100	21560	Freightliner	Conventional	Cummins	500	101
82	64880	11480	23560	29840	Freightliner	Conventional	Detroit Diesel	430	151
83	58940	10960	26180	21800	Volvo	Conventional	Cummins	350	168
84	51120	10600	19460	21060	Freightliner	Conventional	Detroit Diesel	430	119
85	54620	10600	22220	21800	Freightliner	Conventional	Detroit Diesel	430	127
86	56140	11040	23040	22060	Freightliner	Conventional	Detroit Diesel	430	131
87	75340	11180	31420	32740	Freightliner	Conventional	Cat	350	215
88	65400	11320	26500	27580	Freightliner	Conventional	Cummins	370	177
89	33080	11120	12420	9540	Kenworth	Conventional	Cat	425	78
90	58200	11020	29460	17720	Peterbilt	Conventional	Cat	600	97
91	73380	10580	31020	31780	Freightliner	Conventional	Detroit Diesel	475	154
92	41000	10700	14040	16260	Peterbilt	Conventional	Cat	350	117

Table A.3: Summarized data from survey for vehicle class nine (Continued)

93	74840	10660	28760	35420	Kenworth	Over Engine	Cat	310	241
94	58500	11040	28920	18540	Freightliner	Conventional	Cummins	435	134
95	77180	11080	32580	33520	Freightliner	Conventional	Cat	425	182
96	34800	10660	15300	8840	Peterbilt	Conventional	Cummins	525	66
97	31020	10180	12640	8200	Mack	Conventional	Mack	350	89
98	77400	11620	33280	32500	Freightliner	Conventional	Cat	455	170
99	52380	11200	26740	14440	Volvo	Conventional	Volvo	425	123
100	74200	9980	33320	30900	Freightliner	Conventional	Detroit Diesel	375	198
101	59320	10540	27520	21260	Peterbilt	Conventional	Cat	425	140
102	79120	12180	33220	33720	Freightliner	Conventional	Cummins	350	226
103	26980	9360	10240	7380	Kenworth	Conventional	Cummins	425	63
104	54920	11180	20540	23200	Freightliner	Conventional	Detroit Diesel	430	128
105	60620	10860	25020	24740	Freightliner	Conventional	Detroit Diesel	435	139
106	33400	9880	14060	9460	International	Over Engine	Detroit Diesel	330	101
107	38080	10500	16600	10980	Freightliner	Conventional	Detroit Diesel	435	88
108	79400	12300	33680	33420	Freightliner	Conventional	Cummins	500	159
109	66380	10600	28160	27620	International	Conventional	GM	350	190
110	74400	11520	28020	34860	Volvo	Conventional	Cat	435	171
111	35500	10820	14380	10300	Kenworth	Over Engine	Cat	425	84
112	71480	10980	28660	31840	Peterbilt	Conventional	Cat	550	130
113	67100	9840	28900	28360	Kenworth	Conventional	Cat	475	141
114	52180	11420	19280	21480	Freightliner	Conventional	Detroit Diesel	325	161
115	65860	11860	27060	26940	Peterbilt	Conventional	Cummins	480	137
116	50740	10940	20840	18960	Western Star	Conventional	Detroit Diesel	260	195
117	77234	10940	33140	33154	Peterbilt	Conventional	Detroit Diesel	430	180
118	75200	11540	31240	32420	Mack	Conventional	Mack	350	215
119	50100	10700	22520	16880	Freightliner	Conventional	Detroit Diesel	500	100
120	68440	11020	28840	28580	Freightliner	Conventional	Detroit Diesel	500	137
121	58380	11620	22880	23880	Freightliner	Conventional	Detroit Diesel	500	117
122	34820	11300	13540	9980	Volvo	Conventional	Cat	425	82
123	73600	11080	30140	32380	Freightliner	Conventional	Detroit Diesel	470	157
124	74680	11040	30800	32840	International	Conventional	Cummins	350	213
125	76900	11680	32540	32680	Peterbilt	Conventional	Cat	550	140
126	75320	11620	33400	30300	Kenworth	Conventional	Cat	435	173
127	69840	10780	30940	28120	Kenworth	Conventional	Cummins	435	161
128	42980	10980	16420	15580	Freightliner	Conventional	Detroit Diesel	470	91
129	57040	9840	26200	21000	Freightliner	Conventional	Detroit Diesel	470	121
130	70740	11460	30600	28680	Freightliner	Conventional	Cat	430	165
131	34200	10520	13260	10420	Eagle	Conventional	Cummins	435	79
132	75640	11560	31860	32220	Freightliner	Conventional	Detroit Diesel	430	176
133	46440	10120	21780	14540	Eagle	Conventional	Cummins	550	84
134	76580	11280	35360	29940	Peterbilt	Conventional	Cat	500	153
135	76780	11300	33860	31620	Freightliner	Conventional	Detroit Diesel	430	179
136	75240	11680	33420	30140	Freightliner	Conventional	Detroit Diesel	370	203
137	62400	10720	22560	29120	Kenworth	Conventional	Cat	400	156
138	75480	11240	32140	32100	Freightliner	Conventional	Cat	365	207
139	41240	10360	15520	15360	Freightliner	Conventional	Cat	430	96

Table A.3: Summarized data from survey for vehicle class nine (Continued)

140	39800	10860	15580	13360	Freightliner	Conventional	Detroit Diesel	470	85
141	76480	11880	31380	33220	Freightliner	Conventional	Detroit Diesel	430	178
142	78320	12000	33220	33100	Freightliner	Conventional	Detroit Diesel	470	167
143	76580	11700	32380	32500	Volvo	Conventional	Detroit Diesel	460	166
144	80120	12380	33880	33860	Peterbilt	Conventional	Cat	475	169
145	85320	11020	39980	34320	Kenworth	Conventional	Cat	435	196
146	47420	10280	18080	19060	Freightliner	Conventional	Detroit Diesel	500	95
147	43900	10540	20060	13300	Kenworth	Conventional	Detroit Diesel	500	88
148	32760	10060	12400	10300	Freightliner	Conventional	Detroit Diesel	375	87
149	60080	11480	27080	21520	Freightliner	Conventional	Detroit Diesel	475	126
150	56660	11960	22740	21960	Kenworth	Conventional	Cummins	350	162
151	71620	10660	32260	28700	Peterbilt	Conventional	Cat	425	169
152	52260	11460	21280	19520	Kenworth	Conventional	Detroit Diesel	355	147
153	32260	10020	12920	9320	Freightliner	Conventional	Cat	475	68
154	34900	10700	14700	9500	Kenworth	Conventional	Cat	579	60
155	42840	11160	19060	12620	Freightliner	Conventional	Cummins	400	107
156	76120	11660	32340	32120	Peterbilt	Conventional	Cat	550	138

APPENDIX B

Constant Power Vehicle Dynamics Model

260 kW (350 hp) truck

Table B.1: Example Solution to ODE (9-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	97682	0.0596	0.00	2512.77	26200.14	28712.91
1	0.62	4.98	1.54	97682	0.0596	9.30	2602.56	26201.04	28812.90
2	2.77	10.41	1.25	84854	0.0596	40.61	2700.35	26204.05	28945.02
3	6.20	13.97	0.76	63266	0.0596	73.05	2764.36	26208.54	29045.95
4	10.43	16.34	0.56	54069	0.0597	100.02	2807.16	26213.53	29120.71
5	15.23	18.13	0.44	48723	0.0597	123.17	2839.46	26218.49	29181.12
6	20.47	19.57	0.36	45160	0.0597	143.38	2865.23	26223.04	29231.66
7	26.07	20.75	0.30	42591	0.0597	161.20	2886.50	26226.92	29274.62
8	31.98	21.74	0.25	40642	0.0597	177.03	2904.42	26229.91	29311.35
9	38.14	22.59	0.22	39110	0.0597	191.16	2919.76	26231.83	29342.76
10	44.52	23.33	0.19	37874	0.0597	203.85	2933.04	26232.55	29369.44

Table B.2: Example Solution to ODE (8-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	95414	0.0596	0.00	2374.76	24761.23	27135.99
1	0.65	5.22	1.61	95414	0.0596	10.21	2463.66	24762.12	27235.99
2	2.90	10.87	1.27	81252	0.0596	44.29	2559.91	24765.10	27369.29
3	6.47	14.52	0.79	60855	0.0596	78.96	2621.96	24769.48	27470.41
4	10.86	16.98	0.58	52040	0.0597	107.97	2663.83	24774.34	27546.15
5	15.85	18.85	0.46	46886	0.0597	133.01	2695.61	24779.13	27607.76
6	21.30	20.34	0.37	43437	0.0597	154.98	2721.09	24783.48	27659.55
7	27.13	21.58	0.31	40943	0.0597	174.43	2742.18	24787.12	27703.74
8	33.27	22.63	0.27	39046	0.0597	191.79	2760.03	24789.84	27741.66
9	39.68	23.53	0.23	37552	0.0597	207.35	2775.36	24791.46	27774.17
10	46.33	24.31	0.20	36344	0.0597	221.37	2788.68	24791.83	27801.87

Table B.3: Example Solution to ODE (7-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	94343	0.0596	0.00	2236.76	23322.32	25559.08
1	0.70	5.58	1.72	94343	0.0596	11.68	2326.31	23323.21	25661.21
2	3.10	11.51	1.28	76758	0.0596	49.63	2421.36	23326.20	25797.18
3	6.85	15.21	0.81	58102	0.0596	86.62	2480.63	23330.51	25897.76
4	11.44	17.74	0.60	49816	0.0597	117.83	2521.19	23335.23	25974.25
5	16.65	19.67	0.47	44918	0.0597	144.93	2552.21	23339.83	26036.97
6	22.34	21.23	0.39	41618	0.0597	168.82	2577.22	23343.96	26089.99
7	28.42	22.53	0.33	39222	0.0597	190.08	2598.02	23347.33	26135.43
8	34.84	23.63	0.28	37393	0.0597	209.12	2615.69	23349.74	26174.56
9	41.53	24.58	0.24	35947	0.0597	226.28	2630.92	23351.01	26208.21
10	48.48	25.41	0.21	34775	0.0597	241.79	2644.21	23350.98	26236.98

Table B.4: Example Solution to ODE (6-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	90269	0.0596	0.00	2098.76	21883.40	23982.17
1	0.72	5.74	1.77	90269	0.0596	12.32	2185.06	21884.27	24081.65
2	3.19	11.86	1.34	74485	0.0596	52.70	2277.25	21887.14	24217.10
3	7.06	15.75	0.85	56107	0.0596	92.88	2335.72	21891.31	24319.91
4	11.83	18.41	0.63	47991	0.0597	126.96	2375.79	21895.86	24398.62
5	17.23	20.45	0.50	43199	0.0597	156.69	2406.52	21900.28	24463.49
6	23.15	22.10	0.41	39972	0.0597	183.01	2431.37	21904.19	24518.57
7	29.49	23.48	0.35	37627	0.0597	206.53	2452.10	21907.33	24565.96
8	36.18	24.66	0.30	35836	0.0597	227.69	2469.75	21909.47	24606.92
9	43.17	25.67	0.26	34419	0.0597	246.82	2485.02	21910.44	24642.28
10	50.43	26.56	0.23	33269	0.0597	264.18	2498.38	21910.06	24672.62

Table B.5: Example Solution to ODE (5-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	80919	0.0596	0.00	1960.76	20444.49	22405.25
1	0.68	5.42	1.67	80919	0.0596	11.00	2036.94	20445.26	22493.19
2	3.02	11.43	1.56	77306	0.0596	48.93	2121.43	20447.81	22618.16
3	6.86	15.84	0.94	55764	0.0596	94.03	2183.50	20451.68	22729.21
4	11.69	18.79	0.69	47026	0.0597	132.22	2224.88	20456.02	22813.12
5	17.23	21.03	0.55	42020	0.0597	165.60	2256.35	20460.25	22882.20
6	23.33	22.83	0.45	38700	0.0597	195.23	2281.71	20464.01	22940.95
7	29.89	24.33	0.38	36309	0.0597	221.79	2302.84	20467.00	22991.63
8	36.83	25.62	0.33	34493	0.0597	245.76	2320.85	20468.98	23035.59
9	44.10	26.72	0.29	33062	0.0597	267.50	2336.44	20469.77	23073.71
10	51.66	27.70	0.25	31903	0.0597	287.29	2350.09	20469.21	23106.60

Table B.6: Example Solution to ODE (4-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	71755	0.0596	0.00	1822.76	19005.58	20828.34
1	0.63	5.07	1.56	71755	0.0596	9.64	1889.06	19006.24	20904.95
2	2.83	10.70	1.56	71755	0.0596	42.89	1962.60	19008.47	21013.95
3	6.54	15.70	1.08	56272	0.0596	92.34	2027.95	19011.98	21132.27
4	11.39	19.03	0.78	46422	0.0597	135.69	2071.49	19016.06	21223.23
5	17.04	21.53	0.61	41042	0.0597	173.59	2104.09	19020.10	21297.78
6	23.30	23.53	0.50	37557	0.0597	207.30	2130.20	19023.71	21361.21
7	30.07	25.19	0.42	35080	0.0597	237.60	2151.90	19026.56	21416.07
8	37.27	26.60	0.36	33216	0.0597	265.02	2170.38	19028.43	21463.83
9	44.83	27.82	0.32	31755	0.0597	289.97	2186.37	19029.09	21505.43
10	52.72	28.90	0.28	30577	0.0597	312.75	2200.39	19028.38	21541.52

Table B.7: Example Solution to ODE (3-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	68206	0.0596	0.00	1684.76	17566.67	19251.43
1	0.66	5.28	1.63	68206	0.0596	10.43	1748.49	17567.31	19326.23
2	2.94	11.13	1.62	68206	0.0596	46.38	1819.17	17569.44	19435.00
3	6.80	16.38	1.14	53933	0.0596	100.53	1882.64	17572.80	19555.97
4	11.87	19.91	0.82	44371	0.0597	148.52	1925.28	17576.70	19650.50
5	17.79	22.56	0.65	39157	0.0597	190.70	1957.31	17580.54	19728.55
6	24.36	24.69	0.53	35780	0.0597	228.40	1983.03	17583.90	19795.34
7	31.47	26.47	0.45	33380	0.0597	262.43	2004.48	17586.48	19853.40
8	39.04	27.99	0.39	31572	0.0597	293.35	2022.79	17588.04	19904.18
9	47.00	29.30	0.34	30154	0.0597	321.59	2038.69	17588.35	19948.63
10	55.31	30.46	0.30	29008	0.0597	347.48	2052.66	17587.24	19987.39

Table B.8: Example Solution to ODE (2-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	63053	0.0596	0.00	1546.76	16127.75	17674.51
1	0.67	5.33	1.64	63053	0.0596	10.63	1605.83	16128.35	17744.81
2	2.97	11.24	1.64	63053	0.0596	47.28	1671.35	16130.33	17848.96
3	6.89	16.80	1.26	52606	0.0596	105.66	1733.01	16133.45	17972.12
4	12.12	20.65	0.90	42780	0.0597	159.77	1775.79	16137.13	18072.69
5	18.28	23.54	0.70	37539	0.0597	207.50	1807.77	16140.75	18156.01
6	25.15	25.85	0.58	34178	0.0597	250.31	1833.43	16143.89	18227.63
7	32.60	27.78	0.49	31803	0.0597	289.10	1854.84	16146.23	18290.17
8	40.55	29.43	0.42	30019	0.0597	324.47	1873.15	16147.52	18345.14
9	48.93	30.87	0.37	28623	0.0597	356.89	1889.07	16147.54	18393.50
10	57.69	32.13	0.33	27497	0.0597	386.72	1903.09	16146.11	18435.92

Table B.9: Example Solution to ODE (1-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	56001	0.0596	0.00	1408.76	14688.84	16097.60
1	0.64	5.14	1.59	56001	0.0596	9.91	1460.71	14689.36	16159.98
2	2.86	10.85	1.58	56001	0.0596	44.07	1518.32	14691.11	16253.49
3	6.67	16.53	1.48	53462	0.0596	102.30	1575.68	14693.88	16371.86
4	11.92	20.99	1.02	42099	0.0597	164.98	1620.73	14697.26	16482.98
5	18.22	24.25	0.79	36434	0.0597	220.28	1653.69	14700.65	16574.61
6	25.33	26.85	0.65	32910	0.0597	269.97	1679.92	14703.60	16653.49
7	33.09	29.01	0.55	30462	0.0597	315.12	1701.71	14705.78	16722.61
8	41.41	30.85	0.47	28643	0.0597	356.41	1720.31	14706.91	16783.63
9	50.21	32.45	0.41	27230	0.0597	394.36	1736.48	14706.76	16837.61
10	59.42	33.86	0.37	26096	0.0597	429.39	1750.73	14705.14	16885.26

Table B.10: Example Solution to ODE (0-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	47453	0.0596	0.00	1270.88	13251.26	14522.14
1	0.59	4.71	1.45	47453	0.0596	8.29	1313.75	13251.69	14573.73
2	2.62	9.92	1.45	47453	0.0596	36.88	1361.30	13253.13	14651.31
3	6.10	15.13	1.44	47453	0.0596	85.71	1408.72	13255.44	14749.86
4	11.02	20.24	1.27	43655	0.0597	153.43	1455.29	13258.36	14867.08
5	17.22	24.23	0.95	36467	0.0597	219.88	1491.65	13261.47	14973.00
6	24.40	27.32	0.76	32344	0.0597	279.51	1519.79	13264.27	15063.57
7	32.35	29.85	0.64	29602	0.0597	333.69	1542.84	13266.39	15142.92
8	40.95	31.99	0.55	27619	0.0597	383.31	1562.37	13267.52	15213.20
9	50.09	33.84	0.48	26107	0.0597	429.01	1579.25	13267.43	15275.69
10	59.73	35.47	0.42	24909	0.0597	471.27	1594.08	13265.89	15331.24

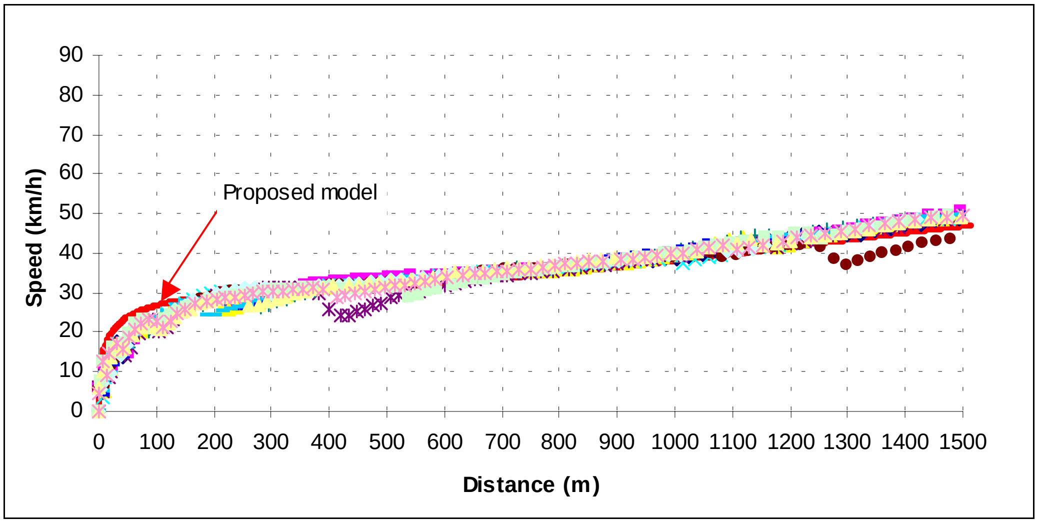


Figure B.1: Predicted and Observed Speed Profile (9-Load Configuration)

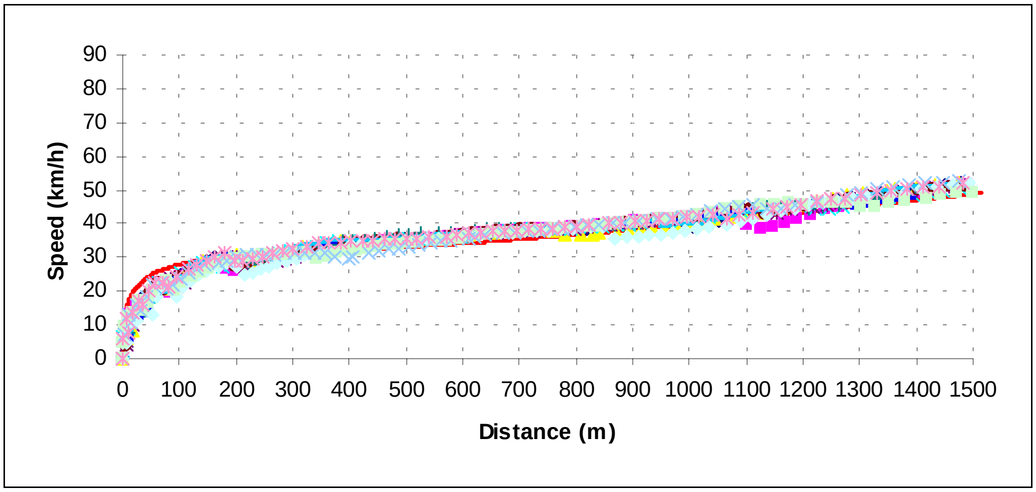


Figure B.2: Predicted and Observed Speed Profile (8-Load Configuration)

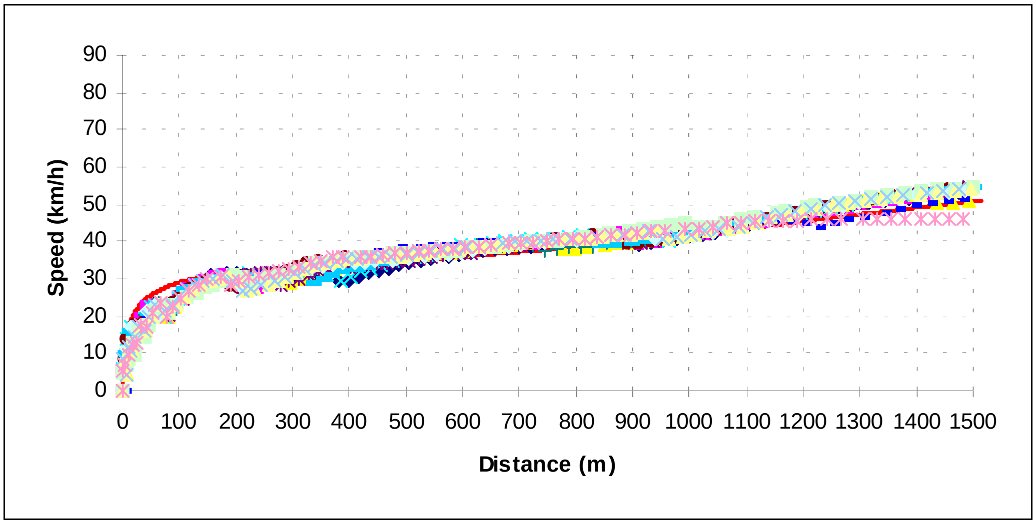


Figure B.3: Predicted and Observed Speed Profile (7-Load Configuration)

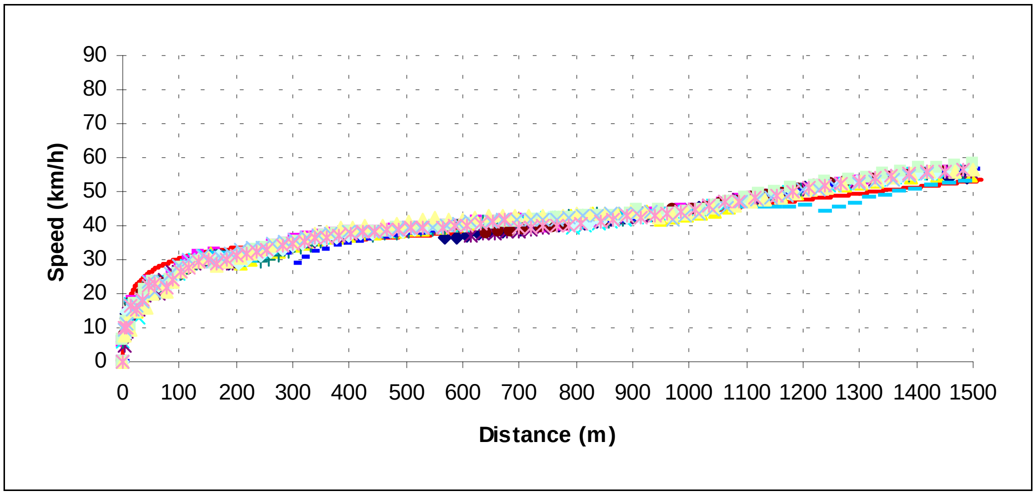


Figure B.4: Predicted and Observed Speed Profile (6-Load Configuration)

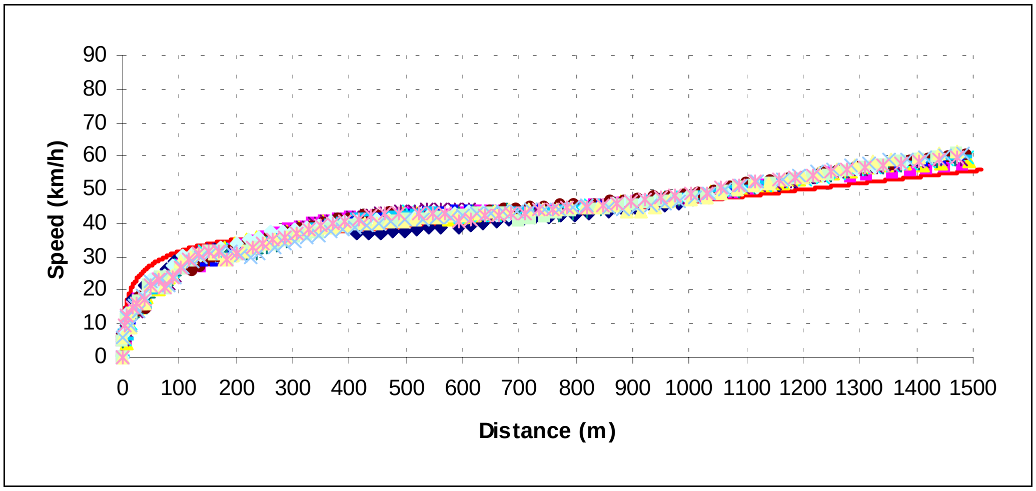


Figure B.5: Predicted and Observed Speed Profile (5-Load Configuration)

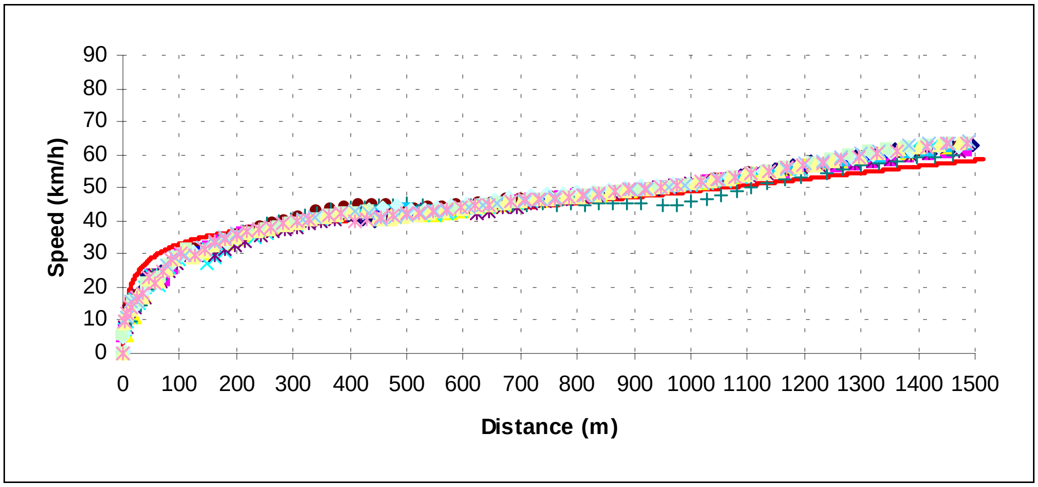


Figure B.6: Predicted and Observed Speed Profile (4-Load Configuration)

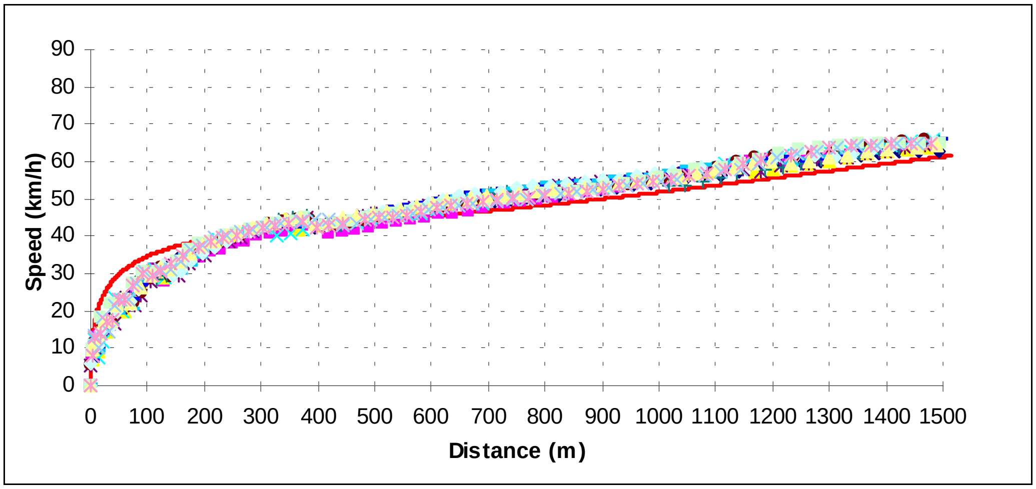


Figure B.7: Predicted and Observed Speed Profile (3-Load Configuration)

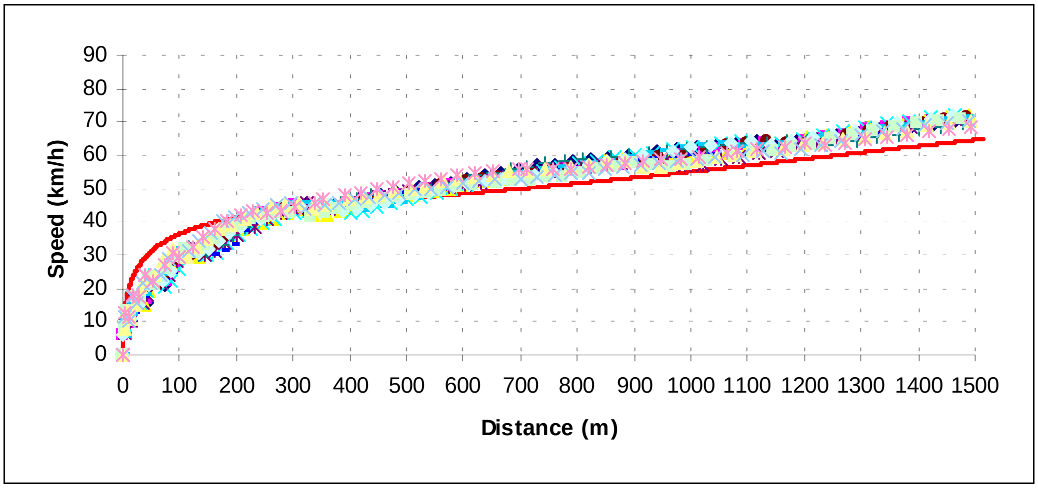


Figure B.8: Predicted and Observed Speed Profile (2-Load Configuration)

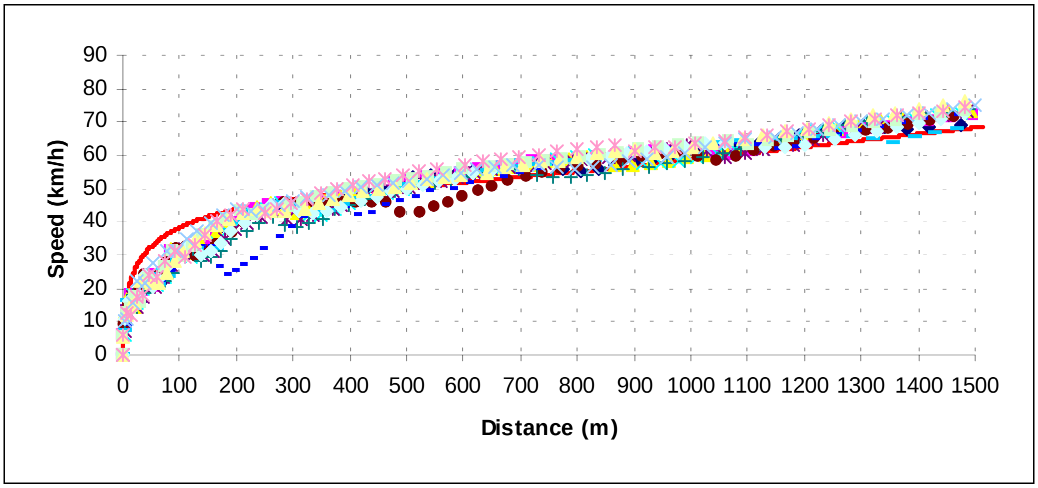


Figure B.9: Predicted and Observed Speed Profile (1-Load Configuration)

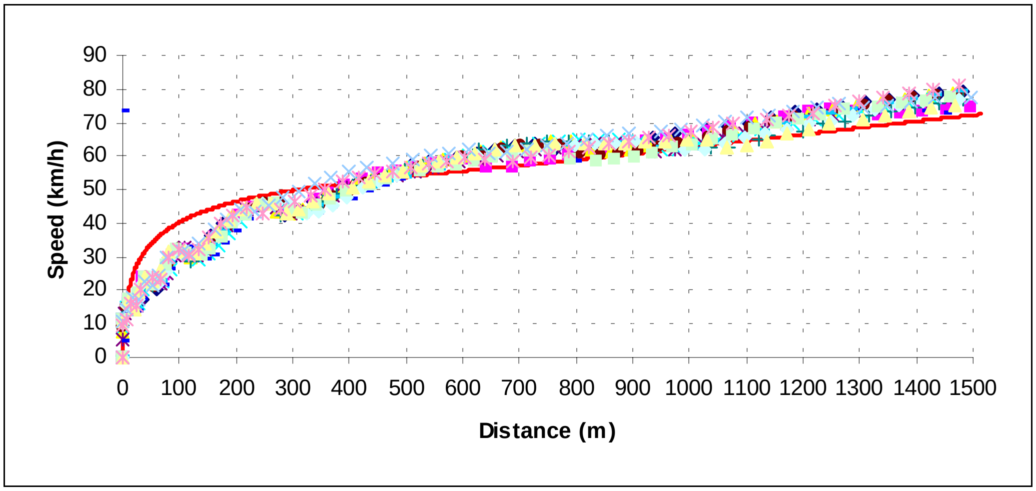


Figure B.10: Predicted and Observed Speed Profile (0-Load Configuration)

320 kW (430 hp) truck

Table B.11: Example Solution to ODE (9-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	96881	0.0596	0.00	2408.98	25117.97	27526.95
1	0.65	5.23	1.61	96881	0.0596	8.40	2499.27	25118.88	27626.55
2	2.91	11.03	1.61	96881	0.0596	37.37	2599.43	25121.91	27758.71
3	6.67	15.60	0.97	69571	0.0596	74.82	2678.46	25126.58	27879.85
4	11.44	18.62	0.71	58310	0.0597	106.51	2730.50	25131.88	27968.89
5	16.94	20.90	0.56	51949	0.0597	134.19	2769.87	25137.09	28041.15
6	23.01	22.73	0.46	47760	0.0597	158.76	2801.52	25141.74	28102.02
7	29.54	24.25	0.39	44755	0.0597	180.79	2827.88	25145.46	28154.13
8	36.46	25.55	0.33	42479	0.0597	200.69	2850.33	25147.97	28198.98
9	43.72	26.68	0.29	40688	0.0597	218.75	2869.75	25149.02	28237.52
10	51.27	27.66	0.26	39238	0.0597	235.20	2886.78	25148.42	28270.40

Table B.12: Example Solution to ODE (8-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	90796	0.0596	0.00	2288.40	23860.75	26149.15
1	0.64	5.13	1.58	90796	0.0596	8.09	2372.57	23861.59	26242.25
2	2.86	10.82	1.58	90796	0.0596	35.98	2465.93	23864.42	26366.33
3	6.59	15.71	1.04	69105	0.0596	75.83	2546.12	23868.84	26490.79
4	11.43	18.94	0.75	57325	0.0597	110.20	2599.08	23873.94	26583.22
5	17.04	21.36	0.59	50811	0.0597	140.26	2638.91	23878.99	26658.15
6	23.25	23.31	0.49	46565	0.0597	167.01	2670.87	23883.48	26721.36
7	29.96	24.93	0.41	43537	0.0597	191.05	2697.47	23887.05	26775.57
8	37.08	26.32	0.35	41251	0.0597	212.82	2720.14	23889.39	26822.35
9	44.56	27.51	0.31	39456	0.0597	232.62	2739.78	23890.26	26862.66
10	52.35	28.56	0.27	38005	0.0597	250.71	2757.01	23889.46	26897.18

Table B.13: Example Solution to ODE (7-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	86312	0.0596	0.00	2175.46	22683.09	24858.55
1	0.64	5.13	1.58	86312	0.0596	8.09	2255.47	22683.90	24947.45
2	2.86	10.82	1.58	86312	0.0596	35.98	2344.21	22686.58	25066.77
3	6.61	15.92	1.11	68181	0.0596	77.90	2423.77	22690.81	25192.49
4	11.54	19.34	0.80	56137	0.0597	114.91	2477.05	22695.74	25287.70
5	17.28	21.90	0.62	49573	0.0597	147.36	2516.99	22700.62	25364.97
6	23.66	23.95	0.51	45322	0.0597	176.30	2549.02	22704.94	25430.27
7	30.55	25.66	0.43	42301	0.0597	202.38	2575.70	22708.33	25486.41
8	37.89	27.12	0.37	40025	0.0597	226.04	2598.45	22710.49	25534.98
9	45.60	28.39	0.33	38241	0.0597	247.63	2618.19	22711.15	25576.96
10	53.65	29.50	0.29	36800	0.0597	267.40	2635.52	22710.10	25613.02

Table B.14: Example Solution to ODE (6-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	82042	0.0596	0.00	2027.92	21144.72	23172.64
1	0.66	5.27	1.63	82042	0.0596	8.54	2104.56	21145.49	23258.59
2	2.94	11.12	1.62	82042	0.0596	37.99	2189.57	21148.05	23375.62
3	6.81	16.46	1.17	65966	0.0596	83.22	2267.17	21152.10	23502.49
4	11.91	20.07	0.84	54075	0.0597	123.84	2319.78	21156.83	23600.45
5	17.88	22.79	0.66	47632	0.0597	159.61	2359.26	21161.48	23680.35
6	24.52	24.97	0.55	43470	0.0597	191.64	2390.98	21165.55	23748.17
7	31.72	26.79	0.46	40516	0.0597	220.61	2417.46	21168.66	23806.72
8	39.38	28.35	0.40	38291	0.0597	246.99	2440.09	21170.49	23857.57
9	47.45	29.70	0.35	36546	0.0597	271.14	2459.77	21170.79	23901.69
10	55.87	30.89	0.31	35136	0.0597	293.33	2477.09	21169.33	23939.75

Table B.15: Example Solution to ODE (5-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	75477	0.0596	0.00	1940.41	20232.30	22172.71
1	0.62	4.99	1.54	75477	0.0596	7.65	2009.81	20233.00	22250.45
2	2.78	10.52	1.54	75477	0.0596	34.02	2086.78	20235.33	22356.13
3	6.47	15.96	1.32	68021	0.0596	78.27	2162.42	20239.04	22479.73
4	11.49	19.96	0.92	54388	0.0597	122.42	2218.07	20243.54	22584.03
5	17.46	22.90	0.71	47393	0.0597	161.23	2259.05	20248.05	22668.33
6	24.16	25.25	0.59	42987	0.0597	195.97	2291.71	20252.05	22739.73
7	31.45	27.20	0.49	39904	0.0597	227.42	2318.85	20255.12	22801.39
8	39.24	28.87	0.43	37604	0.0597	256.10	2342.00	20256.94	22855.04
9	47.47	30.31	0.37	35811	0.0597	282.37	2362.10	20257.25	22901.72
10	56.07	31.58	0.33	34370	0.0597	306.55	2379.78	20255.80	22942.14

Table B.16: Example Solution to ODE (4-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	68858	0.0596	0.00	1797.45	18741.67	20539.12
1	0.61	4.88	1.51	68858	0.0596	7.32	1860.36	18742.30	20609.98
2	2.72	10.30	1.50	68858	0.0596	32.58	1930.13	18744.41	20707.12
3	6.33	15.70	1.50	68858	0.0596	75.74	1999.75	18747.79	20823.28
4	11.36	20.21	1.02	53713	0.0597	125.52	2057.88	18751.98	20935.38
5	17.44	23.47	0.79	46251	0.0597	169.29	2099.90	18756.25	21025.45
6	24.33	26.05	0.64	41670	0.0597	208.56	2133.15	18760.04	21101.76
7	31.88	28.19	0.54	38510	0.0597	244.19	2160.70	18762.93	21167.82
8	39.96	30.01	0.47	36173	0.0597	276.75	2184.16	18764.58	21225.50
9	48.52	31.59	0.41	34363	0.0597	306.68	2204.54	18764.70	21275.92
10	57.50	32.98	0.36	32913	0.0597	334.30	2222.47	18763.05	21319.82

Table B.17: Example Solution to ODE (3-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	61011	0.0596	0.00	1646.86	17171.46	18818.32
1	0.58	4.65	1.43	61011	0.0596	6.65	1701.79	17172.01	18880.45
2	2.59	9.81	1.43	61011	0.0596	29.59	1762.72	17173.86	18966.17
3	6.03	14.96	1.43	61011	0.0596	68.79	1823.51	17176.83	19069.13
4	10.90	19.94	1.20	54433	0.0597	122.22	1882.31	17180.58	19185.11
5	16.99	23.72	0.90	45758	0.0597	172.96	1926.96	17184.56	19284.47
6	24.00	26.66	0.73	40713	0.0597	218.47	1961.66	17188.15	19368.29
7	31.75	29.08	0.61	37333	0.0597	259.83	1990.17	17190.91	19440.91
8	40.12	31.12	0.52	34877	0.0597	297.70	2014.34	17192.47	19504.51
9	49.02	32.90	0.46	32997	0.0597	332.59	2035.27	17192.53	19560.38
10	58.37	34.46	0.41	31505	0.0597	364.86	2053.68	17190.82	19609.35

Table B.18: Example Solution to ODE (2-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	53431	0.0596	0.00	1542.05	16078.69	17620.74
1	0.53	4.22	1.30	53431	0.0596	5.47	1588.67	16079.15	17673.29
2	2.35	8.89	1.30	53431	0.0596	24.31	1640.39	16080.73	17745.43
3	5.47	13.56	1.29	53431	0.0596	56.52	1691.99	16083.27	17831.78
4	9.88	18.22	1.29	53431	0.0597	101.99	1743.45	16086.53	17931.97
5	15.58	22.68	1.08	47862	0.0597	158.08	1792.80	16090.15	18041.03
6	22.38	26.17	0.85	41485	0.0597	210.42	1831.34	16093.62	18135.38
7	30.05	28.97	0.70	37477	0.0597	257.84	1862.28	16096.43	18216.55
8	38.43	31.31	0.60	34673	0.0597	301.23	1888.18	16098.17	18287.58
9	47.41	33.32	0.52	32579	0.0597	341.19	1910.42	16098.51	18350.12
10	56.92	35.08	0.46	30945	0.0597	378.17	1929.87	16097.17	18405.21

Table B.19: Example Solution to ODE (1-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	44731	0.0596	0.00	1399.09	14588.05	15987.14
1	0.47	3.73	1.15	44731	0.0596	4.28	1436.51	14588.43	16029.22
2	2.08	7.87	1.15	44731	0.0596	19.03	1478.02	14589.70	16086.75
3	4.84	12.00	1.15	44731	0.0596	44.24	1519.44	14591.76	16155.44
4	8.74	16.12	1.14	44731	0.0597	79.82	1560.75	14594.44	16235.01
5	13.79	20.22	1.14	44731	0.0597	125.68	1601.94	14597.49	16325.11
6	19.98	24.32	1.13	44643	0.0597	181.70	1642.99	14600.59	16425.28
7	27.26	27.97	0.89	38815	0.0597	240.36	1679.61	14603.35	16523.32
8	35.45	30.92	0.74	35108	0.0597	293.81	1709.23	14605.31	16608.36
9	44.39	33.40	0.63	32496	0.0597	342.94	1734.16	14606.10	16683.19
10	53.98	35.55	0.55	30536	0.0597	388.37	1755.67	14605.37	16749.41

Table B.20: Example Solution to ODE (0-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	43610	0.0596	0.00	1163.53	12131.95	13295.49
1	0.59	4.73	1.46	43610	0.0596	6.88	1203.00	12132.35	13342.23
2	2.63	9.98	1.46	43610	0.0596	30.60	1246.77	12133.68	13411.04
3	6.13	15.21	1.45	43610	0.0596	71.11	1290.43	12135.80	13497.34
4	11.08	20.43	1.45	43610	0.0597	128.25	1333.95	12138.49	13600.69
5	17.48	25.62	1.38	42370	0.0597	201.72	1377.25	12141.41	13720.38
6	25.24	30.04	1.07	36131	0.0597	277.40	1414.16	12144.12	13835.67
7	34.09	33.58	0.89	32322	0.0597	346.63	1443.69	12146.11	13936.43
8	43.84	36.55	0.76	29699	0.0597	410.56	1468.43	12146.95	14025.94
9	54.36	39.10	0.66	27760	0.0597	469.94	1489.74	12146.30	14105.98
10	65.54	41.35	0.58	26255	0.0597	525.34	1508.43	12143.85	14177.63

Table B.21: Example Solution to ODE (Truck Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	25675	0.0596	0.00	477.73	4981.16	5458.88
1	0.96	7.68	2.37	25675	0.0596	18.14	504.04	4981.42	5503.60
2	4.28	16.19	2.36	25675	0.0596	80.57	533.18	4982.28	5596.03
3	9.95	24.65	2.34	25675	0.0597	186.77	562.16	4983.60	5732.54
4	17.97	33.05	2.32	25675	0.0597	335.64	590.91	4985.12	5911.68
5	28.30	41.36	2.29	25675	0.0597	525.71	619.38	4986.49	6131.58
6	40.88	48.94	1.86	22183	0.0597	735.94	645.33	4987.27	6368.54
7	55.36	55.07	1.54	19711	0.0597	932.03	666.34	4986.99	6585.37
8	71.39	60.24	1.32	18020	0.0597	1115.15	684.04	4985.22	6784.42
9	88.76	64.70	1.15	16777	0.0596	1286.58	699.33	4981.62	6967.53
10	107.28	68.63	1.02	15818	0.0596	1447.31	712.77	4975.88	7135.96

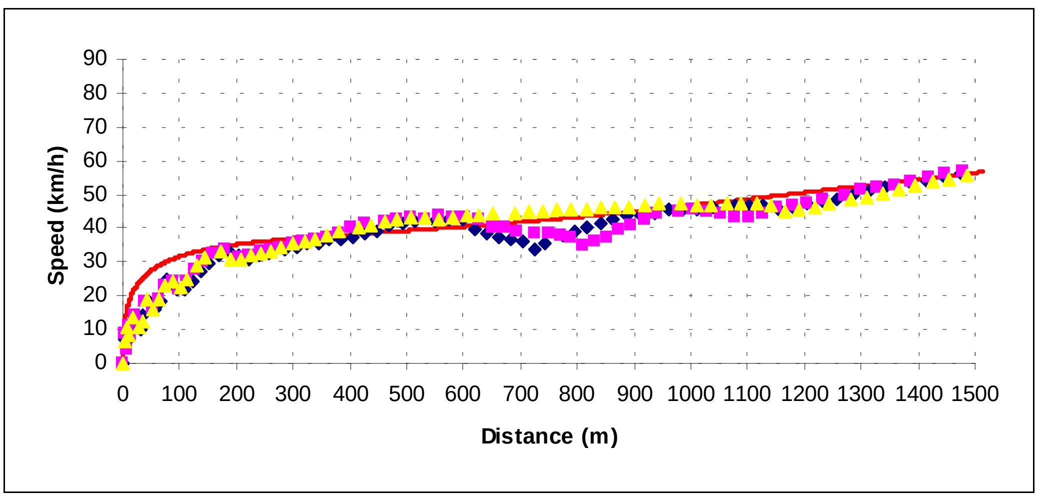


Figure B.11: Predicted and Observed Speed Profile (9-Load Configuration)

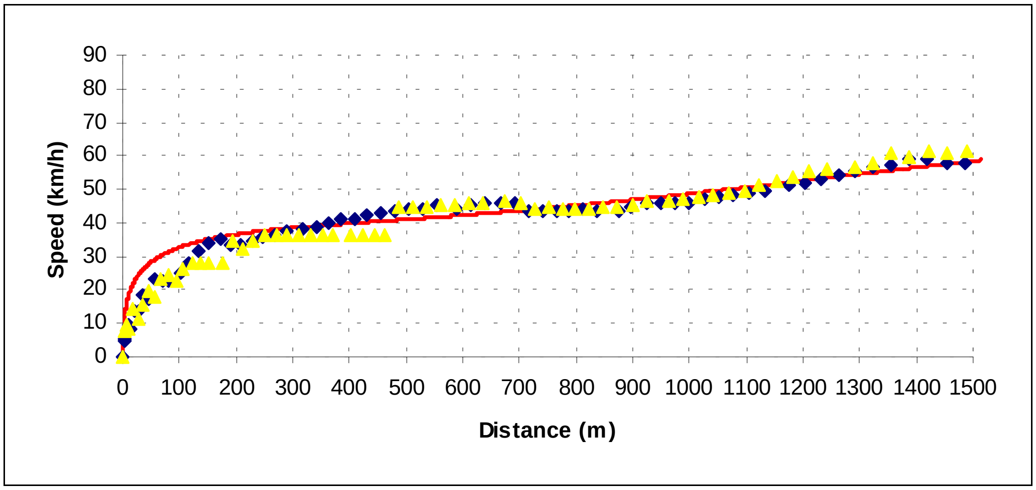


Figure B.12: Predicted and Observed Speed Profile (8-Load Configuration)

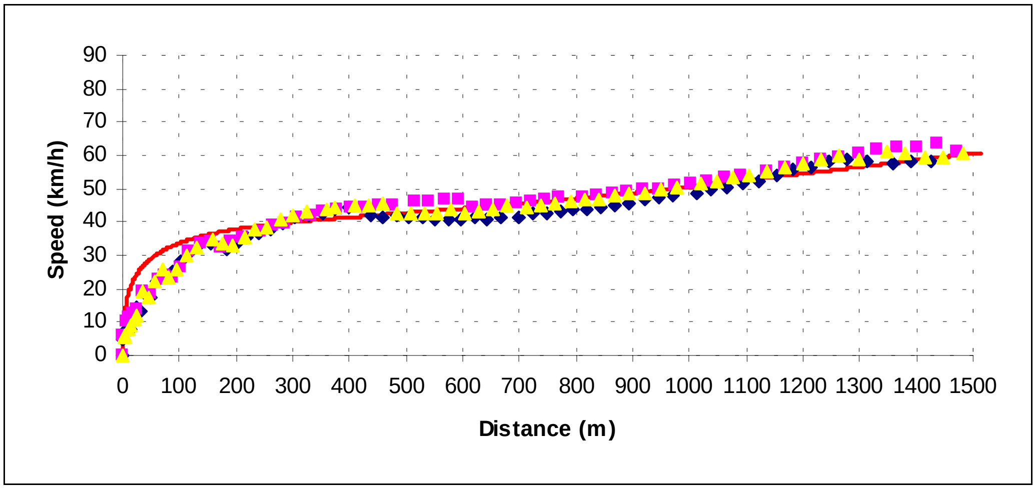


Figure B.13: Predicted and Observed Speed Profile (7-Load Configuration)

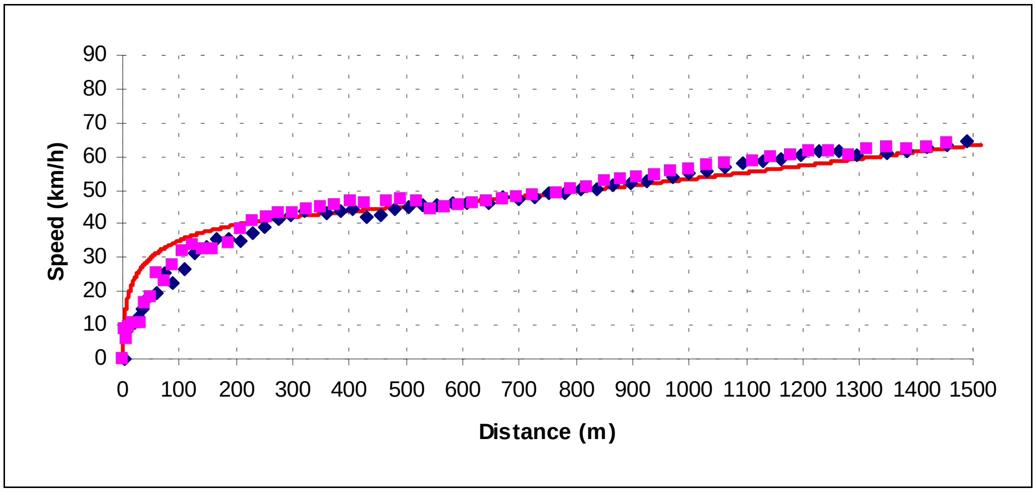


Figure B.14: Predicted and Observed Speed Profile (6-Load Configuration)

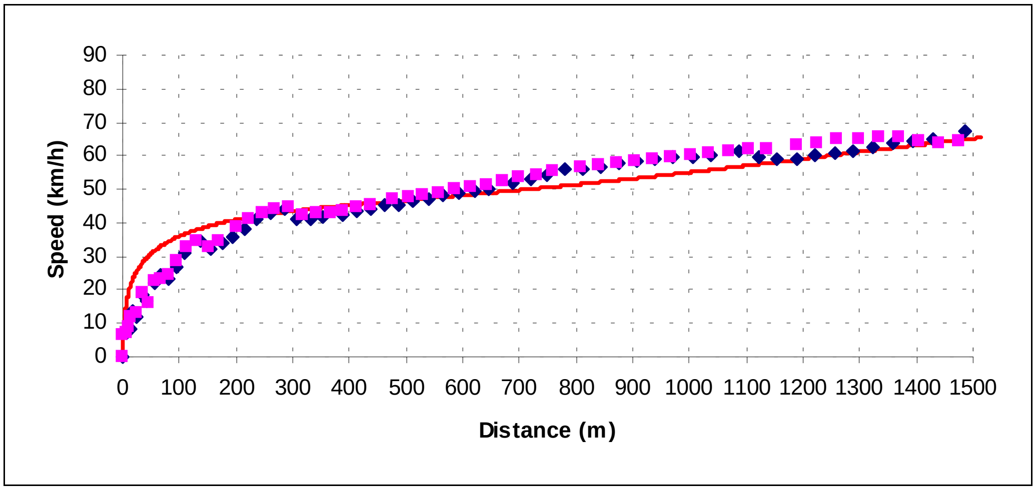


Figure B.15: Predicted and Observed Speed Profile (5-Load Configuration)

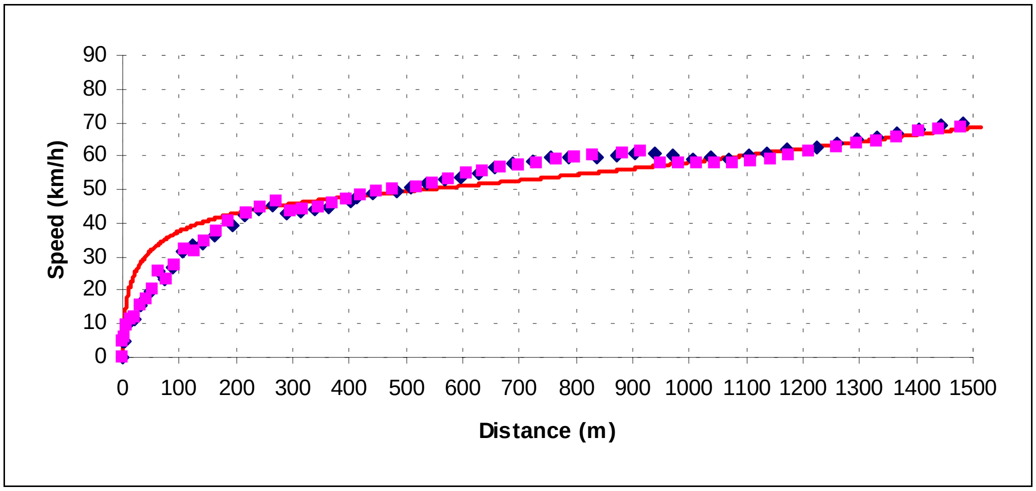


Figure B.16: Predicted and Observed Speed Profile (4-Load Configuration)

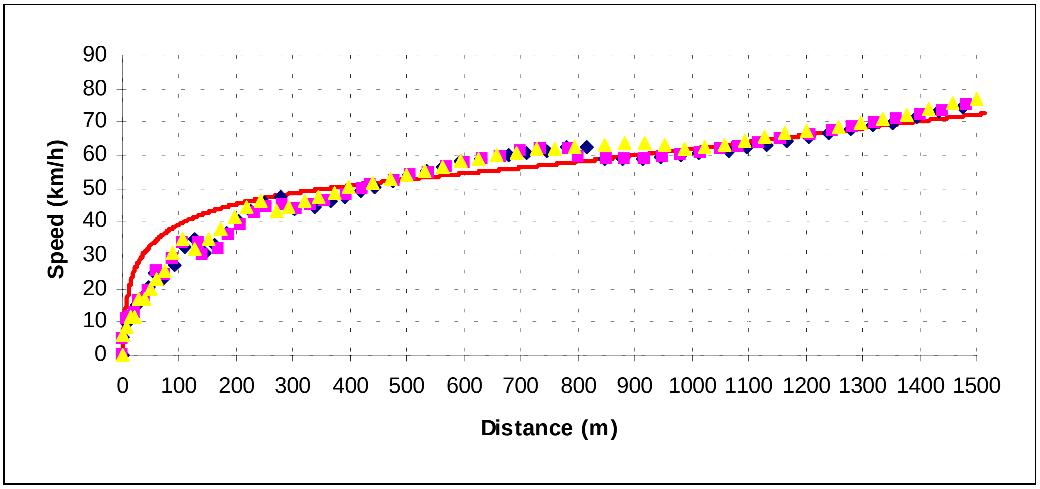


Figure B.17: Predicted and Observed Speed Profile (3-Load Configuration)

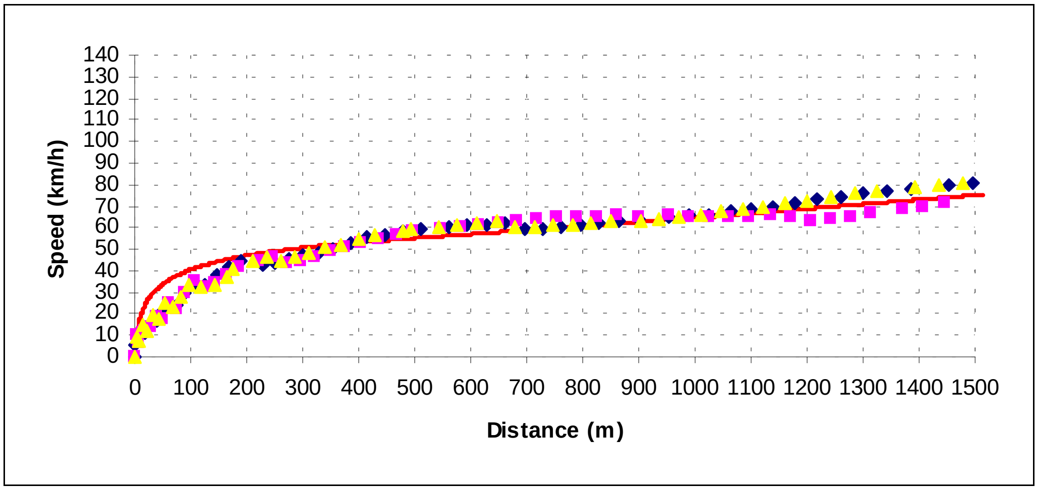


Figure B.18: Predicted and Observed Speed Profile (2-Load Configuration)

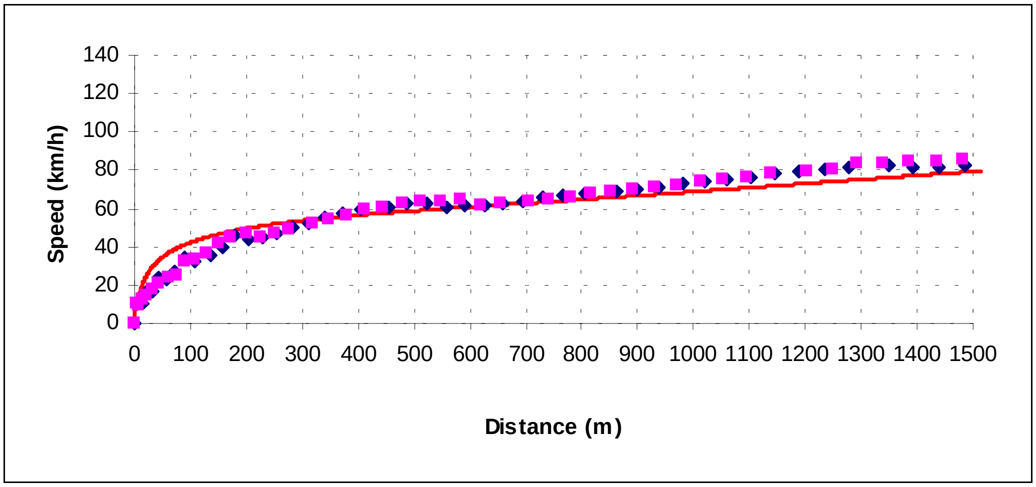


Figure B.19: Predicted and Observed Speed Profile (1-Load Configuration)

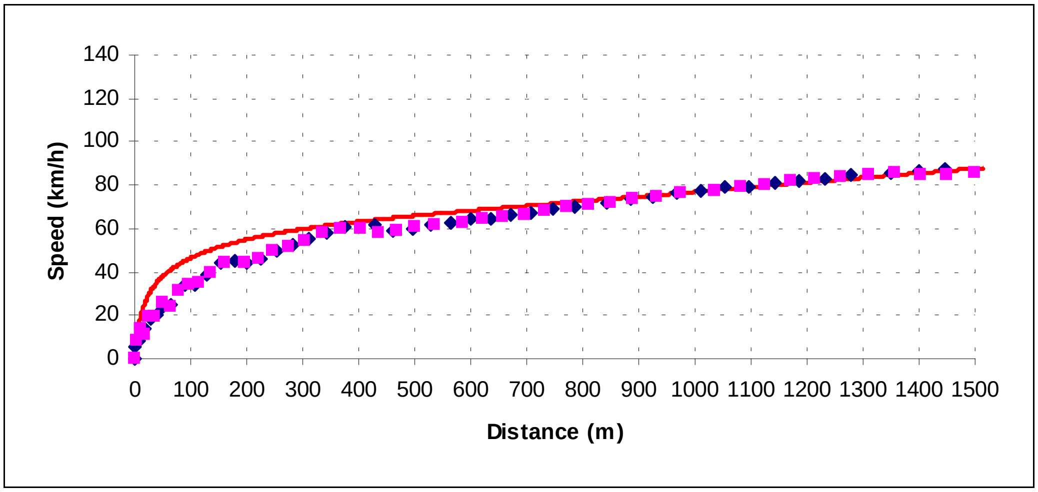


Figure B.20: Predicted and Observed Speed Profile (0-Load Configuration)

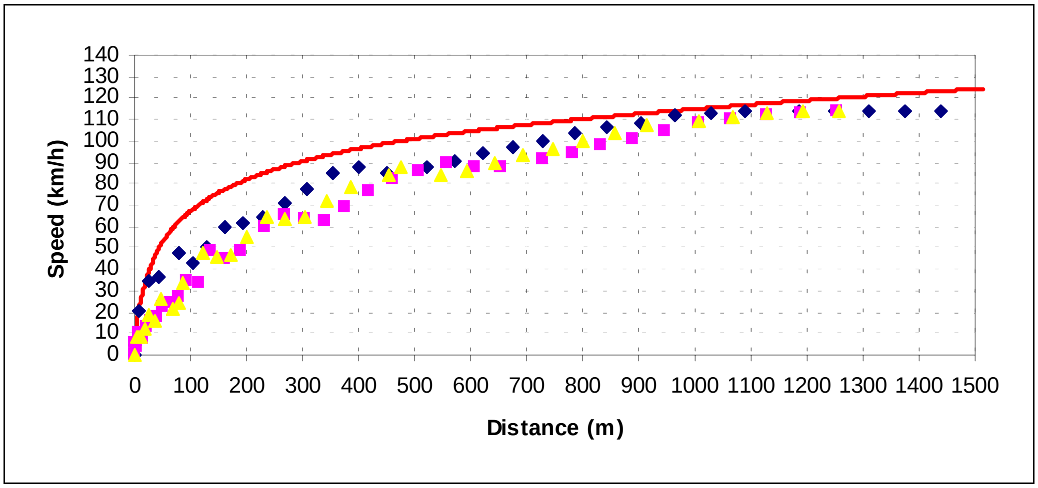


Figure B.21: Predicted and Observed Speed Profile (Truck Configuration)

350 kW (470 hp) truck

Table B.22: Example Solution to ODE (9-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	94479	0.0596	0.00	2481.73	25876.55	28358.28
1	0.60	4.84	1.49	94479	0.0596	6.52	2567.82	25877.42	28451.75
2	2.69	10.21	1.49	94479	0.0596	29.01	2663.31	25880.31	28572.63
3	6.26	15.21	1.11	78014	0.0596	64.42	2752.33	25884.91	28701.67
4	10.98	18.62	0.79	63718	0.0597	96.57	2813.05	25890.38	28800.00
5	16.52	21.15	0.61	56090	0.0597	124.63	2858.11	25895.87	28878.60
6	22.69	23.17	0.50	51201	0.0597	149.56	2894.04	25900.81	28944.41
7	29.36	24.85	0.42	47750	0.0597	171.96	2923.84	25904.78	29000.59
8	36.47	26.27	0.36	45162	0.0597	192.24	2949.18	25907.46	29048.87
9	43.94	27.50	0.32	43139	0.0597	210.69	2971.10	25908.55	29090.34
10	51.73	28.58	0.28	41509	0.0597	227.55	2990.31	25907.82	29125.69

Table B.23: Example Solution to ODE (8-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	93038	0.0596	0.00	2319.44	24184.34	26503.77
1	0.65	5.21	1.61	93038	0.0596	7.56	2406.06	24185.21	26598.82
2	2.90	10.99	1.60	93038	0.0596	33.62	2502.15	24188.11	26723.88
3	6.72	16.17	1.13	73399	0.0596	72.78	2588.24	24192.68	26853.70
4	11.72	19.64	0.81	60422	0.0597	107.40	2645.98	24198.00	26951.37
5	17.55	22.24	0.64	53339	0.0597	137.81	2689.34	24203.24	27030.40
6	24.03	24.34	0.52	48747	0.0597	165.00	2724.18	24207.86	27097.04
7	31.04	26.09	0.44	45483	0.0597	189.53	2753.24	24211.45	27154.22
8	38.50	27.58	0.38	43021	0.0597	211.84	2778.05	24213.66	27203.55
9	46.34	28.88	0.33	41090	0.0597	232.22	2799.61	24214.22	27246.05
10	54.52	30.02	0.30	39529	0.0597	250.92	2818.57	24212.89	27282.39

Table B.24: Example Solution to ODE (7-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	86579	0.0596	0.00	2210.05	23043.82	25253.87
1	0.63	5.04	1.55	86579	0.0596	7.07	2289.89	23044.62	25341.58
2	2.81	10.63	1.55	86579	0.0596	31.46	2378.46	23047.30	25457.22
3	6.52	15.98	1.23	74228	0.0596	71.16	2463.33	23051.56	25586.04
4	11.52	19.76	0.87	60051	0.0597	108.73	2523.12	23056.65	25688.49
5	17.41	22.56	0.68	52597	0.0597	141.73	2567.49	23061.72	25770.94
6	24.00	24.80	0.56	47849	0.0597	171.25	2602.96	23066.22	25840.42
7	31.15	26.66	0.47	44505	0.0597	197.95	2632.47	23069.69	25900.11
8	38.79	28.25	0.41	42001	0.0597	222.25	2657.65	23071.81	25951.72
9	46.83	29.63	0.36	40044	0.0597	244.51	2679.53	23072.27	25996.30
10	55.23	30.84	0.32	38468	0.0597	264.96	2698.77	23070.83	26034.56

Table B.25: Example Solution to ODE (6-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	80334	0.0596	0.00	2091.00	21802.51	23893.51
1	0.61	4.90	1.51	80334	0.0596	6.69	2164.48	21803.24	23974.42
2	2.73	10.34	1.51	80334	0.0596	29.77	2245.99	21805.71	24081.48
3	6.36	15.74	1.37	75373	0.0596	69.02	2326.99	21809.66	24205.66
4	11.34	19.89	0.95	59656	0.0597	110.17	2389.17	21814.48	24313.82
5	17.30	22.92	0.73	51765	0.0597	146.32	2434.61	21819.37	24400.30
6	24.02	25.33	0.60	46842	0.0597	178.69	2470.73	21823.71	24473.13
7	31.34	27.33	0.51	43415	0.0597	208.01	2500.70	21827.06	24535.77
8	39.17	29.03	0.44	40867	0.0597	234.77	2526.25	21829.05	24590.07
9	47.45	30.51	0.38	38885	0.0597	259.31	2548.43	21829.39	24637.13
10	56.11	31.82	0.34	37293	0.0597	281.91	2567.95	21827.82	24677.68

Table B.26: Example Solution to ODE (5-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	76811	0.0596	0.00	1985.18	20699.12	22684.30
1	0.62	4.95	1.53	76811	0.0596	6.83	2055.65	20699.83	22762.30
2	2.76	10.44	1.52	76811	0.0596	30.38	2133.82	20702.19	22866.39
3	6.42	15.92	1.46	74510	0.0596	70.62	2211.82	20705.97	22988.42
4	11.49	20.31	1.00	58432	0.0597	114.84	2274.19	20710.62	23099.64
5	17.59	23.50	0.77	50500	0.0597	153.74	2319.58	20715.33	23188.65
6	24.48	26.03	0.63	45586	0.0597	188.67	2355.62	20719.49	23263.78
7	32.01	28.13	0.53	42180	0.0597	220.38	2385.54	20722.65	23328.56
8	40.08	29.92	0.46	39652	0.0597	249.37	2411.06	20724.44	23384.86
9	48.61	31.48	0.40	37689	0.0597	276.02	2433.24	20724.55	23433.80
10	57.55	32.85	0.36	36114	0.0597	300.62	2452.78	20722.72	23476.12

Table B.27: Example Solution to ODE (4-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	69819	0.0596	0.00	1817.29	18948.55	20765.84
1	0.61	4.90	1.51	69819	0.0596	6.69	1881.15	18949.19	20837.04
2	2.73	10.34	1.51	69819	0.0596	29.77	1951.99	18951.34	20933.10
3	6.36	15.76	1.51	69819	0.0596	69.21	2022.68	18954.77	21046.66
4	11.45	20.65	1.12	57452	0.0597	118.78	2086.36	18959.05	21164.19
5	17.70	24.21	0.86	49007	0.0597	163.25	2132.73	18963.46	21259.44
6	24.83	27.01	0.70	43920	0.0597	203.26	2169.27	18967.36	21339.89
7	32.67	29.34	0.59	40446	0.0597	239.68	2199.50	18970.28	21409.46
8	41.10	31.31	0.51	37891	0.0597	273.08	2225.27	18971.83	21470.18
9	50.04	33.03	0.44	35920	0.0597	303.88	2247.66	18971.69	21523.23
10	59.43	34.55	0.39	34344	0.0597	332.40	2267.40	18969.58	21569.38

Table B.28: Example Solution to ODE (3-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	62346	0.0596	0.00	1720.12	17935.35	19655.46
1	0.56	4.51	1.39	62346	0.0596	5.66	1775.70	17935.90	19717.26
2	2.51	9.51	1.39	62346	0.0596	25.17	1837.35	17937.78	19800.29
3	5.84	14.49	1.38	62346	0.0596	58.51	1898.87	17940.79	19898.17
4	10.56	19.47	1.33	60937	0.0597	105.59	1960.24	17944.62	20010.44
5	16.58	23.63	0.98	50212	0.0597	155.51	2011.53	17948.77	20115.81
6	23.60	26.81	0.78	44248	0.0597	200.26	2050.80	17952.59	20203.66
7	31.42	29.41	0.65	40340	0.0597	240.94	2082.84	17955.57	20279.34
8	39.90	31.61	0.56	37539	0.0597	278.24	2109.91	17957.27	20345.41
9	48.95	33.50	0.49	35413	0.0597	312.65	2133.31	17957.35	20403.30
10	58.50	35.17	0.43	33735	0.0597	344.53	2153.86	17955.53	20453.92

Table B.29: Example Solution to ODE (2-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	54926	0.0596	0.00	1576.65	16439.41	18016.06
1	0.53	4.25	1.31	54926	0.0596	5.03	1624.70	16439.89	18069.62
2	2.37	8.97	1.31	54926	0.0596	22.39	1678.00	16441.51	18141.91
3	5.51	13.67	1.31	54926	0.0596	52.06	1731.19	16444.13	18227.39
4	9.96	18.37	1.30	54926	0.0597	93.94	1784.25	16447.48	18325.68
5	15.71	23.00	1.18	51589	0.0597	147.32	1836.62	16451.21	18435.15
6	22.65	26.78	0.92	44311	0.0597	199.68	1879.32	16454.80	18533.80
7	30.52	29.79	0.75	39823	0.0597	247.23	1913.43	16457.69	18618.35
8	39.15	32.32	0.64	36716	0.0597	290.84	1941.93	16459.42	18692.19
9	48.44	34.48	0.56	34411	0.0597	331.11	1966.40	16459.62	18757.13
10	58.29	36.37	0.49	32620	0.0597	368.48	1987.80	16457.96	18814.25

Table B.30: Example Solution to ODE (1-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	45051	0.0596	0.00	1420.46	14810.85	16231.31
1	0.46	3.68	1.14	45051	0.0596	3.78	1457.98	14811.23	16272.99
2	2.05	7.77	1.13	45051	0.0596	16.82	1499.60	14812.50	16328.92
3	4.78	11.85	1.13	45051	0.0596	39.11	1541.13	14814.57	16394.81
4	8.63	15.92	1.13	45051	0.0597	70.57	1582.56	14817.26	16470.39
5	13.62	19.97	1.13	45051	0.0597	111.12	1623.88	14820.33	16555.33
6	19.73	24.02	1.12	45051	0.0597	160.67	1665.06	14823.47	16649.20
7	26.96	27.98	1.01	42399	0.0597	218.11	1705.45	14826.29	16749.84
8	35.21	31.31	0.83	37891	0.0597	273.08	1739.35	14828.34	16840.77
9	44.30	34.09	0.71	34804	0.0597	323.67	1767.63	14829.17	16920.47
10	54.11	36.47	0.61	32529	0.0597	370.53	1791.91	14828.41	16990.85

Table B.31: Example Solution to ODE (0-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	45638	0.0596	0.00	1258.67	13123.94	14382.61
1	0.56	4.51	1.39	45638	0.0596	5.66	1299.36	13124.35	14429.38
2	2.51	9.51	1.39	45638	0.0596	25.19	1344.50	13125.72	14495.41
3	5.85	14.50	1.38	45638	0.0596	58.56	1389.52	13127.93	14576.01
4	10.57	19.48	1.38	45638	0.0597	105.64	1434.42	13130.73	14670.80
5	16.67	24.44	1.37	45638	0.0597	166.30	1479.18	13133.80	14779.28
6	24.12	29.13	1.15	40733	0.0597	236.31	1521.53	13136.74	14894.58
7	32.76	32.90	0.94	36063	0.0597	301.48	1555.57	13139.01	14996.05
8	42.34	36.03	0.80	32928	0.0597	361.60	1583.83	13140.13	15085.56
9	52.73	38.72	0.69	30647	0.0597	417.45	1608.04	13139.69	15165.18
10	63.82	41.06	0.61	28896	0.0597	469.58	1629.21	13137.35	15236.14

Table B.32: Example Solution to ODE (Truck Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	25408	0.0596	0.00	469.59	4896.28	5365.87
1	0.97	7.75	2.39	25408	0.0596	16.72	495.67	4896.54	5408.94
2	4.31	16.33	2.38	25408	0.0596	74.29	524.57	4897.40	5496.25
3	10.04	24.87	2.36	25408	0.0597	172.25	553.31	4898.70	5624.27
4	18.12	33.34	2.34	25408	0.0597	309.66	581.84	4900.20	5791.70
5	28.56	41.74	2.32	25408	0.0597	485.22	610.11	4901.55	5996.87
6	41.30	49.93	2.09	23765	0.0597	694.24	637.67	4902.30	6234.21
7	56.16	56.82	1.72	20883	0.0597	899.02	660.86	4901.96	6461.85
8	72.76	62.58	1.47	18960	0.0597	1090.66	680.26	4900.06	6670.98
9	90.85	67.54	1.28	17567	0.0596	1270.47	696.97	4896.20	6863.64
10	110.23	71.89	1.13	16504	0.0596	1439.47	711.62	4890.03	7041.12

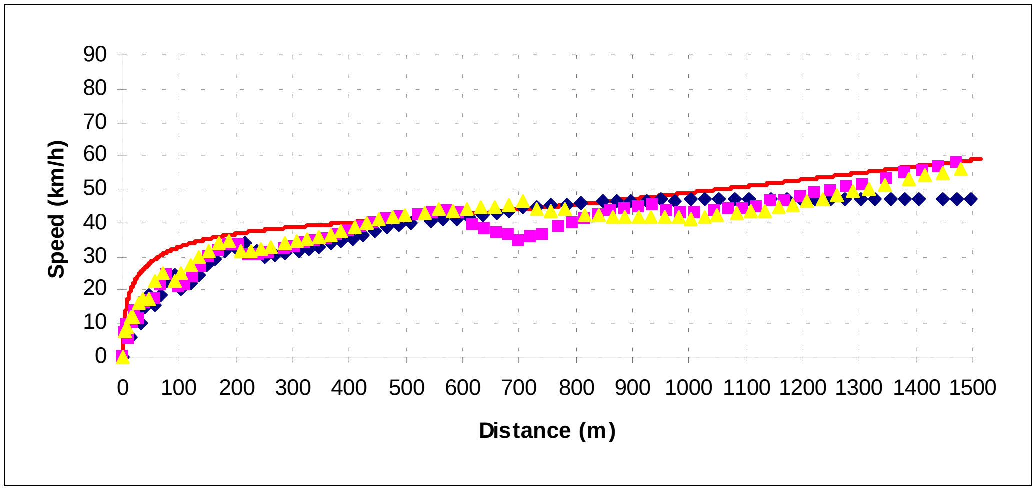


Figure B.22: Predicted and Observed Speed Profile (9-Load Configuration)

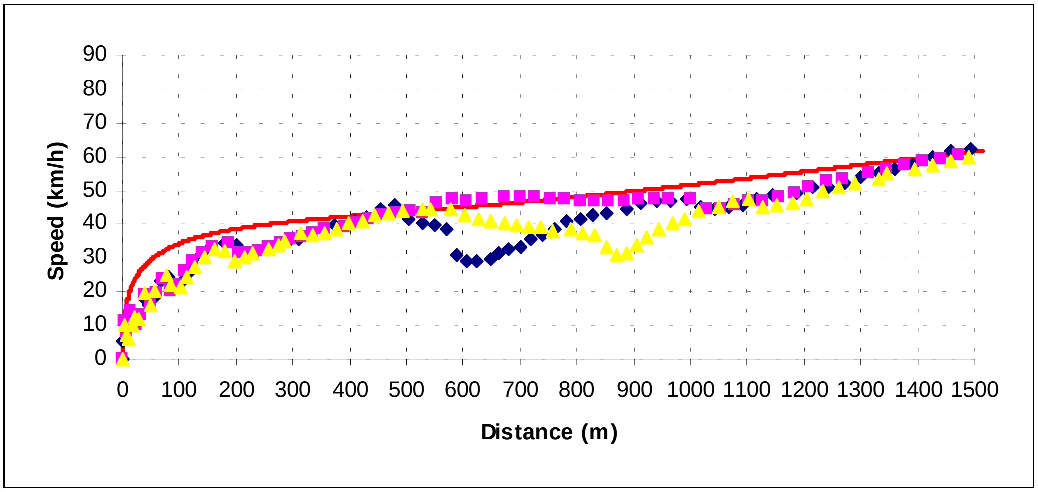


Figure B.23: Predicted and Observed Speed Profile (8-Load Configuration)

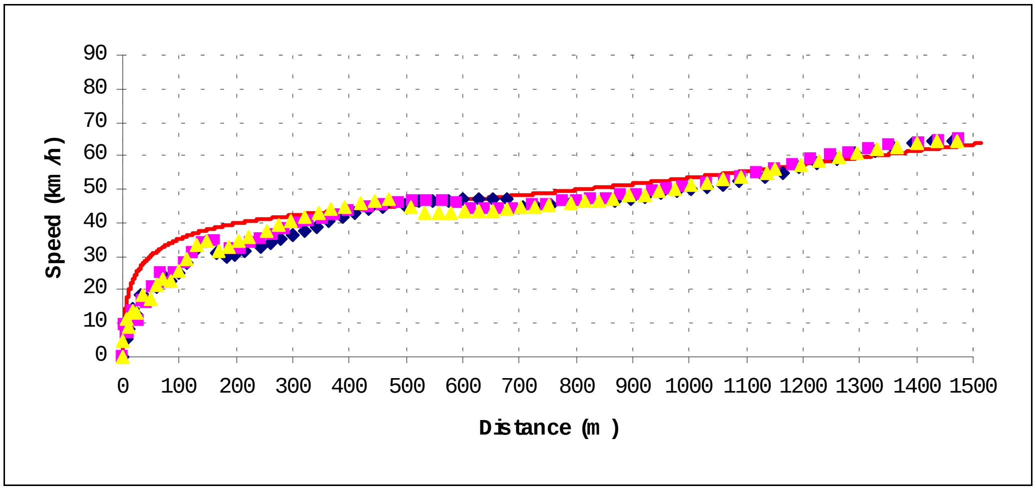


Figure B.24: Predicted and Observed Speed Profile (7-Load Configuration)

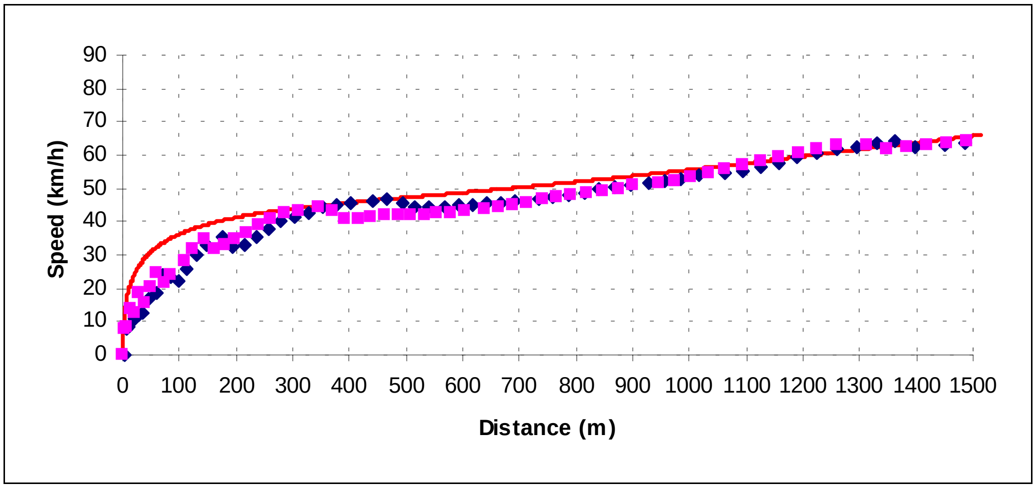


Figure B.25: Predicted and Observed Speed Profile (6-Load Configuration)

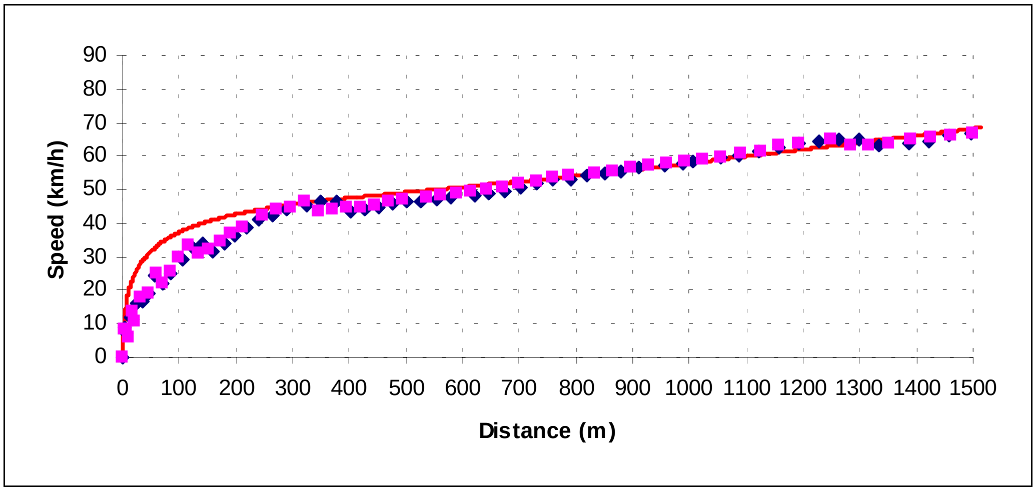


Figure B.26: Predicted and Observed Speed Profile (5-Load Configuration)

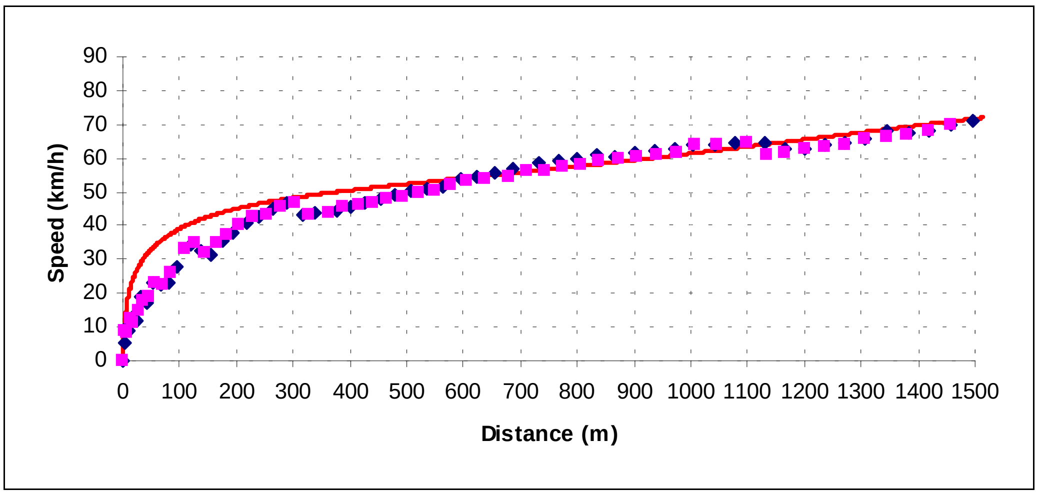


Figure B.27: Predicted and Observed Speed Profile (4-Load Configuration)

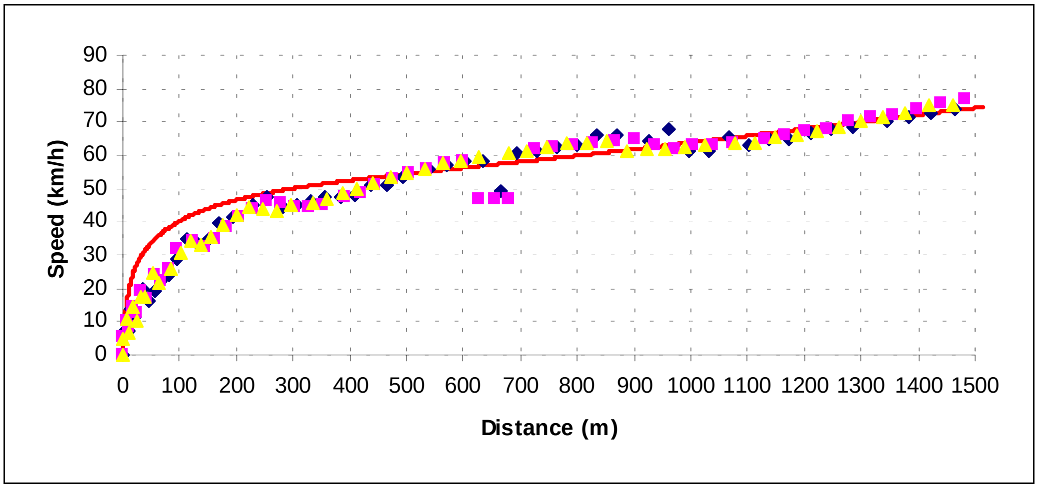


Figure B.28: Predicted and Observed Speed Profile (3-Load Configuration)

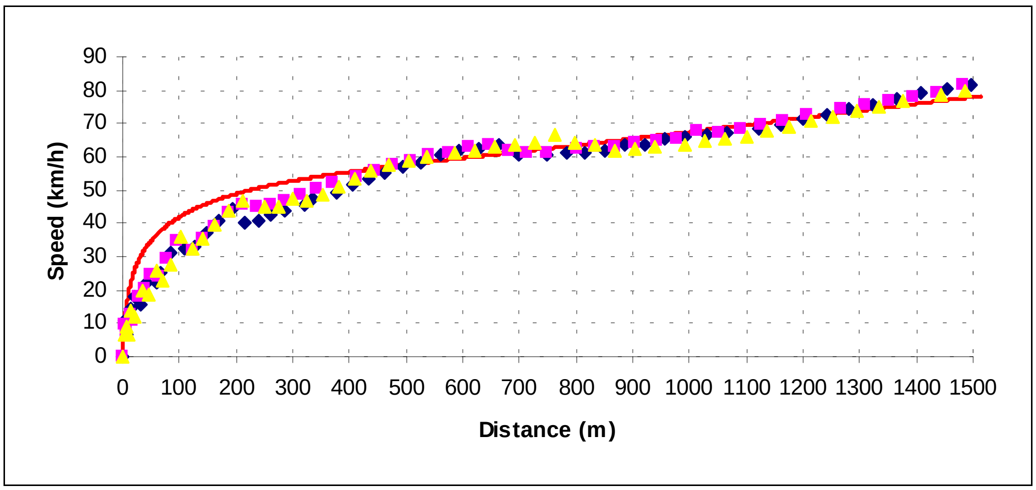


Figure B.29: Predicted and Observed Speed Profile (2-Load Configuration)

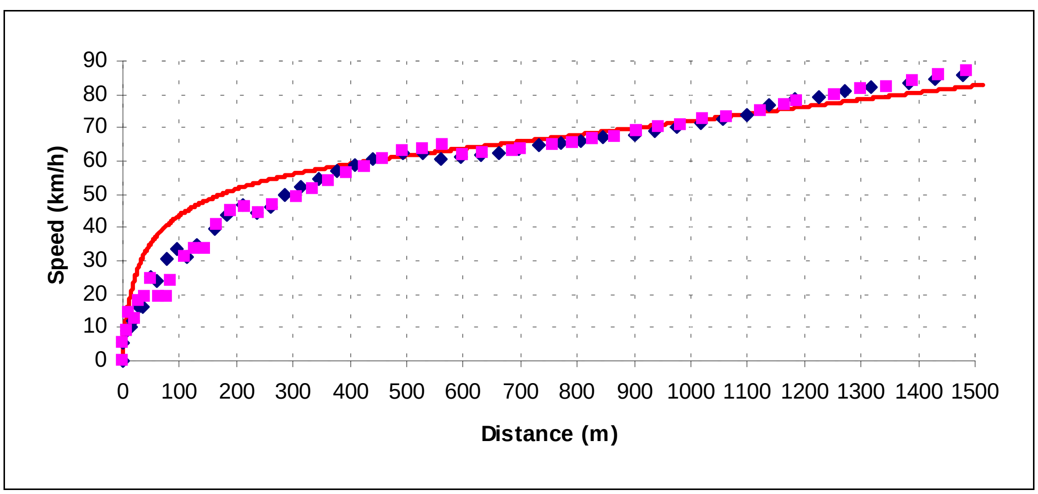


Figure B.30: Predicted and Observed Speed Profile (1-Load Configuration)

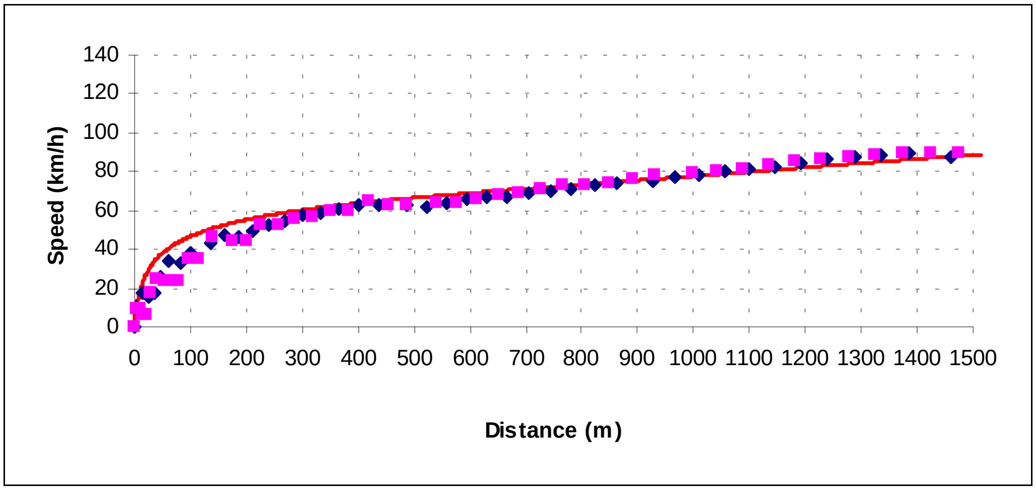


Figure B.31: Predicted and Observed Speed Profile (0-Load Configuration)

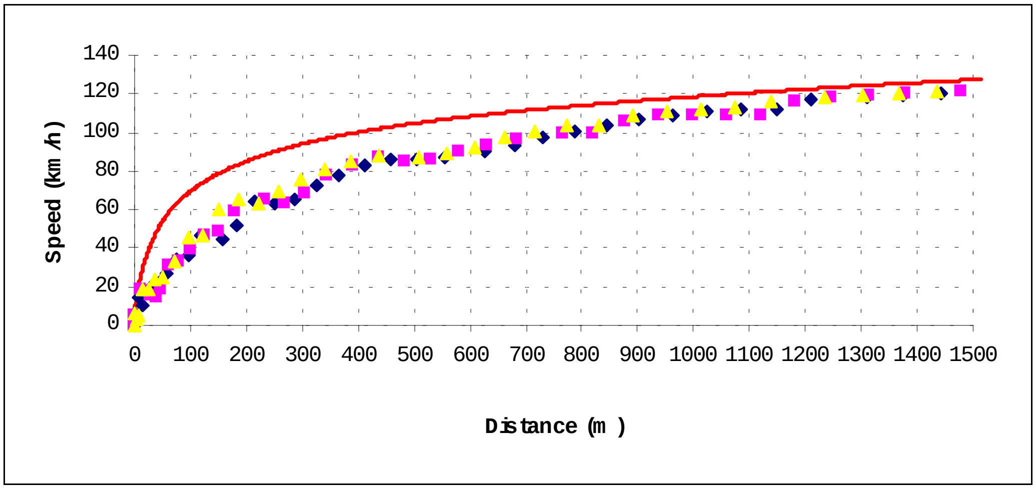


Figure B.32: Predicted and Observed Speed Profile (Truck Configuration)

375 kW (500 hp) truck

Table B.33: Example Solution to ODE (9-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	99858	0.0596	0.00	2512.77	26200.14	28712.91
1	0.64	5.14	1.59	99858	0.0596	8.12	2605.39	26201.07	28814.59
2	2.86	10.85	1.58	99858	0.0596	36.15	2708.14	26204.18	28948.46
3	6.63	15.97	1.11	79042	0.0596	78.37	2800.45	26209.07	29087.90
4	11.57	19.41	0.80	65045	0.0597	115.73	2862.36	26214.78	29192.87
5	17.33	21.98	0.63	57420	0.0597	148.50	2908.78	26220.43	29277.71
6	23.74	24.05	0.52	52484	0.0597	177.76	2946.03	26225.43	29349.21
7	30.66	25.77	0.44	48976	0.0597	204.13	2977.06	26229.34	29410.53
8	38.03	27.24	0.38	46333	0.0597	228.08	3003.54	26231.81	29463.43
9	45.78	28.52	0.33	44261	0.0597	249.94	3026.52	26232.54	29509.00
10	53.86	29.64	0.29	42586	0.0597	269.98	3046.72	26231.27	29547.97

Table B.34: Example Solution to ODE (8-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	97071	0.0596	0.00	2374.76	24761.23	27135.99
1	0.67	5.35	1.65	97071	0.0596	8.79	2465.81	24762.14	27236.74
2	2.98	11.28	1.65	97071	0.0596	39.10	2566.81	24765.19	27371.10
3	6.89	16.57	1.15	76176	0.0596	84.38	2656.88	24769.98	27511.24
4	12.02	20.12	0.83	62732	0.0597	124.42	2717.34	24775.52	27617.28
5	17.99	22.80	0.65	55371	0.0597	159.70	2762.88	24780.95	27703.53
6	24.63	24.95	0.54	50591	0.0597	191.31	2799.55	24785.69	27776.55
7	31.82	26.75	0.46	47187	0.0597	219.90	2830.19	24789.30	27839.39
8	39.47	28.29	0.39	44619	0.0597	245.94	2856.41	24791.42	27893.78
9	47.52	29.63	0.35	42601	0.0597	269.79	2879.22	24791.75	27940.76
10	55.91	30.81	0.31	40969	0.0597	291.71	2899.31	24790.04	27981.06

Table B.35: Example Solution to ODE (7-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	94131	0.0596	0.00	2236.76	23322.32	25559.08
1	0.70	5.57	1.72	94131	0.0596	9.52	2326.04	23323.21	25658.77
2	3.10	11.74	1.71	94131	0.0596	42.37	2425.06	23326.20	25793.63
3	7.17	17.21	1.19	73333	0.0597	91.05	2512.79	23330.86	25934.69
4	12.49	20.89	0.86	60414	0.0597	134.15	2571.81	23336.22	26042.18
5	18.70	23.68	0.68	53310	0.0597	172.29	2616.46	23341.42	26130.17
6	25.60	25.93	0.56	48684	0.0597	206.58	2652.53	23345.90	26205.01
7	33.07	27.81	0.48	45385	0.0597	237.71	2682.76	23349.20	26269.67
8	41.02	29.43	0.42	42891	0.0597	266.15	2708.69	23350.96	26325.80
9	49.40	30.84	0.36	40930	0.0597	292.27	2731.30	23350.88	26374.45
10	58.14	32.08	0.32	39341	0.0597	316.35	2751.27	23348.70	26416.32

Table B.36: Example Solution to ODE (6-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	90976	0.0596	0.00	2098.76	21883.40	23982.17
1	0.72	5.80	1.79	90976	0.0596	10.33	2185.98	21884.28	24080.59
2	3.23	12.23	1.78	90976	0.0596	45.94	2282.72	21887.19	24215.85
3	7.46	17.90	1.23	70521	0.0597	98.45	2368.08	21891.72	24358.25
4	13.00	21.73	0.90	58096	0.0597	145.07	2425.68	21896.88	24467.64
5	19.45	24.63	0.71	51238	0.0597	186.50	2469.43	21901.85	24557.79
6	26.63	26.99	0.59	46765	0.0597	223.89	2504.89	21906.05	24634.82
7	34.41	28.97	0.50	43569	0.0597	257.94	2534.68	21909.02	24701.64
8	42.70	30.67	0.44	41151	0.0597	289.15	2560.30	21910.41	24759.86
9	51.43	32.16	0.39	39246	0.0597	317.89	2582.70	21909.90	24810.50
10	60.55	33.48	0.34	37702	0.0597	344.47	2602.53	21907.24	24854.24

Table B.37: Example Solution to ODE (5-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	83118	0.0596	0.00	1960.76	20444.49	22405.25
1	0.70	5.62	1.73	83118	0.0596	8.81	2039.80	20445.28	22493.89
2	3.13	11.86	1.73	83118	0.0596	39.17	2127.48	20447.93	22614.57
3	7.28	17.82	1.37	70825	0.0597	88.46	2211.29	20452.08	22751.84
4	12.85	22.05	0.98	57246	0.0597	135.40	2270.72	20456.97	22863.09
5	19.43	25.22	0.77	50048	0.0597	177.15	2315.30	20461.72	22954.17
6	26.81	27.78	0.64	45440	0.0597	214.90	2351.25	20465.73	23031.88
7	34.83	29.92	0.55	42183	0.0597	249.37	2381.40	20468.53	23099.30
8	43.40	31.77	0.47	39735	0.0597	281.04	2407.31	20469.75	23158.10
9	52.45	33.38	0.42	37816	0.0597	310.28	2429.97	20469.07	23209.32
10	61.93	34.81	0.37	36266	0.0597	337.39	2450.04	20466.21	23253.63

Table B.38: Example Solution to ODE (4-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	77608	0.0596	0.00	1822.76	19005.58	20828.34
1	0.71	5.66	1.74	77608	0.0596	9.83	1896.68	19006.32	20912.83
2	3.15	11.93	1.74	77608	0.0596	43.74	1978.67	19008.79	21031.20
3	7.33	18.09	1.50	69769	0.0597	100.59	2059.18	19012.68	21172.45
4	13.03	22.66	1.06	55694	0.0597	157.85	2118.93	19017.31	21294.09
5	19.82	26.07	0.83	48415	0.0597	208.89	2163.46	19021.82	21394.16
6	27.45	28.81	0.69	43807	0.0597	255.14	2199.30	19025.59	21480.02
7	35.78	31.11	0.59	40571	0.0597	297.47	2229.33	19028.14	21554.95
8	44.71	33.09	0.51	38148	0.0597	336.46	2255.16	19029.09	21620.71
9	54.14	34.82	0.45	36253	0.0597	372.55	2277.76	19028.10	21678.41
10	64.03	36.35	0.40	34724	0.0597	406.07	2297.79	19024.90	21728.76

Table B.39: Example Solution to ODE (3-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	72483	0.0596	0.00	1684.76	17566.67	19251.43
1	0.72	5.74	1.77	72483	0.0596	10.12	1754.06	17567.36	19331.54
2	3.20	12.10	1.77	72483	0.0596	45.00	1830.92	17569.67	19445.60
3	7.44	18.43	1.63	68489	0.0597	104.38	1907.37	17573.32	19585.07
4	13.29	23.38	1.14	53985	0.0597	168.01	1967.17	17577.69	19712.87
5	20.31	27.05	0.89	46665	0.0597	224.85	2011.47	17581.94	19818.26
6	28.25	30.00	0.74	42081	0.0597	276.51	2047.07	17585.45	19909.02
7	36.93	32.47	0.63	38879	0.0597	323.92	2076.90	17587.73	19988.54
8	46.25	34.59	0.55	36491	0.0597	367.70	2102.56	17588.38	20058.64
9	56.12	36.45	0.48	34628	0.0597	408.34	2125.04	17587.06	20120.44
10	66.48	38.10	0.43	33127	0.0597	446.18	2144.99	17583.48	20174.65

Table B.40: Example Solution to ODE (2-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	65962	0.0596	0.00	1546.76	16127.75	17674.51
1	0.71	5.67	1.75	65962	0.0596	9.88	1609.62	16128.38	17747.88
2	3.16	11.96	1.74	65962	0.0596	43.93	1679.34	16130.48	17853.76
3	7.35	18.23	1.74	65962	0.0597	102.11	1748.90	16133.80	17984.80
4	13.22	23.76	1.27	53128	0.0597	173.47	1810.22	16137.83	18121.52
5	20.41	27.82	0.98	45375	0.0597	237.81	1855.24	16141.83	18234.87
6	28.60	31.06	0.81	40645	0.0597	296.39	1891.14	16145.11	18332.64
7	37.62	33.76	0.69	37389	0.0597	350.25	1921.13	16147.19	18418.57
8	47.32	36.08	0.60	34982	0.0597	400.12	1946.89	16147.65	18494.65
9	57.63	38.12	0.53	33115	0.0597	446.49	1969.44	16146.12	18562.05
10	68.48	39.92	0.47	31618	0.0597	489.77	1989.45	16142.32	18621.55

Table B.41: Example Solution to ODE (1-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	56353	0.0596	0.00	1408.76	14688.84	16097.60
1	0.65	5.19	1.60	56353	0.0596	8.27	1461.16	14689.37	16158.81
2	2.89	10.94	1.60	56353	0.0596	36.81	1519.29	14691.12	16247.22
3	6.73	16.68	1.59	56353	0.0596	85.55	1577.27	14693.92	16356.74
4	12.16	22.41	1.59	56328	0.0597	154.32	1635.08	14697.40	16486.80
5	19.11	27.37	1.17	46123	0.0597	230.16	1685.16	14701.07	16616.39
6	27.26	31.19	0.95	40468	0.0597	298.99	1723.79	14704.24	16727.02
7	36.37	34.33	0.79	36765	0.0597	362.24	1755.51	14706.37	16824.12
8	46.29	37.00	0.68	34111	0.0597	420.81	1782.49	14706.99	16910.30
9	56.90	39.33	0.60	32095	0.0597	475.33	1805.97	14705.73	16987.03
10	68.11	41.38	0.54	30502	0.0597	526.27	1826.71	14702.26	17055.24

Table B.42: Example Solution to ODE (0-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	47754	0.0596	0.00	1270.88	13251.26	14522.14
1	0.59	4.75	1.46	47754	0.0596	6.93	1314.15	13251.69	14572.77
2	2.64	10.01	1.46	47754	0.0596	30.82	1362.13	13253.15	14646.10
3	6.16	15.27	1.46	47754	0.0596	71.64	1409.99	13255.47	14737.10
4	11.12	20.51	1.45	47754	0.0597	129.22	1457.71	13258.42	14845.35
5	17.55	25.72	1.45	47754	0.0597	203.37	1505.27	13261.61	14970.25
6	25.38	30.50	1.16	41387	0.0597	285.85	1548.77	13264.59	15099.21
7	34.40	34.31	0.95	36788	0.0597	361.80	1583.51	13266.77	15212.07
8	44.38	37.49	0.81	33665	0.0597	432.04	1612.51	13267.65	15312.19
9	55.19	40.23	0.70	31375	0.0597	497.41	1637.45	13266.80	15401.66
10	66.70	42.63	0.62	29608	0.0597	558.52	1659.31	13263.86	15481.70

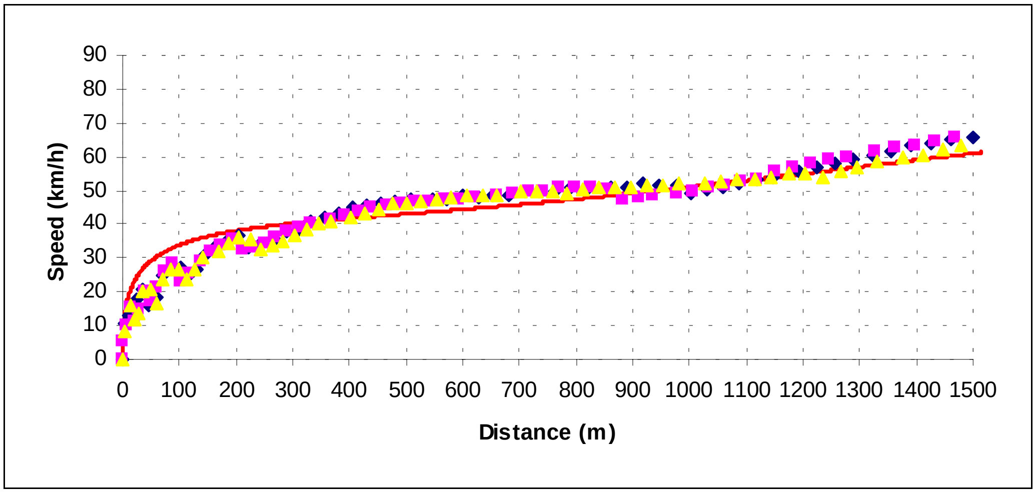


Figure B.33: Predicted and Observed Speed Profile (9-Load Configuration)

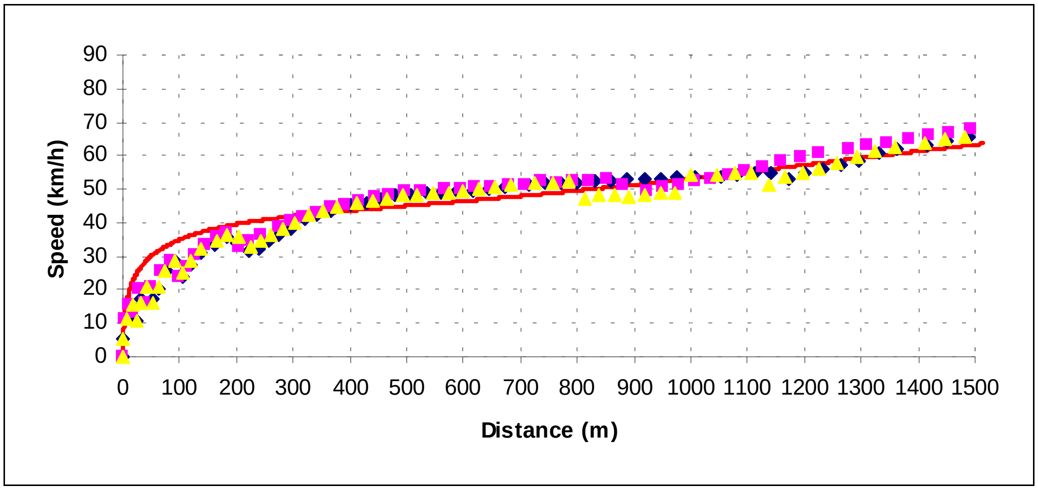


Figure B.34: Predicted and Observed Speed Profile (8-Load Configuration)

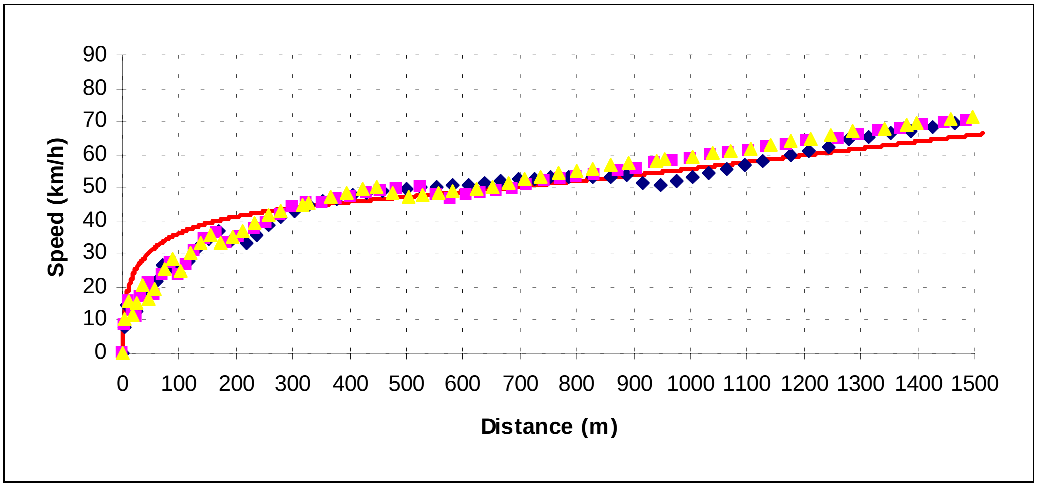


Figure B.35: Predicted and Observed Speed Profile (7-Load Configuration)

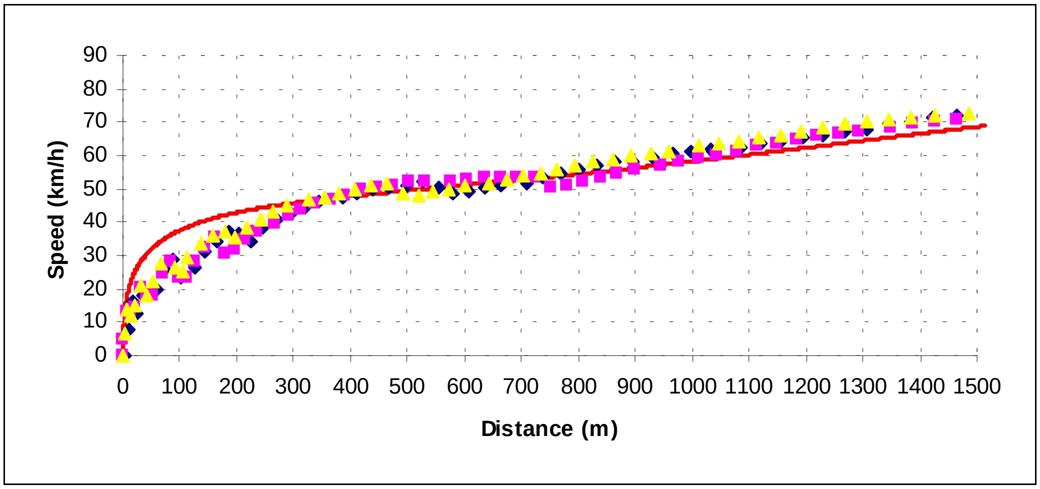


Figure B.36: Predicted and Observed Speed Profile (6-Load Configuration)

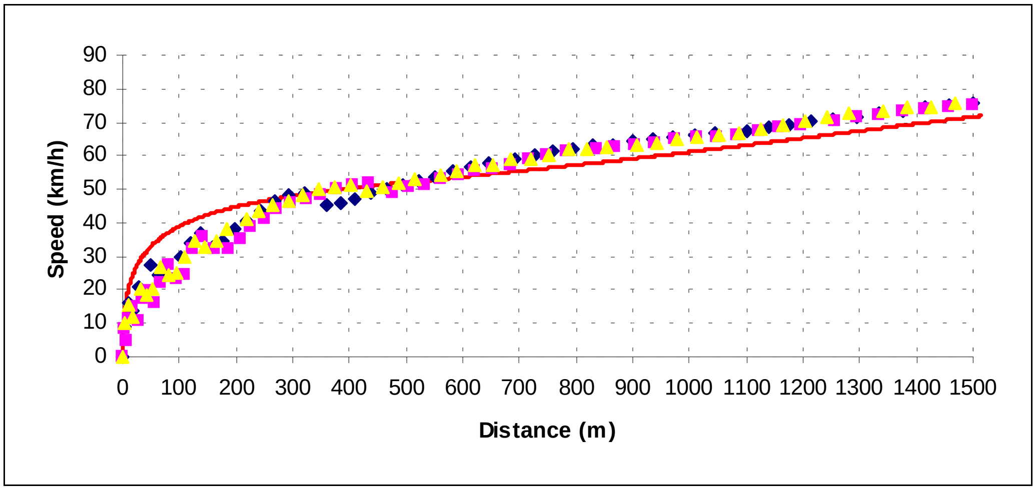


Figure B.37: Predicted and Observed Speed Profile (5-Load Configuration)

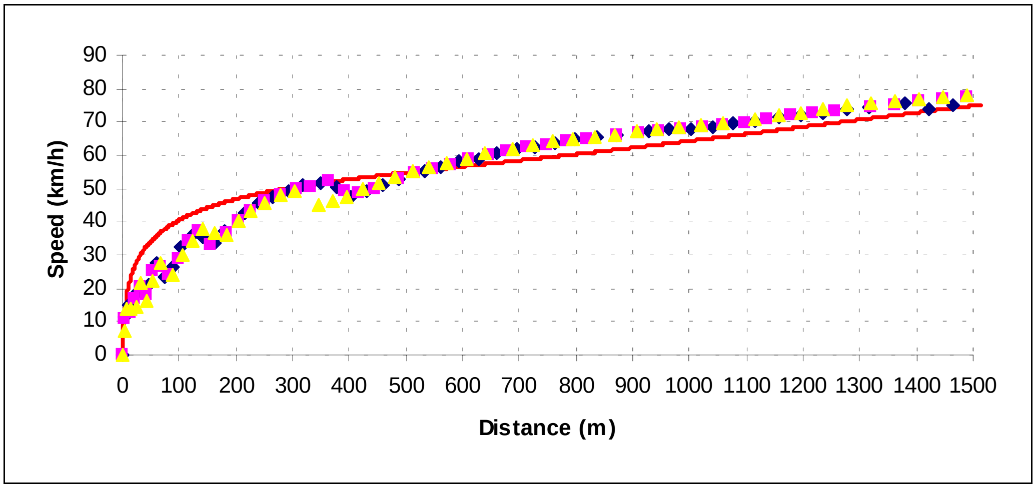


Figure B.38: Predicted and Observed Speed Profile (4-Load Configuration)

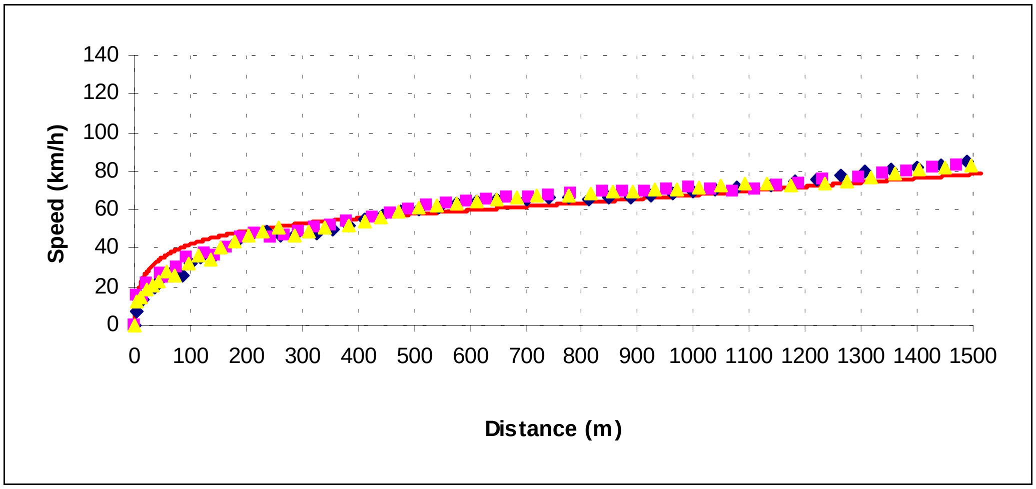


Figure B.39: Predicted and Observed Speed Profile (3-Load Configuration)

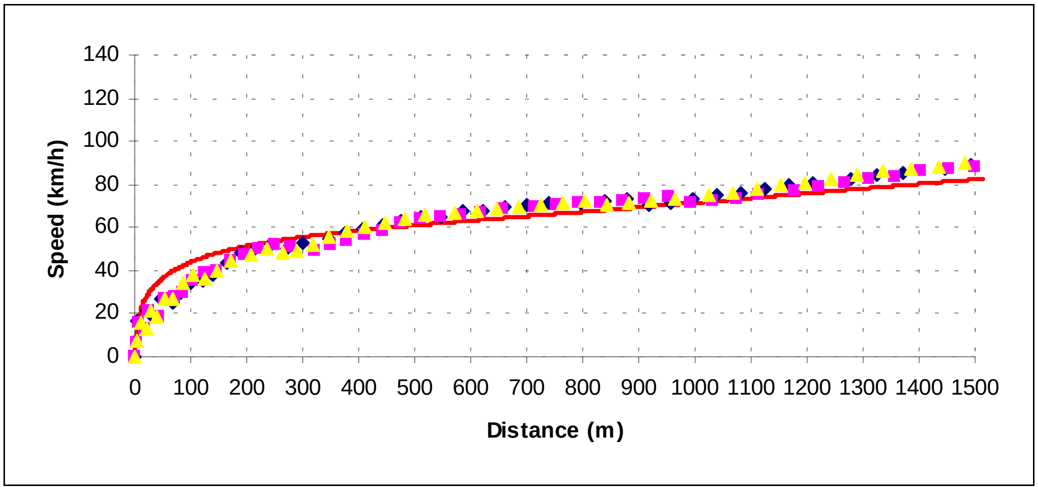


Figure B.40: Predicted and Observed Speed Profile (2-Load Configuration)

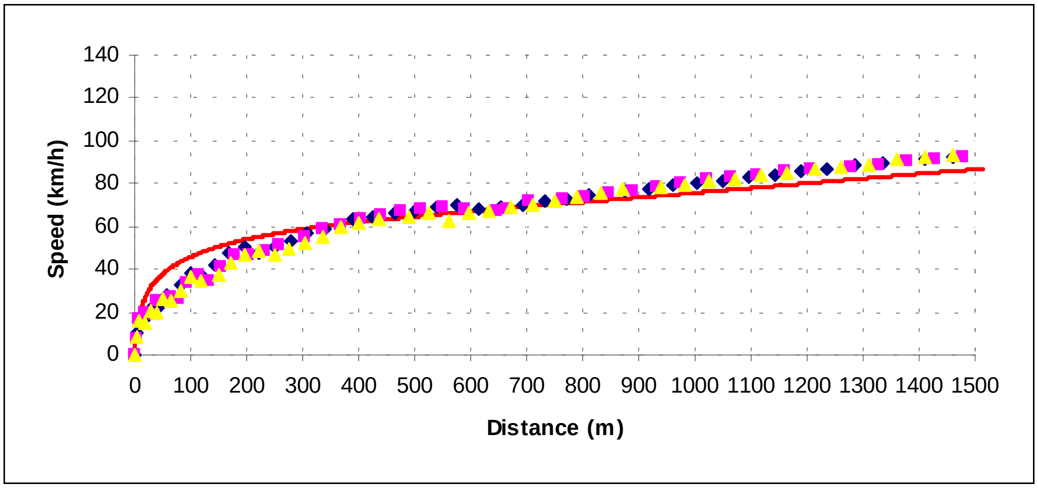


Figure B.41: Predicted and Observed Speed Profile (1-Load Configuration)

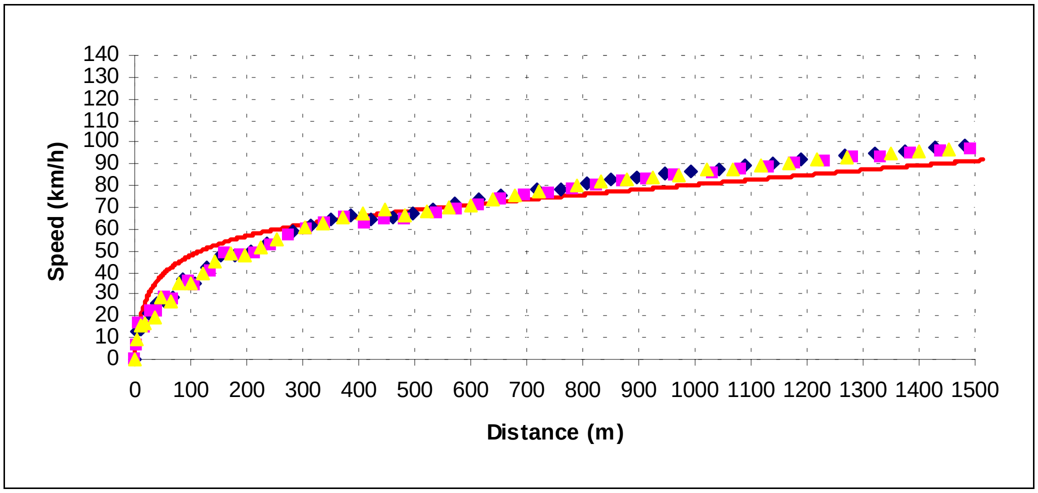


Figure B.42: Predicted and Observed Speed Profile (0-Load Configuration)

Variable Power Vehicle Dynamics Model

260 kW (350 hp) truck

Table B.43: Example Solution to ODE (9-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	39165	0.0596	0.0	2512.8	26200.1	28712.9
1	0.00	0.00	0.23	39165	0.0596	0.0	2512.8	26200.1	28712.9
2	0.00	0.84	0.23	39165	0.0596	0.3	2527.9	26200.1	28728.3
3	0.23	1.68	0.23	39165	0.0596	1.1	2543.0	26200.5	28744.5
4	0.70	2.52	0.23	39165	0.0596	2.4	2558.1	26201.2	28761.6
5	1.40	3.35	0.23	39165	0.0596	4.2	2573.1	26202.1	28779.5
6	2.33	4.19	0.23	39165	0.0596	6.6	2588.2	26203.4	28798.2
7	3.49	5.02	0.23	39165	0.0596	9.4	2603.2	26205.0	28817.6
8	4.89	5.85	0.23	39165	0.0596	12.8	2618.2	26206.9	28837.8
9	6.51	6.68	0.23	39165	0.0596	16.7	2633.1	26208.9	28858.7
10	8.37	7.51	0.23	39165	0.0597	21.1	2648.0	26211.2	28880.3

Table B.44: Example Solution to ODE (8-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	37598	0.0596	0.0	2374.8	24761.2	27136.0
1	0.00	0.00	0.25	37598	0.0596	0.0	2374.8	24761.2	27136.0
2	0.00	0.89	0.25	37598	0.0596	0.3	2389.9	24761.2	27151.4
3	0.25	1.78	0.25	37598	0.0596	1.2	2405.0	24761.6	27167.8
4	0.74	2.66	0.25	37598	0.0596	2.7	2420.1	24762.2	27185.0
5	1.48	3.55	0.25	37598	0.0596	4.7	2435.2	24763.2	27203.2
6	2.47	4.43	0.25	37598	0.0596	7.4	2450.2	24764.5	27222.1
7	3.70	5.32	0.24	37598	0.0596	10.6	2465.3	24766.1	27242.0
8	5.18	6.20	0.24	37598	0.0596	14.4	2480.3	24767.9	27262.6
9	6.90	7.07	0.24	37598	0.0596	18.7	2495.2	24770.0	27283.9
10	8.86	7.95	0.24	37598	0.0597	23.7	2510.1	24772.2	27306.0

Table B.45: Example Solution to ODE (7-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	37598	0.0596	0.0	2236.8	23322.3	25559.1
1	0.00	0.00	0.30	37598	0.0596	0.0	2236.8	23322.3	25559.1
2	0.00	1.09	0.30	37598	0.0596	0.4	2254.2	23322.3	25576.9
3	0.30	2.17	0.30	37598	0.0596	1.8	2271.6	23322.7	25596.1
4	0.91	3.26	0.30	37598	0.0596	4.0	2289.0	23323.5	25616.4
5	1.81	4.34	0.30	37598	0.0596	7.0	2306.3	23324.6	25638.0
6	3.01	5.42	0.30	37598	0.0596	11.0	2323.6	23326.1	25660.7
7	4.52	6.49	0.30	37598	0.0596	15.8	2340.9	23327.9	25684.6
8	6.32	7.57	0.30	37598	0.0596	21.5	2358.1	23329.9	25709.5
9	8.42	8.64	0.30	37598	0.0597	28.0	2375.4	23332.2	25735.5
10	10.83	9.71	0.30	37598	0.0597	35.3	2392.5	23334.6	25762.5

Table B.46: Example Solution to ODE (6-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	34813	0.0596	0.0	2098.8	21883.4	23982.2
1	0.00	0.00	0.29	34813	0.0596	0.0	2098.8	21883.4	23982.2
2	0.00	1.04	0.29	34813	0.0596	0.4	2114.4	21883.4	23998.3
3	0.29	2.08	0.29	34813	0.0596	1.6	2130.1	21883.8	24015.5
4	0.87	3.12	0.29	34813	0.0596	3.6	2145.7	21884.4	24033.8
5	1.73	4.16	0.29	34813	0.0596	6.5	2161.3	21885.5	24053.3
6	2.89	5.19	0.29	34813	0.0596	10.1	2176.9	21886.8	24073.8
7	4.33	6.23	0.29	34813	0.0596	14.5	2192.4	21888.4	24095.4
8	6.06	7.26	0.29	34813	0.0596	19.7	2208.0	21890.3	24118.0
9	8.08	8.29	0.29	34813	0.0597	25.7	2223.4	21892.3	24141.5
10	10.38	9.31	0.28	34813	0.0597	32.5	2238.9	21894.5	24165.9

Table B.47: Example Solution to ODE (5-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	32412	0.0596	0.0	1960.8	20444.5	22405.3
1	0.00	0.00	0.29	32412	0.0596	0.0	1960.8	20444.5	22405.3
2	0.00	1.03	0.29	32412	0.0596	0.4	1975.2	20444.5	22420.1
3	0.29	2.06	0.29	32412	0.0596	1.6	1989.7	20444.8	22436.1
4	0.86	3.09	0.28	32412	0.0596	3.6	2004.1	20445.5	22453.2
5	1.72	4.11	0.28	32412	0.0596	6.3	2018.6	20446.4	22471.3
6	2.86	5.14	0.28	32412	0.0596	9.9	2033.0	20447.6	22490.5
7	4.28	6.16	0.28	32412	0.0596	14.2	2047.3	20449.1	22510.6
8	5.99	7.18	0.28	32412	0.0596	19.3	2061.6	20450.8	22531.8
9	7.99	8.19	0.28	32412	0.0597	25.1	2076.0	20452.7	22553.8
10	10.26	9.21	0.28	32412	0.0597	31.8	2090.2	20454.8	22576.8

Table B.48: Example Solution to ODE (4-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	31332	0.0596	0.0	1822.8	19005.6	20828.3
1	0.00	0.00	0.32	31332	0.0596	0.0	1822.8	19005.6	20828.3
2	0.00	1.16	0.32	31332	0.0596	0.5	1838.0	19005.6	20844.0
3	0.32	2.33	0.32	31332	0.0596	2.0	1853.1	19005.9	20861.1
4	0.97	3.48	0.32	31332	0.0596	4.5	1868.3	19006.6	20879.4
5	1.94	4.64	0.32	31332	0.0596	8.1	1883.4	19007.6	20899.1
6	3.23	5.80	0.32	31332	0.0596	12.6	1898.5	19008.9	20920.0
7	4.84	6.95	0.32	31332	0.0596	18.1	1913.6	19010.4	20942.1
8	6.77	8.10	0.32	31332	0.0596	24.6	1928.6	19012.2	20965.4
9	9.02	9.25	0.32	31332	0.0597	32.1	1943.6	19014.1	20989.8
10	11.59	10.40	0.32	31332	0.0597	40.5	1958.6	19016.2	21015.3

Table B.49: Example Solution to ODE (3-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	28484	0.0596	0.0	1684.8	17566.7	19251.4
1	0.00	0.00	0.31	28484	0.0596	0.0	1684.8	17566.7	19251.4
2	0.00	1.11	0.31	28484	0.0596	0.5	1698.1	17566.7	19265.2
3	0.31	2.21	0.31	28484	0.0596	1.8	1711.5	17567.0	19280.3
4	0.92	3.31	0.31	28484	0.0596	4.1	1724.8	17567.6	19296.5
5	1.84	4.41	0.31	28484	0.0596	7.3	1738.1	17568.4	19313.8
6	3.07	5.51	0.30	28484	0.0596	11.4	1751.4	17569.6	19332.3
7	4.60	6.61	0.30	28484	0.0596	16.4	1764.6	17570.9	19351.9
8	6.44	7.70	0.30	28484	0.0596	22.2	1777.8	17572.5	19372.5
9	8.58	8.80	0.30	28484	0.0597	29.0	1791.0	17574.2	19394.2
10	11.02	9.89	0.30	28484	0.0597	36.6	1804.2	17576.1	19416.9

Table B.50: Example Solution to ODE (2-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	26110	0.0596	0.0	1546.8	16127.8	17674.5
1	0.00	0.00	0.31	26110	0.0596	0.0	1546.8	16127.8	17674.5
2	0.00	1.10	0.31	26110	0.0596	0.5	1559.0	16127.8	17687.2
3	0.31	2.20	0.30	26110	0.0596	1.8	1571.2	16128.0	17701.0
4	0.92	3.30	0.30	26110	0.0596	4.1	1583.3	16128.6	17716.0
5	1.83	4.39	0.30	26110	0.0596	7.2	1595.5	16129.4	17732.1
6	3.05	5.49	0.30	26110	0.0596	11.3	1607.6	16130.4	17749.3
7	4.58	6.58	0.30	26110	0.0596	16.2	1619.7	16131.6	17767.6
8	6.41	7.67	0.30	26110	0.0596	22.0	1631.8	16133.1	17786.9
9	8.54	8.75	0.30	26110	0.0597	28.7	1643.8	16134.7	17807.2
10	10.97	9.84	0.30	26110	0.0597	36.2	1655.9	16136.4	17828.5

Table B.51: Example Solution to ODE (1-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	24736	0.0596	0.0	1408.8	14688.8	16097.6
1	0.00	0.00	0.34	24736	0.0596	0.0	1408.8	14688.8	16097.6
2	0.00	1.24	0.34	24736	0.0596	0.6	1421.3	14688.8	16110.7
3	0.34	2.47	0.34	24736	0.0596	2.3	1433.7	14689.1	16125.2
4	1.03	3.71	0.34	24736	0.0596	5.1	1446.2	14689.7	16141.0
5	2.06	4.94	0.34	24736	0.0596	9.1	1458.6	14690.5	16158.3
6	3.43	6.17	0.34	24736	0.0596	14.3	1471.1	14691.5	16176.9
7	5.15	7.40	0.34	24736	0.0596	20.5	1483.5	14692.8	16196.7
8	7.20	8.62	0.34	24736	0.0597	27.8	1495.8	14694.2	16217.9
9	9.60	9.84	0.34	24736	0.0597	36.3	1508.1	14695.8	16240.2
10	12.33	11.06	0.34	24736	0.0597	45.8	1520.4	14697.5	16263.7

Table B.52: Example Solution to ODE (0-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	22380	0.0596	0.0	1270.9	13251.3	14522.1
1	0.00	0.00	0.35	22380	0.0596	0.0	1270.9	13251.3	14522.1
2	0.00	1.25	0.35	22380	0.0596	0.6	1282.3	13251.3	14534.1
3	0.35	2.49	0.35	22380	0.0596	2.3	1293.6	13251.5	14547.5
4	1.04	3.74	0.34	22380	0.0596	5.2	1305.0	13252.0	14562.2
5	2.08	4.98	0.34	22380	0.0596	9.3	1316.3	13252.8	14578.3
6	3.46	6.22	0.34	22380	0.0596	14.5	1327.6	13253.7	14595.8
7	5.19	7.46	0.34	22380	0.0596	20.8	1338.8	13254.9	14614.5
8	7.26	8.69	0.34	22380	0.0597	28.3	1350.1	13256.2	14634.5
9	9.68	9.92	0.34	22380	0.0597	36.9	1361.3	13257.6	14655.7
10	12.43	11.15	0.34	22380	0.0597	46.5	1372.5	13259.1	14678.1

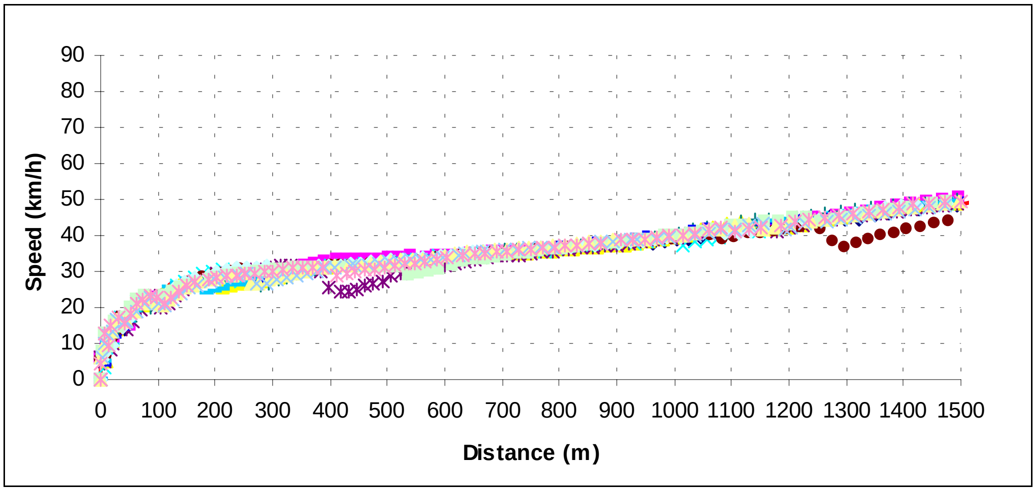


Figure B.43: Predicted and Observed Speed Profile (9-Load Configuration)

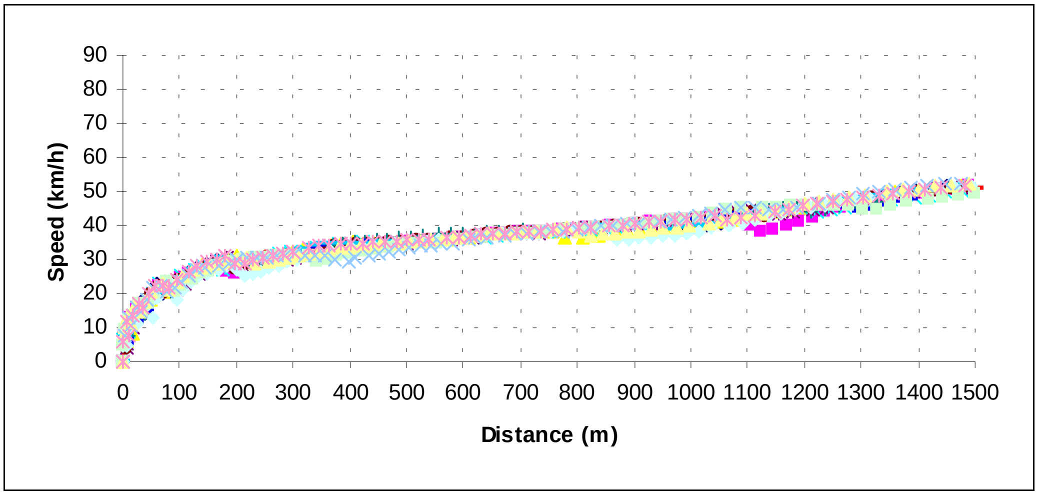


Figure B.44: Predicted and Observed Speed Profile (8-Load Configuration)

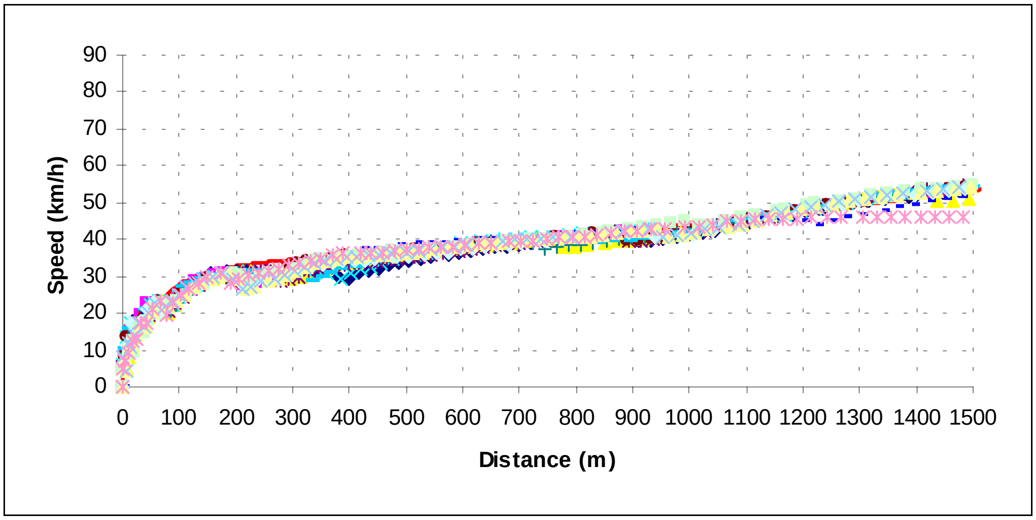


Figure B.45: Predicted and Observed Speed Profile (7-Load Configuration)

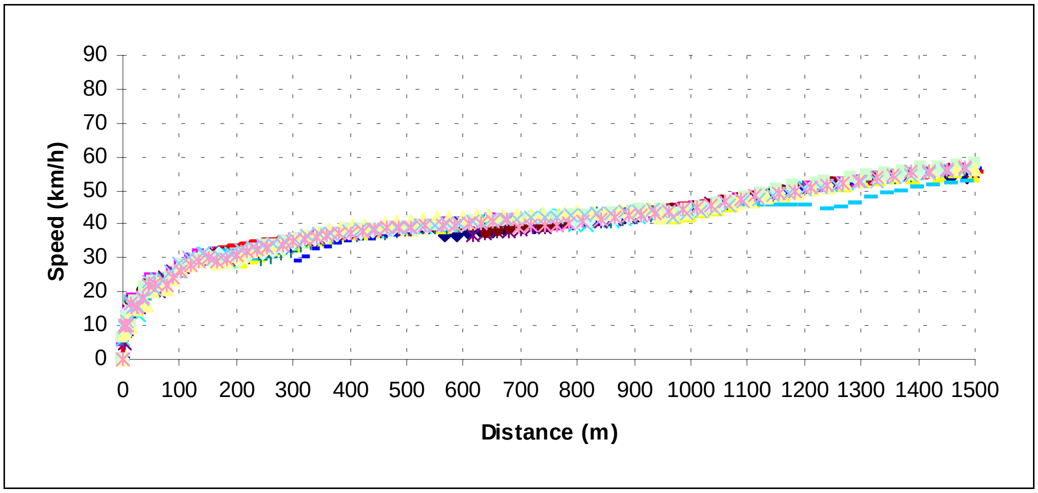


Figure B.46: Predicted and Observed Speed Profile (6-Load Configuration)

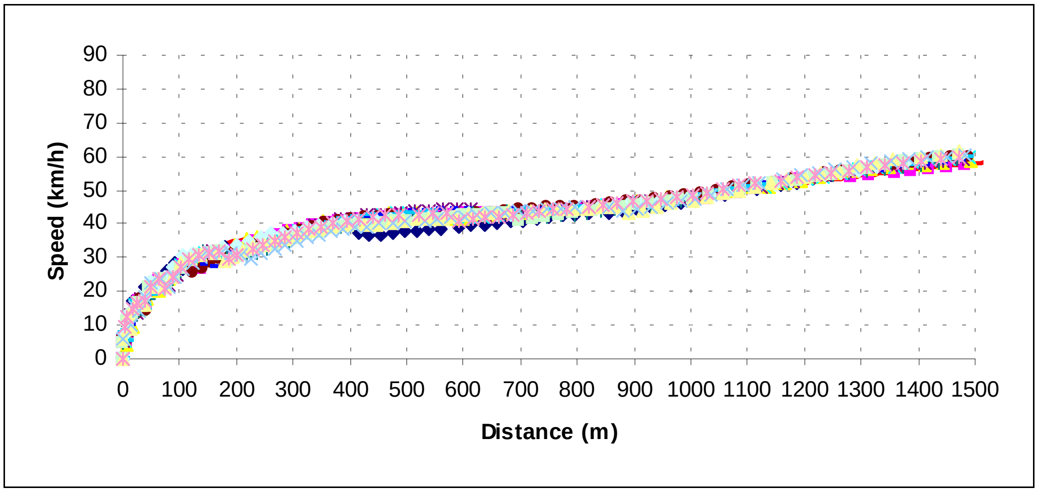


Figure B.47: Predicted and Observed Speed Profile (5-Load Configuration)

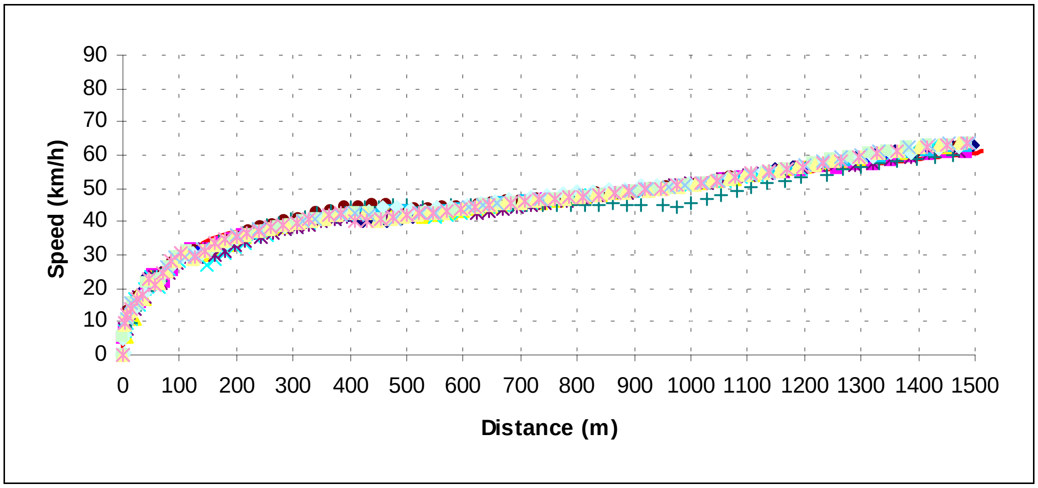


Figure B.48: Predicted and Observed Speed Profile (4-Load Configuration)

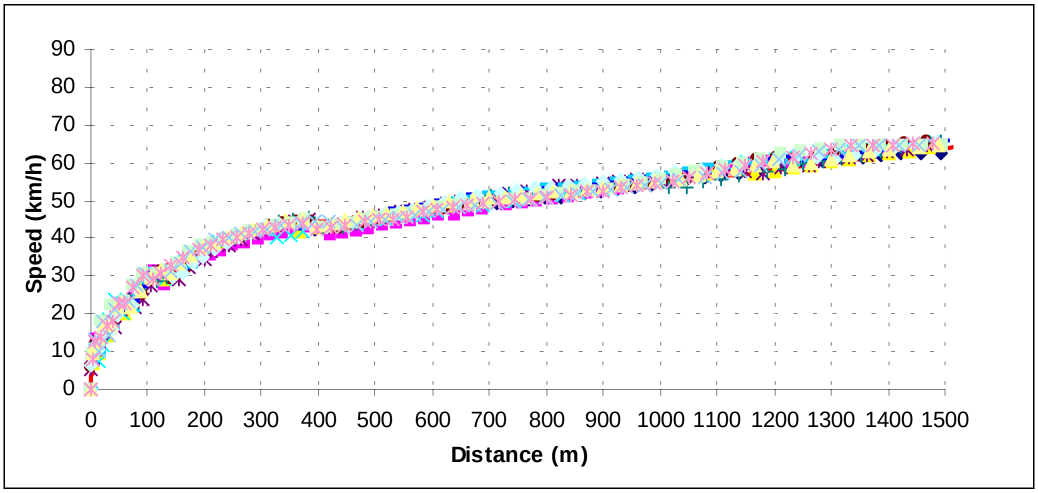


Figure B.49: Predicted and Observed Speed Profile (3-Load Configuration)

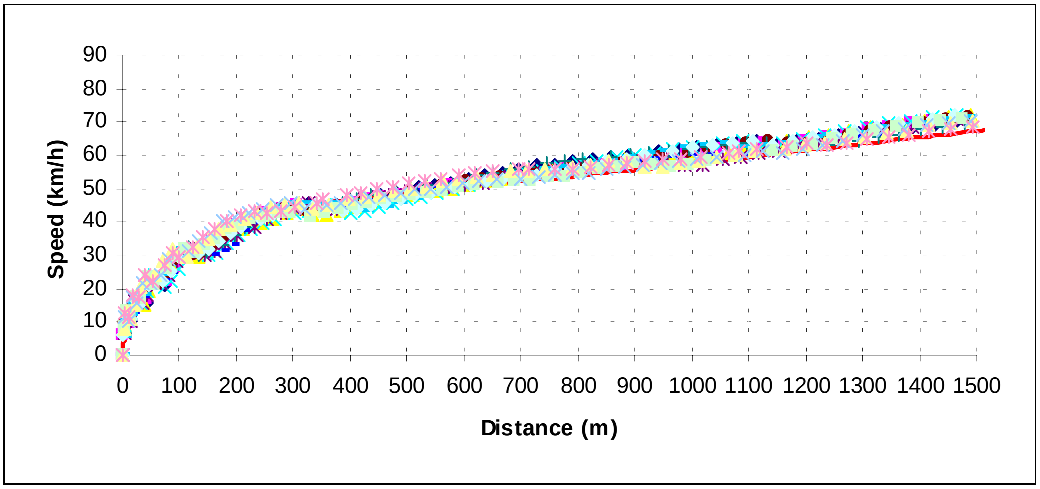


Figure B.50: Predicted and Observed Speed Profile (2-Load Configuration)

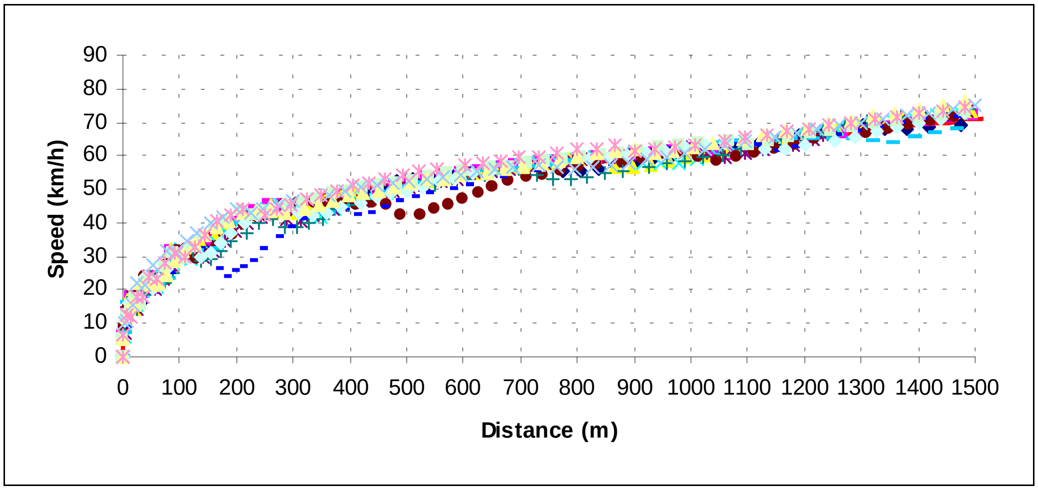


Figure B.51: Predicted and Observed Speed Profile (1-Load Configuration)

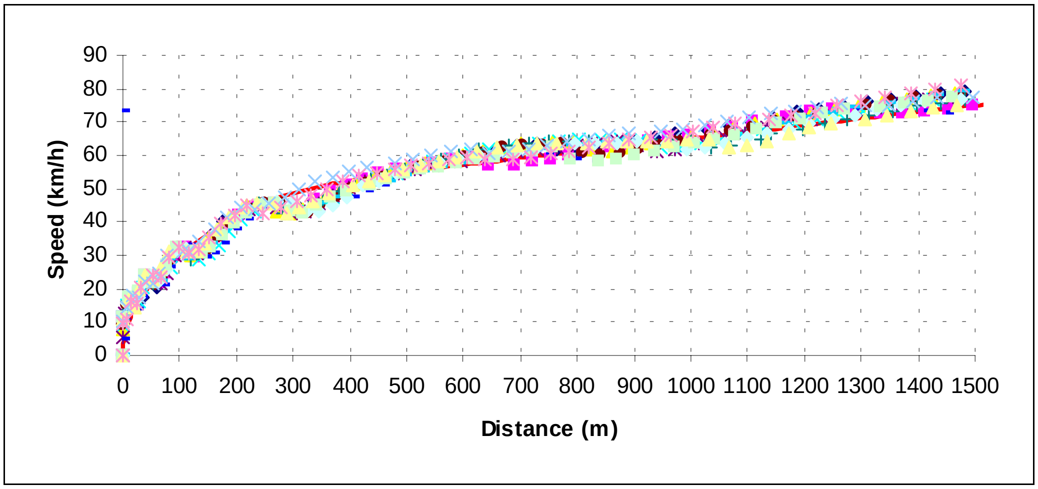


Figure B.52: Predicted and Observed Speed Profile (0-Load Configuration)

320 kW (430 hp) truck

Table B.53: Example Solution to ODE (9-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	1.61	96881	0.0596	0.0	2409.0	25118.0	27527.0
1	0.00	5.81	0.22	37252	0.0596	9.4	2509.4	25118.0	27636.7
2	1.61	6.62	0.22	37252	0.0596	12.2	2523.3	25120.2	27655.7
3	3.45	7.42	0.22	37252	0.0596	15.3	2537.2	25122.6	27675.1
4	5.51	8.23	0.22	37252	0.0596	18.8	2551.0	25125.2	27695.1
5	7.80	9.03	0.22	37252	0.0597	22.7	2564.9	25127.9	27715.5
6	10.31	9.83	0.22	37252	0.0597	26.9	2578.7	25130.7	27736.2
7	13.04	10.62	0.22	37252	0.0597	31.4	2592.4	25133.5	27757.4
8	15.99	11.42	0.22	37252	0.0597	36.3	2606.2	25136.3	27778.8
9	19.16	12.21	0.22	37252	0.0597	41.5	2619.9	25138.9	27800.4
10	22.55	13.00	0.22	37252	0.0597	47.1	2633.6	25141.4	27822.1

Table B.54: Example Solution to ODE (8-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	37252	0.0596	0.0	2288.4	23860.7	26149.2
1	0.00	0.00	0.27	37252	0.0596	0.0	2288.4	23860.7	26149.2
2	0.00	0.98	0.27	37252	0.0596	0.3	2304.5	23860.7	26165.5
3	0.27	1.96	0.27	37252	0.0596	1.1	2320.5	23861.1	26182.7
4	0.82	2.93	0.27	37252	0.0596	2.4	2336.5	23861.8	26200.8
5	1.63	3.91	0.27	37252	0.0596	4.3	2352.5	23862.9	26219.7
6	2.72	4.88	0.27	37252	0.0596	6.6	2368.5	23864.2	26239.4
7	4.07	5.85	0.27	37252	0.0596	9.5	2384.4	23865.9	26259.9
8	5.70	6.82	0.27	37252	0.0596	13.0	2400.4	23867.8	26281.1
9	7.59	7.79	0.27	37252	0.0597	16.9	2416.2	23870.0	26303.1
10	9.76	8.76	0.27	37252	0.0597	21.4	2432.1	23872.3	26325.7

Table B.55: Example Solution to ODE (7-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	36088	0.0596	0.0	2175.5	22683.1	24858.6
1	0.00	0.00	0.29	36088	0.0596	0.0	2175.5	22683.1	24858.6
2	0.00	1.04	0.29	36088	0.0596	0.3	2191.7	22683.1	24875.1
3	0.29	2.08	0.29	36088	0.0596	1.2	2207.9	22683.5	24892.6
4	0.87	3.12	0.29	36088	0.0596	2.7	2224.1	22684.2	24911.0
5	1.74	4.16	0.29	36088	0.0596	4.8	2240.3	22685.2	24930.4
6	2.89	5.19	0.29	36088	0.0596	7.5	2256.5	22686.6	24950.6
7	4.33	6.23	0.29	36088	0.0596	10.8	2272.6	22688.3	24971.7
8	6.06	7.26	0.29	36088	0.0596	14.7	2288.7	22690.2	24993.6
9	8.08	8.29	0.29	36088	0.0597	19.1	2304.7	22692.4	25016.2
10	10.38	9.32	0.28	36088	0.0597	24.2	2320.8	22694.6	25039.6

Table B.56: Example Solution to ODE (6-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	34994	0.0596	0.0	2027.9	21144.7	23172.6
1	0.00	0.00	0.33	34994	0.0596	0.0	2027.9	21144.7	23172.6
2	0.00	1.18	0.33	34994	0.0596	0.4	2045.0	21144.7	23190.1
3	0.33	2.35	0.33	34994	0.0596	1.5	2062.1	21145.1	23208.8
4	0.98	3.53	0.33	34994	0.0596	3.5	2079.2	21145.9	23228.5
5	1.96	4.70	0.32	34994	0.0596	6.1	2096.2	21147.0	23249.3
6	3.26	5.87	0.32	34994	0.0596	9.6	2113.2	21148.4	23271.2
7	4.89	7.03	0.32	34994	0.0596	13.8	2130.2	21150.2	23294.1
8	6.85	8.20	0.32	34994	0.0596	18.7	2147.1	21152.1	23318.0
9	9.12	9.36	0.32	34994	0.0597	24.4	2164.0	21154.3	23342.7
10	11.72	10.52	0.32	34994	0.0597	30.8	2180.9	21156.7	23368.4

Table B.57: Example Solution to ODE (5-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	32995	0.0596	0.0	1940.4	20232.3	22172.7
1	0.00	0.00	0.31	32995	0.0596	0.0	1940.4	20232.3	22172.7
2	0.00	1.13	0.31	32995	0.0596	0.4	1956.1	20232.3	22188.7
3	0.31	2.25	0.31	32995	0.0596	1.4	1971.7	20232.7	22205.8
4	0.94	3.37	0.31	32995	0.0596	3.2	1987.3	20233.3	22223.8
5	1.87	4.49	0.31	32995	0.0596	5.6	2002.9	20234.4	22242.9
6	3.12	5.61	0.31	32995	0.0596	8.8	2018.5	20235.7	22262.9
7	4.68	6.73	0.31	32995	0.0596	12.6	2034.0	20237.3	22283.9
8	6.55	7.84	0.31	32995	0.0596	17.1	2049.5	20239.1	22305.8
9	8.73	8.96	0.31	32995	0.0597	22.3	2065.0	20241.1	22328.5
10	11.22	10.07	0.31	32995	0.0597	28.2	2080.4	20243.3	22352.0

Table B.58: Example Solution to ODE (4-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	31211	0.0596	0.0	1797.4	18741.7	20539.1
1	0.00	0.00	0.33	31211	0.0596	0.0	1797.4	18741.7	20539.1
2	0.00	1.20	0.33	31211	0.0596	0.4	1812.9	18741.7	20555.0
3	0.33	2.40	0.33	31211	0.0596	1.6	1828.3	18742.0	20571.9
4	1.00	3.59	0.33	31211	0.0596	3.6	1843.7	18742.7	20590.0
5	2.00	4.78	0.33	31211	0.0596	6.4	1859.1	18743.7	20609.2
6	3.32	5.97	0.33	31211	0.0596	9.9	1874.4	18745.0	20629.4
7	4.98	7.16	0.33	31211	0.0596	14.3	1889.8	18746.6	20650.6
8	6.97	8.35	0.33	31211	0.0596	19.4	1905.0	18748.4	20672.8
9	9.29	9.53	0.33	31211	0.0597	25.3	1920.3	18750.3	20695.9
10	11.94	10.71	0.33	31211	0.0597	32.0	1935.5	18752.4	20719.9

Table B.59: Example Solution to ODE (3-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	28870	0.0596	0.0	1646.9	17171.5	18818.3
1	0.00	0.00	0.34	28870	0.0596	0.0	1646.9	17171.5	18818.3
2	0.00	1.23	0.34	28870	0.0596	0.4	1661.4	17171.5	18833.3
3	0.34	2.46	0.34	28870	0.0596	1.7	1675.9	17171.8	18849.4
4	1.03	3.69	0.34	28870	0.0596	3.8	1690.4	17172.4	18866.7
5	2.05	4.92	0.34	28870	0.0596	6.7	1704.9	17173.4	18885.0
6	3.42	6.14	0.34	28870	0.0596	10.5	1719.4	17174.6	18904.5
7	5.12	7.36	0.34	28870	0.0596	15.1	1733.8	17176.1	18925.0
8	7.17	8.58	0.34	28870	0.0597	20.5	1748.2	17177.8	18946.5
9	9.55	9.80	0.34	28870	0.0597	26.7	1762.6	17179.6	18968.9
10	12.28	11.01	0.34	28870	0.0597	33.8	1776.9	17181.6	18992.2

Table B.60: Example Solution to ODE (2-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	28166	0.0596	0.0	1542.1	16078.7	17620.7
1	0.00	0.00	0.38	28166	0.0596	0.0	1542.1	16078.7	17620.7
2	0.00	1.38	0.38	28166	0.0596	0.5	1557.3	16078.7	17636.5
3	0.38	2.76	0.38	28166	0.0596	2.1	1572.6	16079.0	17653.7
4	1.15	4.14	0.38	28166	0.0596	4.8	1587.8	16079.7	17672.2
5	2.30	5.51	0.38	28166	0.0596	8.5	1603.0	16080.7	17692.1
6	3.83	6.88	0.38	28166	0.0596	13.2	1618.1	16082.0	17713.3
7	5.74	8.25	0.38	28166	0.0596	19.0	1633.3	16083.5	17735.7
8	8.03	9.61	0.38	28166	0.0597	25.7	1648.4	16085.2	17759.3
9	10.70	10.98	0.38	28166	0.0597	33.6	1663.4	16087.1	17784.1
10	13.75	12.34	0.38	28166	0.0597	42.4	1678.4	16089.1	17809.9

Table B.61: Example Solution to ODE (1-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	26856	0.0596	0.0	1399.1	14588.1	15987.1
1	0.00	0.00	0.44	26856	0.0596	0.0	1399.1	14588.1	15987.1
2	0.00	1.57	0.44	26856	0.0596	0.7	1414.8	14588.1	16003.6
3	0.44	3.13	0.43	26856	0.0596	2.7	1430.5	14588.4	16021.7
4	1.31	4.70	0.43	26856	0.0596	6.1	1446.2	14589.1	16041.5
5	2.61	6.26	0.43	26856	0.0596	10.9	1461.9	14590.1	16062.9
6	4.35	7.82	0.43	26856	0.0596	17.0	1477.5	14591.4	16085.9
7	6.52	9.37	0.43	26856	0.0596	24.5	1493.1	14592.9	16110.5
8	9.12	10.92	0.43	26856	0.0597	33.2	1508.6	14594.7	16136.5
9	12.16	12.47	0.43	26856	0.0597	43.3	1524.1	14596.6	16164.0
10	15.62	14.01	0.43	26856	0.0597	54.7	1539.6	14598.5	16192.8

Table B.62: Example Solution to ODE (0-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	22643	0.0596	0.0	1163.5	12132.0	13295.5
1	0.00	0.00	0.45	22643	0.0596	0.0	1163.5	12132.0	13295.5
2	0.00	1.62	0.45	22643	0.0596	0.7	1177.1	12132.0	13309.8
3	0.45	3.24	0.45	22643	0.0596	2.9	1190.6	12132.3	13325.8
4	1.35	4.86	0.45	22643	0.0596	6.6	1204.1	12132.9	13343.5
5	2.70	6.47	0.45	22643	0.0596	11.7	1217.5	12133.7	13362.9
6	4.50	8.08	0.45	22643	0.0596	18.2	1231.0	12134.8	13384.0
7	6.74	9.69	0.45	22643	0.0596	26.1	1244.4	12136.2	13406.7
8	9.43	11.29	0.44	22643	0.0597	35.5	1257.7	12137.6	13430.9
9	12.57	12.89	0.44	22643	0.0597	46.3	1271.1	12139.2	13456.6
10	16.15	14.48	0.44	22643	0.0597	58.4	1284.4	12140.9	13483.6

Table B.63: Example Solution to ODE (Truck Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	11548	0.0596	0.0	477.7	4981.2	5458.9
1	0.00	0.00	0.71	11548	0.0596	0.0	477.7	4981.2	5458.9
2	0.00	2.57	0.71	11548	0.0596	1.6	486.5	4981.2	5469.3
3	0.71	5.14	0.71	11548	0.0596	6.3	495.3	4981.4	5483.0
4	2.14	7.71	0.71	11548	0.0596	14.3	504.1	4981.7	5500.1
5	4.28	10.26	0.71	11548	0.0596	25.3	512.9	4982.3	5520.4
6	7.13	12.81	0.70	11548	0.0597	39.4	521.6	4983.0	5544.0
7	10.69	15.35	0.70	11548	0.0597	56.5	530.3	4983.8	5570.6
8	14.95	17.87	0.70	11548	0.0597	76.7	538.9	4984.6	5600.2
9	19.92	20.39	0.69	11548	0.0597	99.8	547.5	4985.4	5632.8
10	25.58	22.89	0.69	11548	0.0597	125.8	556.1	4986.2	5668.1

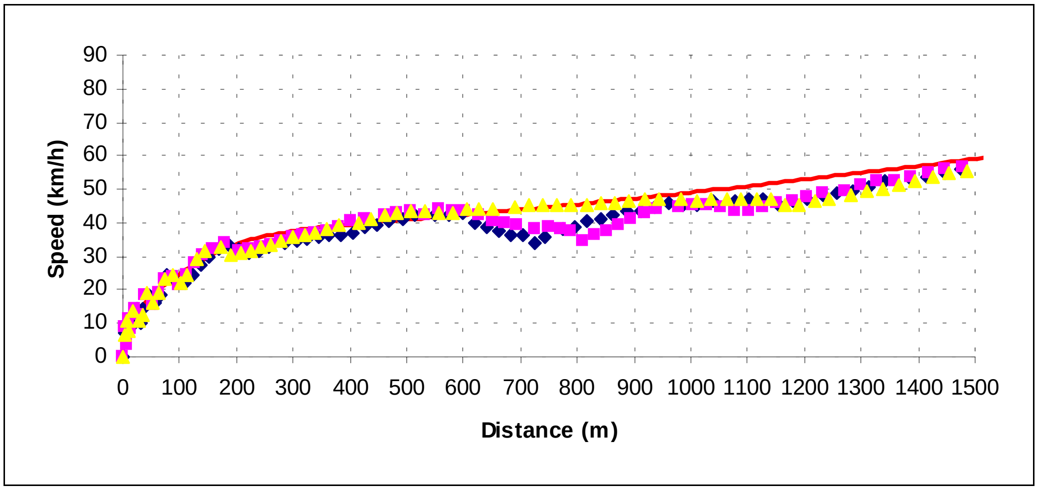


Figure B.53: Predicted and Observed Speed Profile (9-Load Configuration)

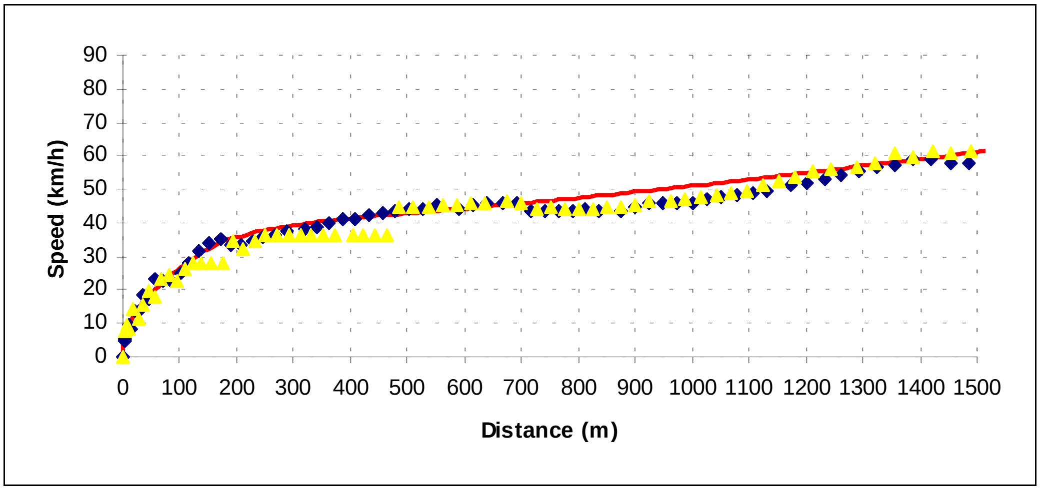


Figure B.54: Predicted and Observed Speed Profile (8-Load Configuration)

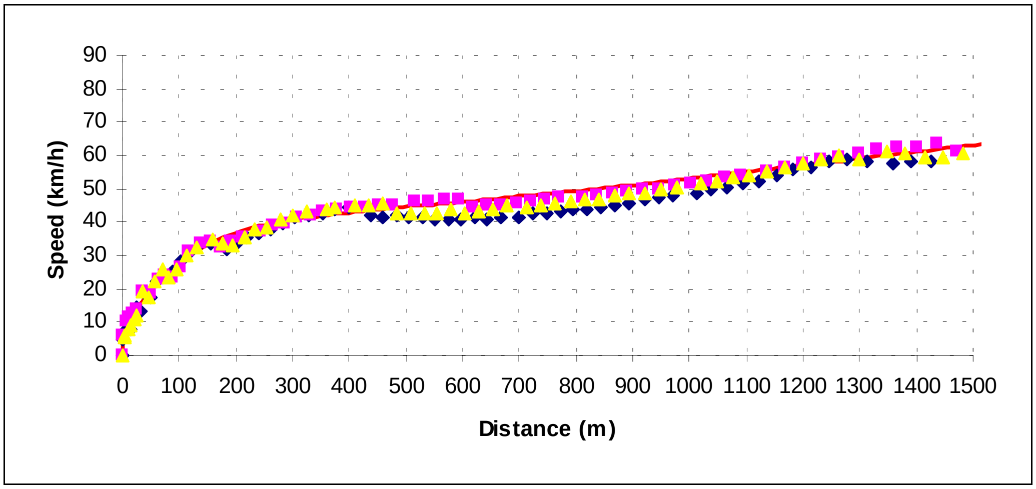


Figure B.55: Predicted and Observed Speed Profile (7-Load Configuration)

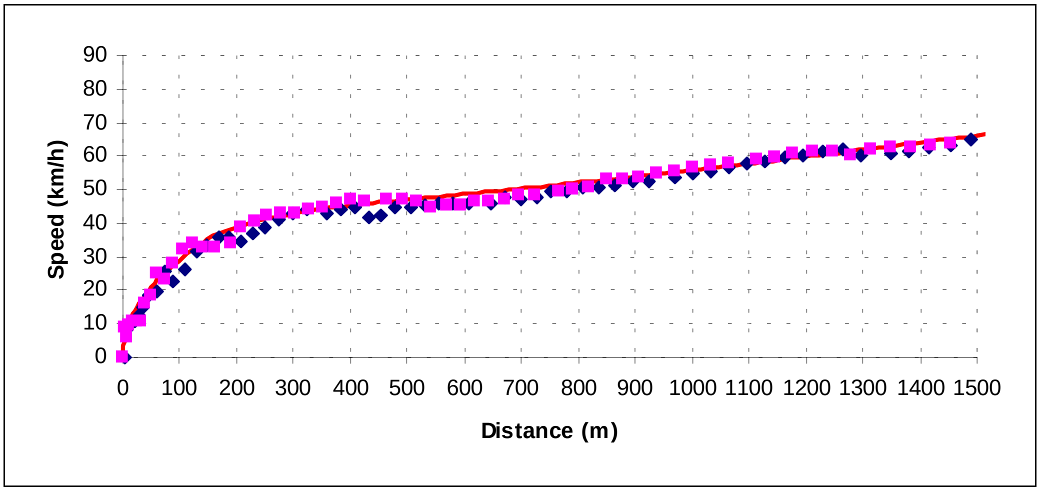


Figure B.56: Predicted and Observed Speed Profile (6-Load Configuration)

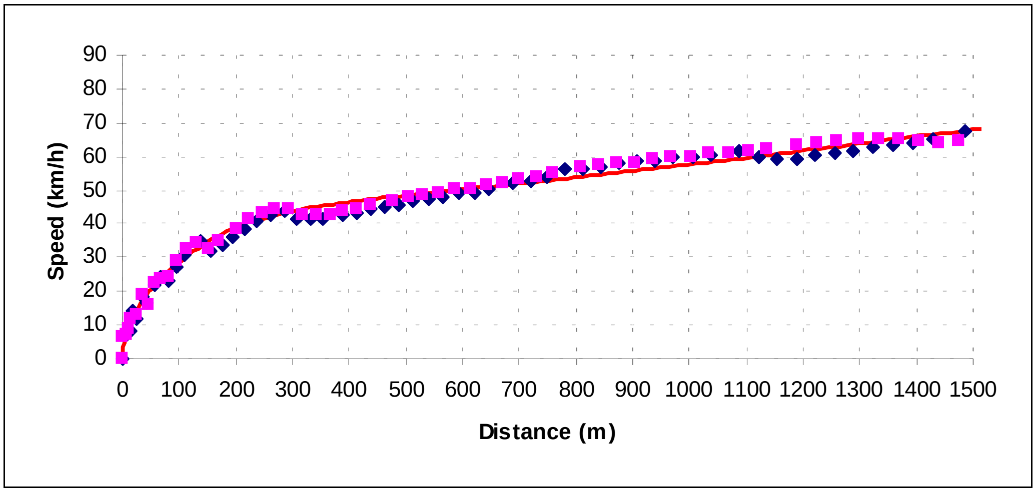


Figure B.57: Predicted and Observed Speed Profile (5-Load Configuration)

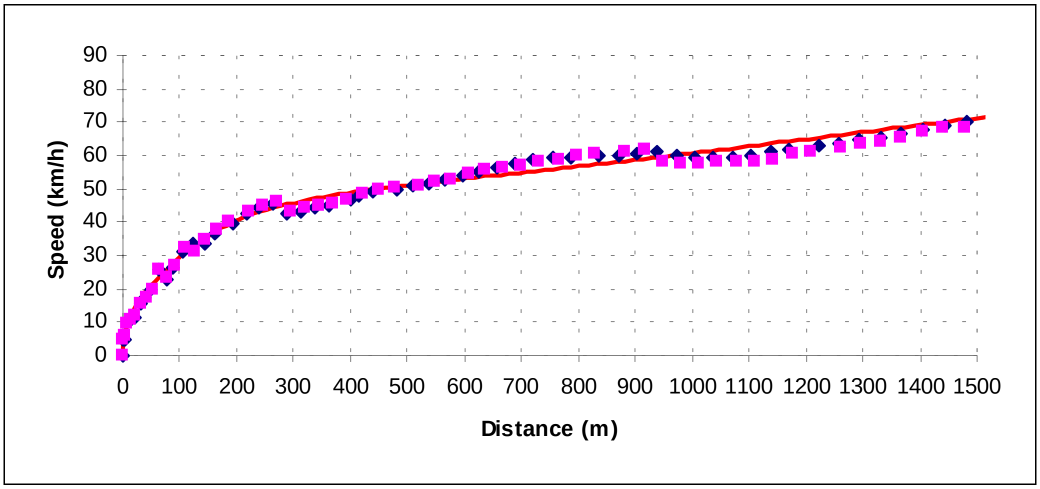


Figure B.58: Predicted and Observed Speed Profile (4-Load Configuration)

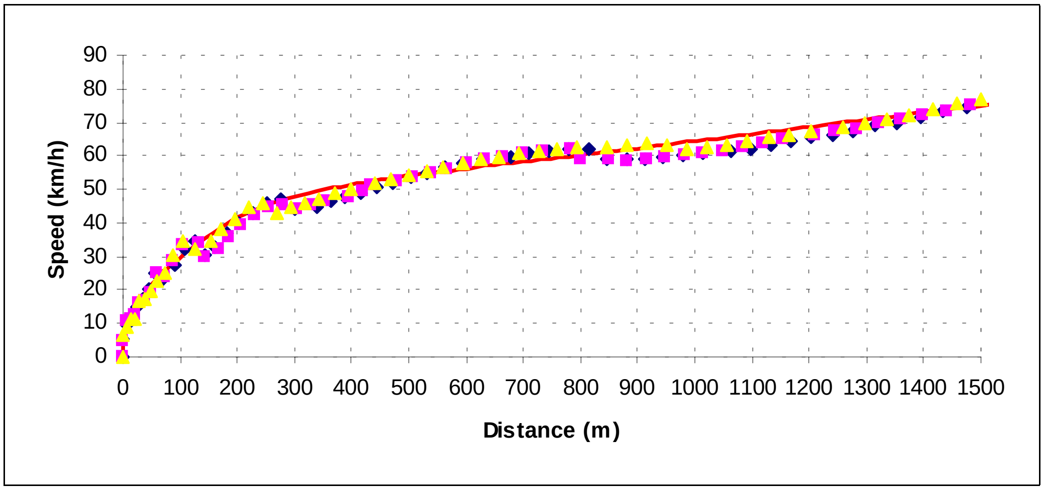


Figure B.59: Predicted and Observed Speed Profile (3-Load Configuration)

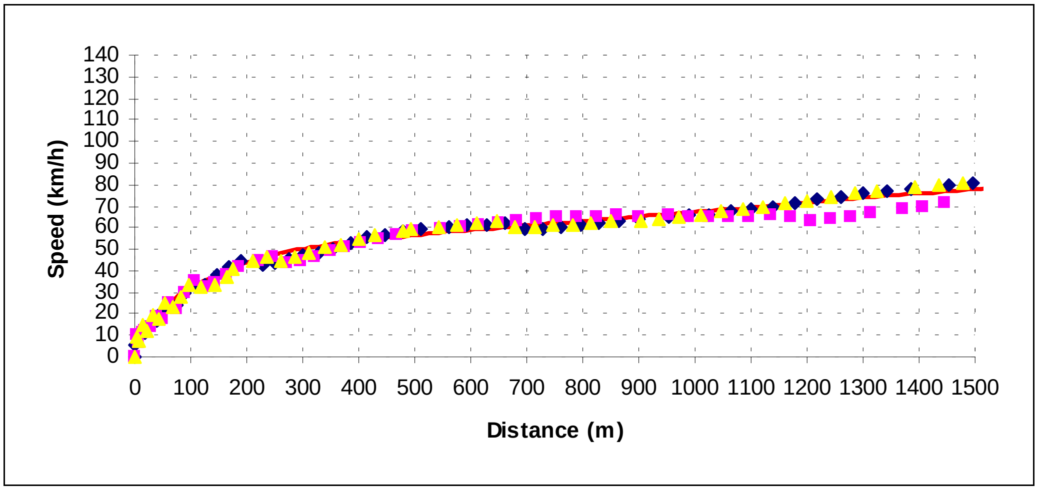


Figure B.60: Predicted and Observed Speed Profile (2-Load Configuration)

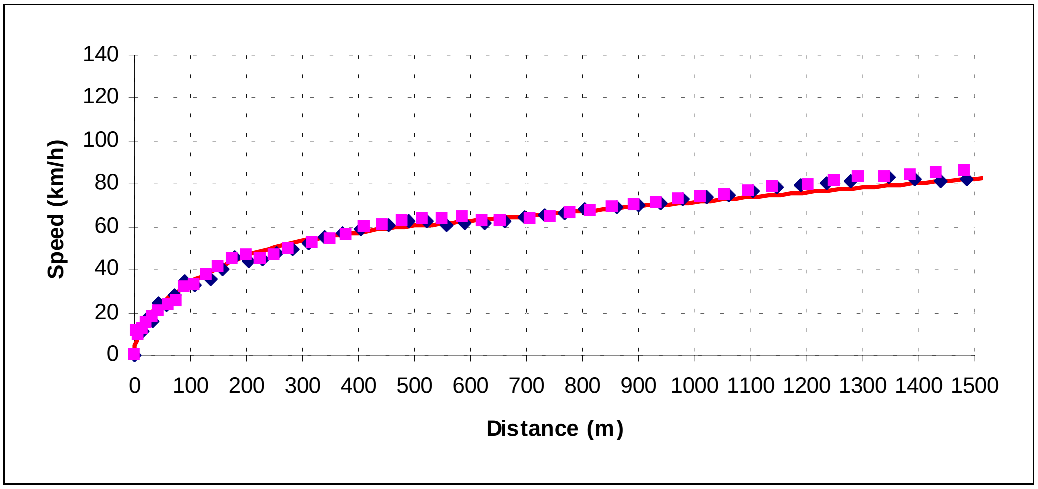


Figure B.61: Predicted and Observed Speed Profile (1-Load Configuration)

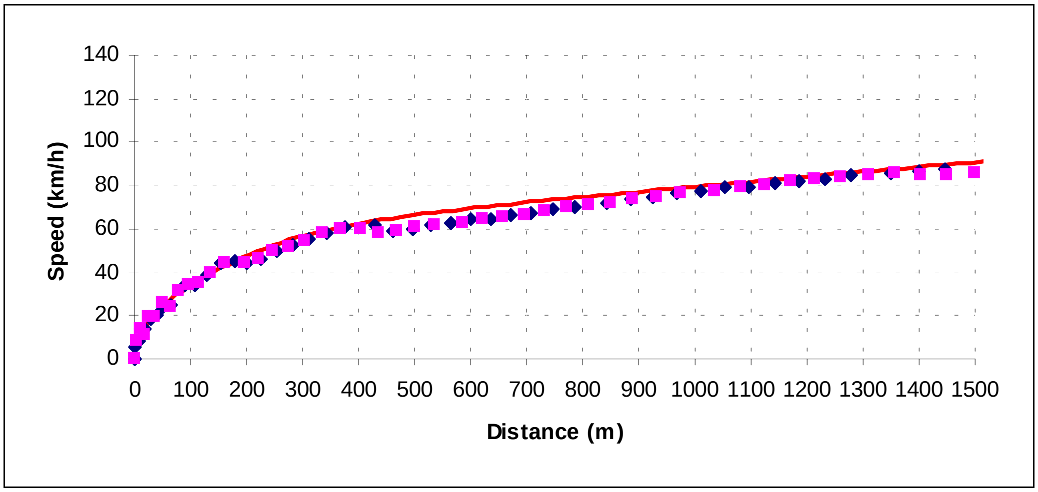


Figure B.62: Predicted and Observed Speed Profile (0-Load Configuration)

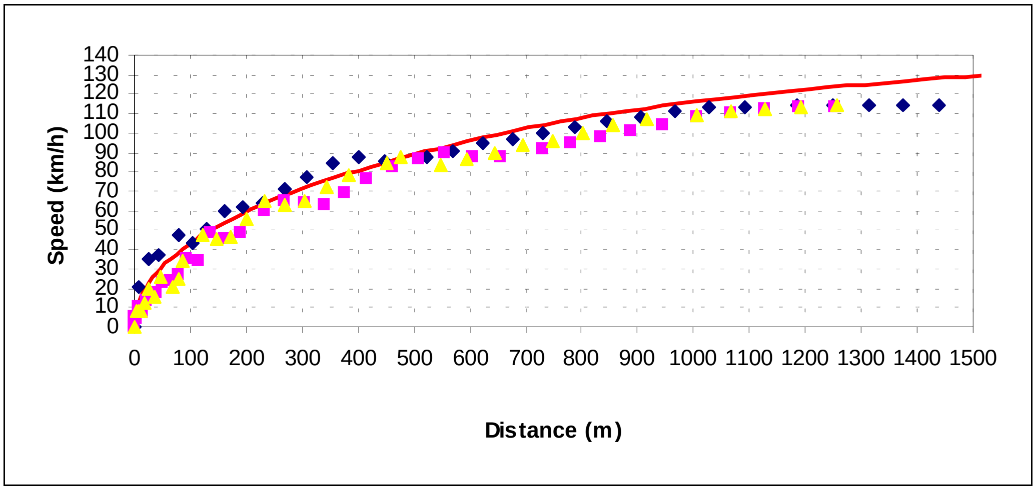


Figure B.63: Predicted and Observed Speed Profile (Truck Configuration)

350 kW (470 hp) truck

Table B.64: Example Solution to ODE (9-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	38249	0.0596	0.0	2481.7	25876.6	28358.3
1	0.00	0.00	0.22	38249	0.0596	0.0	2481.7	25876.6	28358.3
2	0.00	0.80	0.22	38249	0.0596	0.2	2496.0	25876.6	28372.8
3	0.22	1.61	0.22	38249	0.0596	0.7	2510.3	25876.9	28387.9
4	0.67	2.41	0.22	38249	0.0596	1.6	2524.6	25877.5	28403.7
5	1.34	3.21	0.22	38249	0.0596	2.9	2538.9	25878.5	28420.2
6	2.23	4.01	0.22	38249	0.0596	4.5	2553.1	25879.7	28437.3
7	3.35	4.81	0.22	38249	0.0596	6.4	2567.3	25881.2	28454.9
8	4.68	5.61	0.22	38249	0.0596	8.8	2581.5	25882.9	28473.2
9	6.24	6.40	0.22	38249	0.0596	11.4	2595.6	25884.9	28491.9
10	8.02	7.20	0.22	38249	0.0597	14.4	2609.8	25887.0	28511.2

Table B.65: Example Solution to ODE (8-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	37124	0.0596	0.0	2319.4	24184.3	26503.8
1	0.00	0.00	0.26	37124	0.0596	0.0	2319.4	24184.3	26503.8
2	0.00	0.92	0.26	37124	0.0596	0.2	2334.8	24184.3	26519.4
3	0.26	1.85	0.26	37124	0.0596	1.0	2350.2	24184.7	26535.8
4	0.77	2.77	0.26	37124	0.0596	2.1	2365.5	24185.4	26553.0
5	1.54	3.69	0.26	37124	0.0596	3.8	2380.8	24186.4	26571.0
6	2.56	4.61	0.25	37124	0.0596	5.9	2396.1	24187.7	26589.7
7	3.84	5.53	0.25	37124	0.0596	8.5	2411.3	24189.3	26609.1
8	5.38	6.44	0.25	37124	0.0596	11.6	2426.5	24191.1	26629.2
9	7.17	7.35	0.25	37124	0.0597	15.1	2441.7	24193.2	26650.0
10	9.21	8.27	0.25	37124	0.0597	19.0	2456.9	24195.4	26671.3

Table B.66: Example Solution to ODE (7-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	36064	0.0596	0.0	2210.1	23043.8	25253.9
1	0.00	0.00	0.27	36064	0.0596	0.0	2210.1	23043.8	25253.9
2	0.00	0.99	0.27	36064	0.0596	0.3	2225.7	23043.8	25269.8
3	0.27	1.97	0.27	36064	0.0596	1.1	2241.3	23044.2	25286.6
4	0.82	2.96	0.27	36064	0.0596	2.4	2256.9	23044.9	25304.2
5	1.64	3.94	0.27	36064	0.0596	4.3	2272.5	23045.9	25322.7
6	2.74	4.92	0.27	36064	0.0596	6.7	2288.0	23047.2	25342.0
7	4.11	5.90	0.27	36064	0.0596	9.7	2303.6	23048.8	25362.1
8	5.75	6.88	0.27	36064	0.0596	13.2	2319.1	23050.7	25382.9
9	7.66	7.86	0.27	36064	0.0597	17.2	2334.5	23052.8	25404.5
10	9.84	8.83	0.27	36064	0.0597	21.7	2349.9	23055.0	25426.7

Table B.67: Example Solution to ODE (6-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	35062	0.0596	0.0	2091.0	21802.5	23893.5
1	0.00	0.00	0.30	35062	0.0596	0.0	2091.0	21802.5	23893.5
2	0.00	1.08	0.30	35062	0.0596	0.3	2107.2	21802.5	23910.0
3	0.30	2.16	0.30	35062	0.0596	1.3	2123.3	21802.9	23927.5
4	0.90	3.23	0.30	35062	0.0596	2.9	2139.4	21803.6	23945.9
5	1.80	4.30	0.30	35062	0.0596	5.2	2155.5	21804.6	23965.3
6	2.99	5.37	0.30	35062	0.0596	8.0	2171.6	21806.0	23985.6
7	4.48	6.44	0.30	35062	0.0596	11.6	2187.6	21807.7	24006.8
8	6.27	7.51	0.30	35062	0.0596	15.7	2203.6	21809.6	24028.9
9	8.36	8.58	0.30	35062	0.0597	20.5	2219.6	21811.7	24051.8
10	10.74	9.64	0.29	35062	0.0597	25.9	2235.5	21813.9	24075.3

Table B.68: Example Solution to ODE (5-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	34114	0.0596	0.0	1985.2	20699.1	22684.3
1	0.00	0.00	0.32	34114	0.0596	0.0	1985.2	20699.1	22684.3
2	0.00	1.16	0.32	34114	0.0596	0.4	2001.7	20699.1	22701.2
3	0.32	2.32	0.32	34114	0.0596	1.5	2018.2	20699.5	22719.2
4	0.97	3.48	0.32	34114	0.0596	3.4	2034.7	20700.2	22738.3
5	1.94	4.64	0.32	34114	0.0596	6.0	2051.2	20701.3	22758.5
6	3.22	5.79	0.32	34114	0.0596	9.3	2067.6	20702.7	22779.7
7	4.83	6.95	0.32	34114	0.0596	13.4	2084.1	20704.4	22801.9
8	6.76	8.10	0.32	34114	0.0596	18.3	2100.4	20706.3	22825.0
9	9.01	9.25	0.32	34114	0.0597	23.8	2116.8	20708.4	22849.0
10	11.58	10.39	0.32	34114	0.0597	30.1	2133.1	20710.7	22873.8

Table B.69: Example Solution to ODE (4-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	31556	0.0596	0.0	1817.3	18948.6	20765.8
1	0.00	0.00	0.33	31556	0.0596	0.0	1817.3	18948.6	20765.8
2	0.00	1.20	0.33	31556	0.0596	0.4	1832.9	18948.6	20781.9
3	0.33	2.40	0.33	31556	0.0596	1.6	1848.5	18948.9	20799.0
4	1.00	3.59	0.33	31556	0.0596	3.6	1864.1	18949.6	20817.3
5	2.00	4.78	0.33	31556	0.0596	6.4	1879.6	18950.6	20836.6
6	3.32	5.97	0.33	31556	0.0596	9.9	1895.1	18951.9	20857.0
7	4.98	7.16	0.33	31556	0.0596	14.3	1910.6	18953.5	20878.4
8	6.97	8.35	0.33	31556	0.0596	19.4	1926.1	18955.3	20900.8
9	9.29	9.53	0.33	31556	0.0597	25.3	1941.5	18957.3	20924.1
10	11.94	10.71	0.33	31556	0.0597	32.0	1956.9	18959.4	20948.3

Table B.70: Example Solution to ODE (3-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	30053	0.0596	0.0	1720.1	17935.3	19655.5
1	0.00	0.00	0.34	30053	0.0596	0.0	1720.1	17935.3	19655.5
2	0.00	1.22	0.34	30053	0.0596	0.4	1735.2	17935.3	19670.9
3	0.34	2.44	0.34	30053	0.0596	1.7	1750.2	17935.7	19687.5
4	1.02	3.66	0.34	30053	0.0596	3.7	1765.2	17936.3	19705.3
5	2.03	4.87	0.34	30053	0.0596	6.6	1780.2	17937.3	19724.1
6	3.38	6.08	0.34	30053	0.0596	10.3	1795.1	17938.6	19744.0
7	5.07	7.29	0.34	30053	0.0596	14.8	1810.1	17940.1	19765.0
8	7.10	8.50	0.33	30053	0.0596	20.1	1824.9	17941.9	19786.9
9	9.46	9.70	0.33	30053	0.0597	26.2	1839.8	17943.8	19809.8
10	12.16	10.91	0.33	30053	0.0597	33.1	1854.6	17945.8	19833.6

Table B.71: Example Solution to ODE (2-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	28687	0.0596	0.0	1576.6	16439.4	18016.1
1	0.00	0.00	0.38	28687	0.0596	0.0	1576.6	16439.4	18016.1
2	0.00	1.37	0.38	28687	0.0596	0.5	1592.1	16439.4	18032.0
3	0.38	2.73	0.38	28687	0.0596	2.1	1607.5	16439.8	18049.3
4	1.14	4.09	0.38	28687	0.0596	4.7	1622.9	16440.4	18068.0
5	2.28	5.45	0.38	28687	0.0596	8.3	1638.3	16441.4	18088.0
6	3.79	6.81	0.38	28687	0.0596	12.9	1653.6	16442.7	18109.3
7	5.68	8.16	0.38	28687	0.0596	18.6	1668.9	16444.3	18131.8
8	7.95	9.52	0.37	28687	0.0597	25.2	1684.2	16446.0	18155.5
9	10.59	10.86	0.37	28687	0.0597	32.9	1699.5	16447.9	18180.3
10	13.61	12.21	0.37	28687	0.0597	41.5	1714.7	16449.9	18206.1

Table B.72: Example Solution to ODE (1-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	26297	0.0596	0.0	1420.5	14810.9	16231.3
1	0.00	0.00	0.40	26297	0.0596	0.0	1420.5	14810.9	16231.3
2	0.00	1.43	0.40	26297	0.0596	0.6	1435.0	14810.9	16246.4
3	0.40	2.86	0.40	26297	0.0596	2.3	1449.6	14811.2	16263.0
4	1.19	4.29	0.40	26297	0.0596	5.1	1464.1	14811.8	16281.0
5	2.38	5.71	0.39	26297	0.0596	9.1	1478.6	14812.8	16300.4
6	3.97	7.13	0.39	26297	0.0596	14.2	1493.1	14814.0	16321.2
7	5.95	8.55	0.39	26297	0.0596	20.3	1507.5	14815.4	16343.3
8	8.32	9.96	0.39	26297	0.0597	27.6	1521.9	14817.1	16366.6
9	11.09	11.37	0.39	26297	0.0597	36.0	1536.3	14818.8	16391.1
10	14.25	12.78	0.39	26297	0.0597	45.5	1550.6	14820.7	16416.8

Table B.73: Example Solution to ODE (0-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	25760	0.0596	0.0	1258.7	13123.9	14382.6
1	0.00	0.00	0.51	25760	0.0596	0.0	1258.7	13123.9	14382.6
2	0.00	1.82	0.51	25760	0.0596	0.9	1275.1	13123.9	14400.0
3	0.51	3.65	0.51	25760	0.0596	3.7	1291.6	13124.3	14419.6
4	1.52	5.47	0.50	25760	0.0596	8.3	1308.0	13125.0	14441.4
5	3.04	7.28	0.50	25760	0.0596	14.8	1324.4	13126.1	14465.2
6	5.06	9.09	0.50	25760	0.0596	23.0	1340.7	13127.4	14491.2
7	7.59	10.90	0.50	25760	0.0597	33.1	1357.0	13129.0	14519.1
8	10.61	12.70	0.50	25760	0.0597	44.9	1373.3	13130.8	14549.0
9	14.14	14.50	0.50	25760	0.0597	58.6	1389.5	13132.6	14580.7
10	18.17	16.30	0.50	25760	0.0597	74.0	1405.7	13134.5	14614.1

Table B.74: Example Solution to ODE (Truck Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	11475	0.0596	0.0	469.6	4896.3	5365.9
1	0.00	0.00	0.73	11475	0.0596	0.0	469.6	4896.3	5365.9
2	0.00	2.63	0.73	11475	0.0596	1.9	478.4	4896.3	5376.6
3	0.73	5.25	0.73	11475	0.0596	7.7	487.3	4896.5	5391.4
4	2.19	7.86	0.72	11475	0.0596	17.2	496.1	4896.9	5410.1
5	4.37	10.47	0.72	11475	0.0596	30.5	504.8	4897.4	5432.8
6	7.28	13.07	0.72	11475	0.0597	47.6	513.6	4898.1	5459.3
7	10.91	15.66	0.71	11475	0.0597	68.3	522.3	4898.9	5489.4
8	15.26	18.23	0.71	11475	0.0597	92.5	531.0	4899.7	5523.2
9	20.32	20.79	0.71	11475	0.0597	120.4	539.6	4900.5	5560.5
10	26.10	23.33	0.70	11475	0.0597	151.6	548.1	4901.3	5601.0

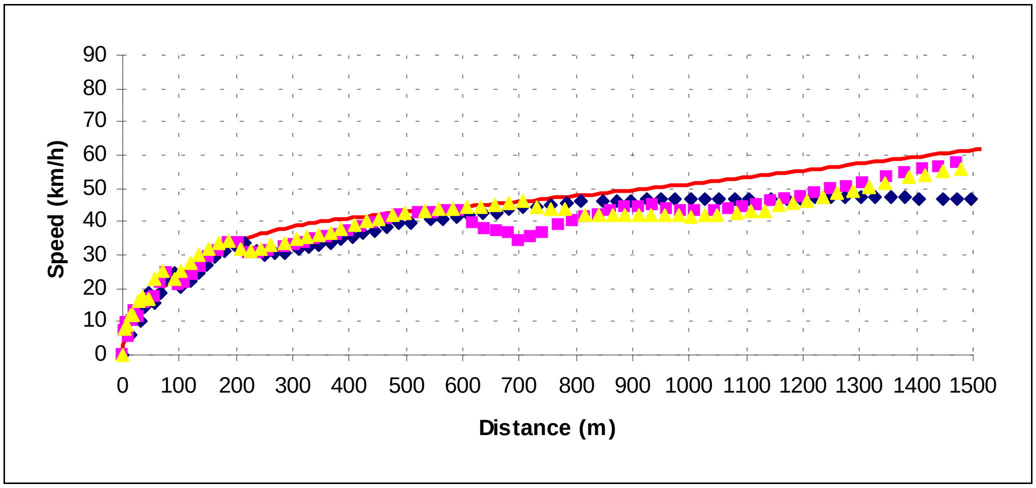


Figure B.64: Predicted and Observed Speed Profile (9-Load Configuration)

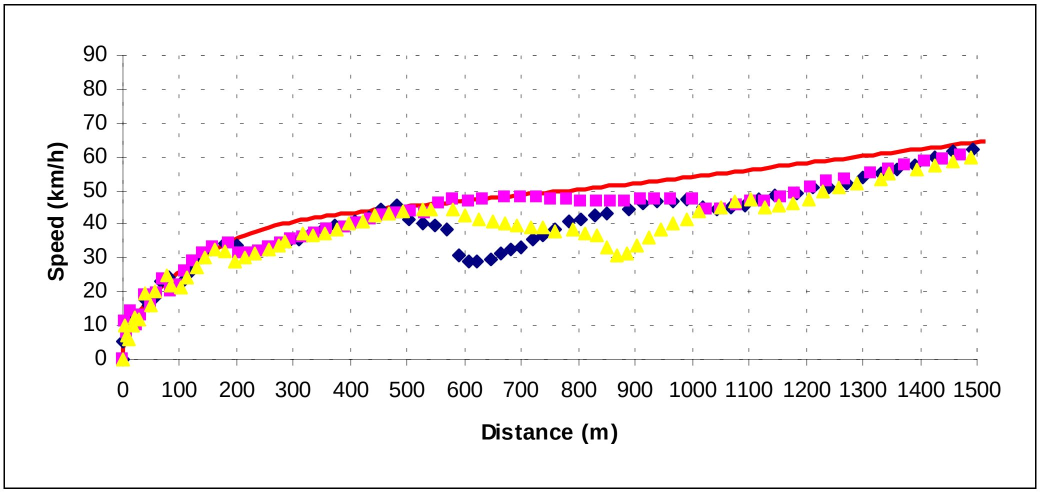


Figure B.65: Predicted and Observed Speed Profile (8-Load Configuration)

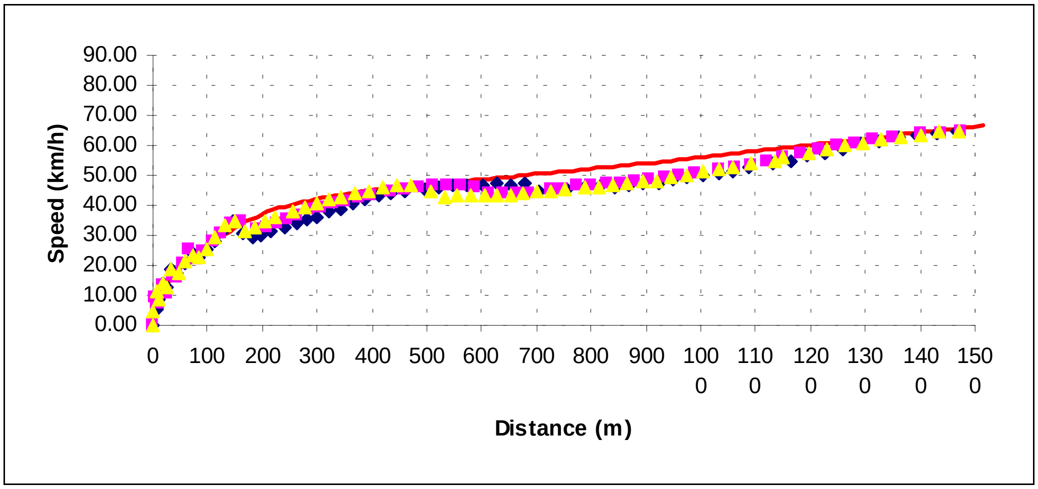


Figure B.66: Predicted and Observed Speed Profile (7-Load Configuration)

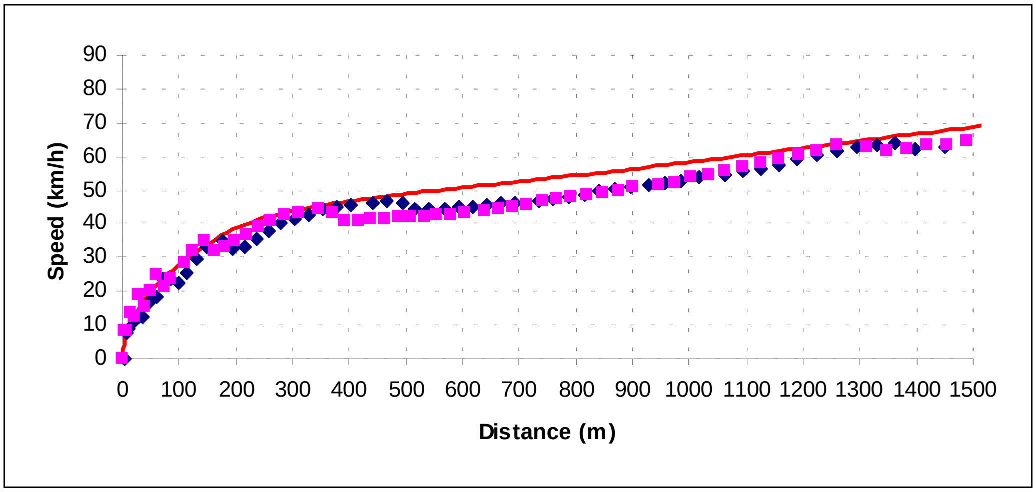


Figure B.67: Predicted and Observed Speed Profile (6-Load Configuration)

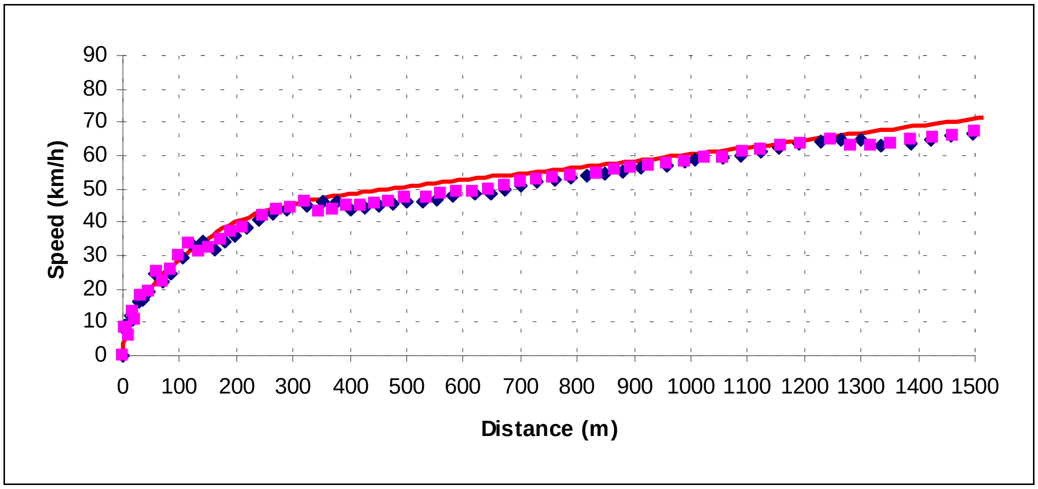


Figure B.68: Predicted and Observed Speed Profile (5-Load Configuration)

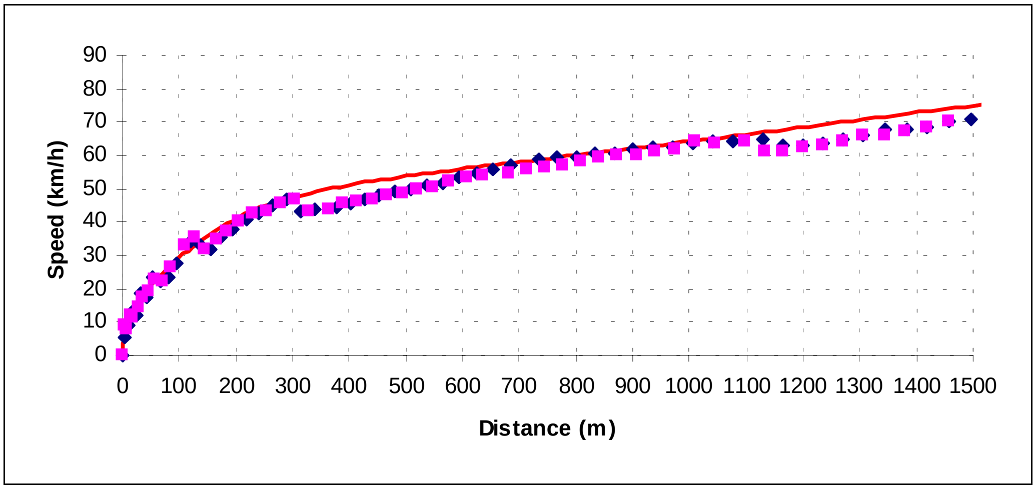


Figure B.69: Predicted and Observed Speed Profile (4-Load Configuration)

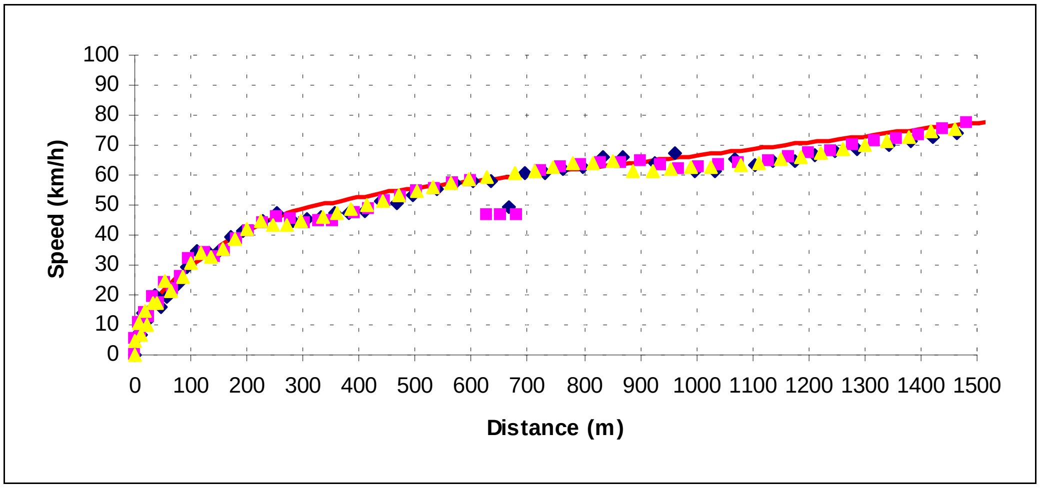


Figure B.70: Predicted and Observed Speed Profile (3-Load Configuration)

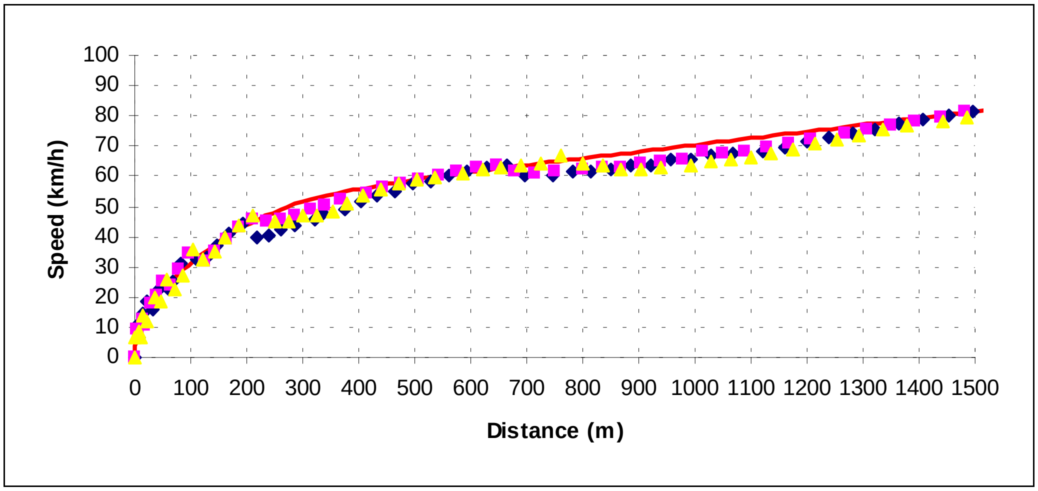


Figure B.71: Predicted and Observed Speed Profile (2-Load Configuration)

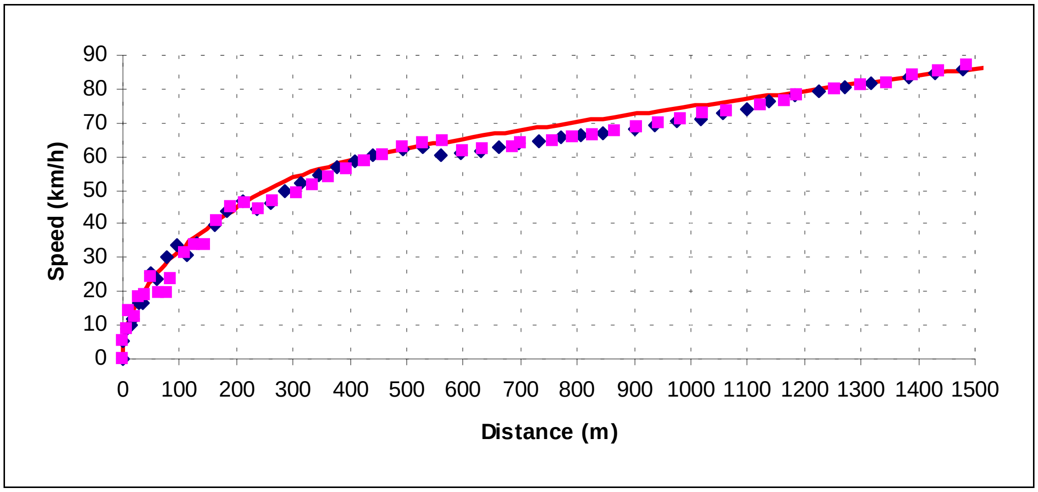


Figure B.72: Predicted and Observed Speed Profile (1-Load Configuration)

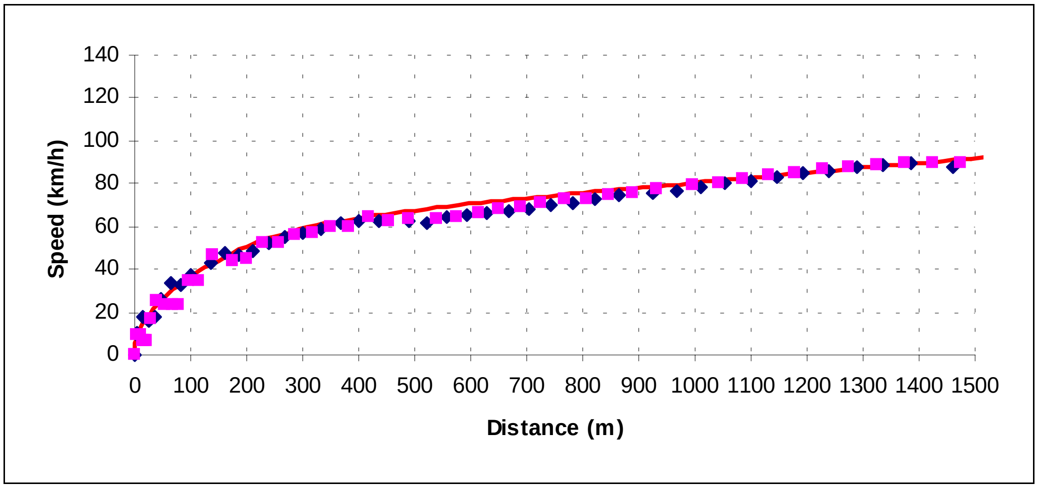


Figure B.73: Predicted and Observed Speed Profile (0-Load Configuration)

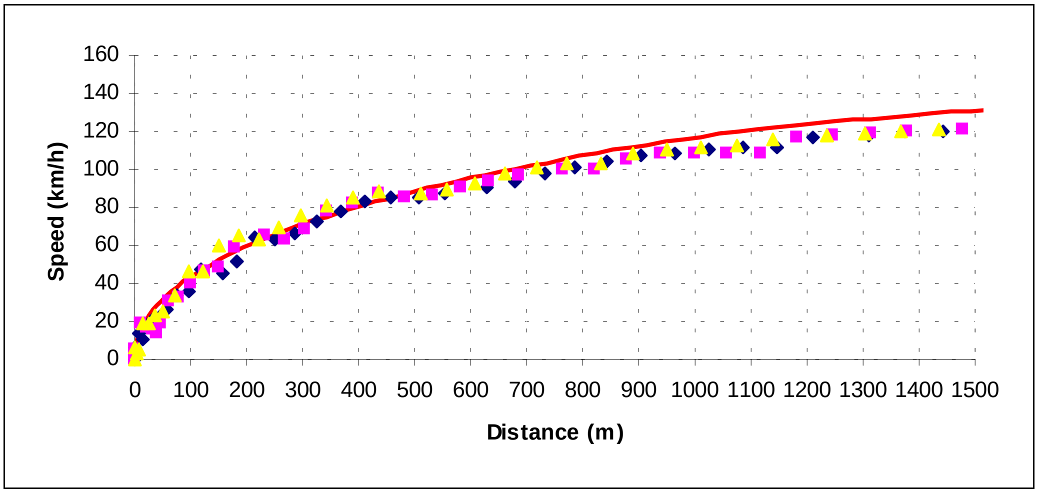


Figure B.74: Predicted and Observed Speed Profile (Truck Configuration)

375 kW (500 hp) truck

Table B.75: Example Solution to ODE (9-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	41963	0.0596	0.0	2512.8	26200.1	28712.9
1	0.00	0.00	0.30	41963	0.0596	0.0	2512.8	26200.1	28712.9
2	0.00	1.06	0.30	41963	0.0596	0.3	2531.9	26200.1	28732.4
3	0.30	2.13	0.29	41963	0.0596	1.3	2551.1	26200.6	28752.9
4	0.89	3.19	0.29	41963	0.0596	2.8	2570.2	26201.4	28774.5
5	1.77	4.25	0.29	41963	0.0596	5.0	2589.3	26202.7	28797.0
6	2.95	5.31	0.29	41963	0.0596	7.8	2608.4	26204.3	28820.5
7	4.43	6.36	0.29	41963	0.0596	11.3	2627.4	26206.3	28844.9
8	6.19	7.42	0.29	41963	0.0596	15.3	2646.4	26208.5	28870.2
9	8.25	8.47	0.29	41963	0.0597	20.0	2665.3	26211.0	28896.3
10	10.61	9.52	0.29	41963	0.0597	25.2	2684.2	26213.7	28923.2

Table B.76: Example Solution to ODE (8-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	40691	0.0596	0.0	2374.8	24761.2	27136.0
1	0.00	0.00	0.32	40691	0.0596	0.0	2374.8	24761.2	27136.0
2	0.00	1.15	0.32	40691	0.0596	0.4	2394.4	24761.2	27156.0
3	0.32	2.30	0.32	40691	0.0596	1.5	2414.0	24761.7	27177.1
4	0.96	3.45	0.32	40691	0.0596	3.3	2433.5	24762.5	27199.4
5	1.92	4.60	0.32	40691	0.0596	5.9	2453.1	24763.8	27222.8
6	3.20	5.74	0.32	40691	0.0596	9.2	2472.6	24765.5	27247.2
7	4.79	6.89	0.32	40691	0.0596	13.2	2492.0	24767.5	27272.7
8	6.70	8.03	0.32	40691	0.0596	17.9	2511.4	24769.8	27299.1
9	8.93	9.17	0.32	40691	0.0597	23.4	2530.8	24772.3	27326.5
10	11.48	10.30	0.31	40691	0.0597	29.6	2550.2	24775.0	27354.7

Table B.77: Example Solution to ODE (7-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	37300	0.0596	0.0	2236.8	23322.3	25559.1
1	0.00	0.00	0.29	37300	0.0596	0.0	2236.8	23322.3	25559.1
2	0.00	1.06	0.29	37300	0.0596	0.3	2253.8	23322.3	25576.4
3	0.29	2.12	0.29	37300	0.0596	1.2	2270.7	23322.7	25594.7
4	0.88	3.17	0.29	37300	0.0596	2.8	2287.7	23323.4	25613.9
5	1.76	4.23	0.29	37300	0.0596	5.0	2304.6	23324.6	25634.1
6	2.94	5.28	0.29	37300	0.0596	7.8	2321.5	23326.0	25655.2
7	4.41	6.33	0.29	37300	0.0596	11.2	2338.3	23327.7	25677.2
8	6.17	7.38	0.29	37300	0.0596	15.2	2355.2	23329.8	25700.1
9	8.22	8.43	0.29	37300	0.0597	19.8	2371.9	23332.0	25723.7
10	10.56	9.47	0.29	37300	0.0597	25.0	2388.7	23334.4	25748.1

Table B.78: Example Solution to ODE (6-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	36292	0.0596	0.0	2098.8	21883.4	23982.2
1	0.00	0.00	0.33	36292	0.0596	0.0	2098.8	21883.4	23982.2
2	0.00	1.18	0.33	36292	0.0596	0.4	2116.6	21883.4	24000.4
3	0.33	2.37	0.33	36292	0.0596	1.6	2134.4	21883.8	24019.7
4	0.99	3.55	0.33	36292	0.0596	3.5	2152.1	21884.6	24040.2
5	1.97	4.73	0.33	36292	0.0596	6.2	2169.9	21885.7	24061.8
6	3.28	5.90	0.33	36292	0.0596	9.7	2187.6	21887.3	24084.5
7	4.92	7.08	0.33	36292	0.0596	13.9	2205.2	21889.1	24108.2
8	6.89	8.25	0.32	36292	0.0596	18.9	2222.9	21891.1	24133.0
9	9.18	9.42	0.32	36292	0.0597	24.7	2240.5	21893.4	24158.6
10	11.80	10.59	0.32	36292	0.0597	31.2	2258.0	21895.8	24185.1

Table B.79: Example Solution to ODE (5-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	34431	0.0596	0.0	1960.8	20444.5	22405.3
1	0.00	0.00	0.34	34431	0.0596	0.0	1960.8	20444.5	22405.3
2	0.00	1.24	0.34	34431	0.0596	0.4	1978.2	20444.5	22423.1
3	0.34	2.47	0.34	34431	0.0596	1.7	1995.5	20444.9	22442.1
4	1.03	3.71	0.34	34431	0.0596	3.8	2012.9	20445.7	22462.4
5	2.06	4.94	0.34	34431	0.0596	6.8	2030.2	20446.8	22483.8
6	3.43	6.17	0.34	34431	0.0596	10.6	2047.5	20448.2	22506.4
7	5.15	7.40	0.34	34431	0.0596	15.2	2064.8	20450.0	22530.0
8	7.20	8.62	0.34	34431	0.0597	20.7	2082.0	20452.0	22554.7
9	9.60	9.85	0.34	34431	0.0597	27.0	2099.2	20454.2	22580.4
10	12.34	11.07	0.34	34431	0.0597	34.1	2116.3	20456.6	22607.0

Table B.80: Example Solution to ODE (4-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	32751	0.0596	0.0	1822.8	19005.6	20828.3
1	0.00	0.00	0.37	32751	0.0596	0.0	1822.8	19005.6	20828.3
2	0.00	1.32	0.37	32751	0.0596	0.5	1840.0	19005.6	20846.1
3	0.37	2.64	0.37	32751	0.0596	1.9	1857.3	19006.0	20865.2
4	1.10	3.96	0.37	32751	0.0596	4.4	1874.5	19006.7	20885.5
5	2.20	5.27	0.36	32751	0.0596	7.7	1891.6	19007.8	20907.2
6	3.66	6.58	0.36	32751	0.0596	12.1	1908.8	19009.3	20930.1
7	5.49	7.89	0.36	32751	0.0596	17.3	1925.9	19011.0	20954.2
8	7.68	9.20	0.36	32751	0.0597	23.6	1943.0	19013.0	20979.5
9	10.24	10.50	0.36	32751	0.0597	30.7	1960.0	19015.1	21005.9
10	13.16	11.80	0.36	32751	0.0597	38.8	1977.0	19017.4	21033.2

Table B.81: Example Solution to ODE (3-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	31971	0.0596	0.0	1684.8	17566.7	19251.4
1	0.00	0.00	0.42	31971	0.0596	0.0	1684.8	17566.7	19251.4
2	0.00	1.52	0.42	31971	0.0596	0.6	1703.2	17566.7	19270.5
3	0.42	3.05	0.42	31971	0.0596	2.6	1721.6	17567.1	19291.2
4	1.27	4.57	0.42	31971	0.0596	5.8	1739.9	17567.9	19313.6
5	2.54	6.08	0.42	31971	0.0596	10.3	1758.2	17569.1	19337.6
6	4.23	7.60	0.42	31971	0.0596	16.1	1776.5	17570.6	19363.2
7	6.34	9.11	0.42	31971	0.0596	23.1	1794.8	17572.4	19390.3
8	8.87	10.62	0.42	31971	0.0597	31.4	1813.0	17574.5	19418.8
9	11.82	12.12	0.42	31971	0.0597	40.9	1831.1	17576.7	19448.7
10	15.18	13.62	0.42	31971	0.0597	51.7	1849.3	17578.9	19479.9

Table B.82: Example Solution to ODE (2-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	29840	0.0596	0.0	1546.8	16127.8	17674.5
1	0.00	0.00	0.44	29840	0.0596	0.0	1546.8	16127.8	17674.5
2	0.00	1.59	0.44	29840	0.0596	0.7	1564.4	16127.8	17692.8
3	0.44	3.17	0.44	29840	0.0596	2.8	1581.9	16128.1	17712.9
4	1.32	4.76	0.44	29840	0.0596	6.3	1599.5	16128.9	17734.7
5	2.64	6.34	0.44	29840	0.0596	11.2	1617.0	16130.1	17758.3
6	4.40	7.91	0.44	29840	0.0596	17.4	1634.5	16131.5	17783.5
7	6.60	9.49	0.44	29840	0.0596	25.1	1652.0	16133.2	17810.3
8	9.24	11.06	0.44	29840	0.0597	34.1	1669.4	16135.2	17838.6
9	12.31	12.62	0.43	29840	0.0597	44.4	1686.7	16137.3	17868.4
10	15.82	14.19	0.43	29840	0.0597	56.1	1704.1	16139.4	17899.5

Table B.83: Example Solution to ODE (1-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	27975	0.0596	0.0	1408.8	14688.8	16097.6
1	0.00	0.00	0.47	27975	0.0596	0.0	1408.8	14688.8	16097.6
2	0.00	1.70	0.47	27975	0.0596	0.8	1425.9	14688.8	16115.6
3	0.47	3.40	0.47	27975	0.0596	3.2	1443.1	14689.2	16135.6
4	1.42	5.10	0.47	27975	0.0596	7.2	1460.3	14690.0	16157.5
5	2.83	6.79	0.47	27975	0.0596	12.8	1477.4	14691.1	16181.3
6	4.72	8.48	0.47	27975	0.0596	20.0	1494.4	14692.5	16207.0
7	7.08	10.17	0.47	27975	0.0596	28.8	1511.5	14694.2	16234.4
8	9.90	11.85	0.47	27975	0.0597	39.1	1528.5	14696.0	16263.6
9	13.19	13.53	0.46	27975	0.0597	51.0	1545.4	14698.0	16294.4
10	16.95	15.20	0.46	27975	0.0597	64.4	1562.3	14700.0	16326.7

Table B.84: Example Solution to ODE (0-Load Configuration)

T	S	v	a	F	i	Ra	Rr	Rg	R
0	0.00	0.00	0.00	26856	0.0596	0.0	1270.9	13251.3	14522.1
1	0.00	0.00	0.54	26856	0.0596	0.0	1270.9	13251.3	14522.1
2	0.00	1.96	0.54	26856	0.0596	1.1	1288.7	13251.3	14541.1
3	0.54	3.92	0.54	26856	0.0596	4.3	1306.6	13251.7	14562.5
4	1.63	5.87	0.54	26856	0.0596	9.6	1324.4	13252.4	14586.4
5	3.26	7.82	0.54	26856	0.0596	17.0	1342.1	13253.6	14612.7
6	5.43	9.76	0.54	26856	0.0596	26.5	1359.8	13255.0	14641.4
7	8.15	11.70	0.54	26856	0.0597	38.1	1377.5	13256.7	14672.4
8	11.40	13.64	0.54	26856	0.0597	51.8	1395.2	13258.6	14705.5
9	15.19	15.57	0.53	26856	0.0597	67.5	1412.7	13260.5	14740.8
10	19.51	17.49	0.53	26856	0.0597	85.2	1430.3	13262.5	14778.0

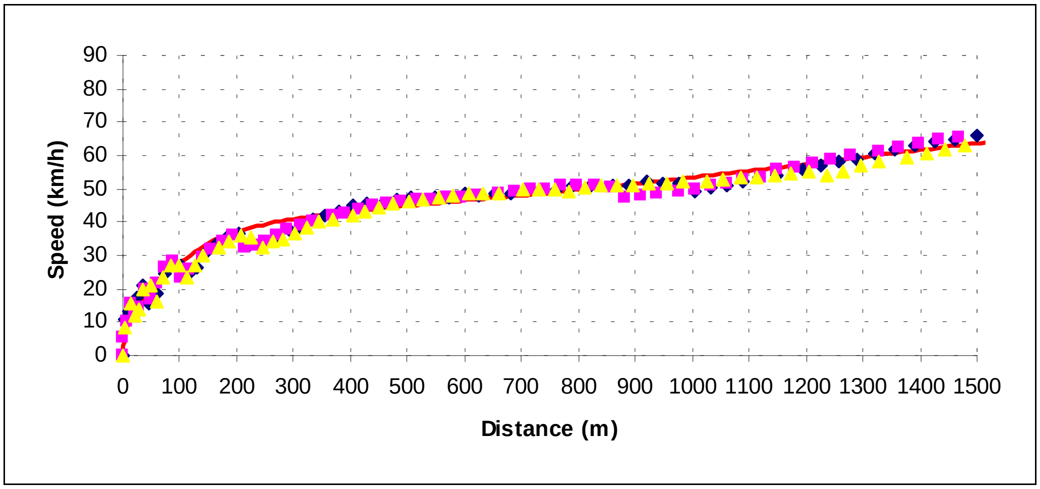


Figure B.75: Predicted and Observed Speed Profile (9-Load Configuration)

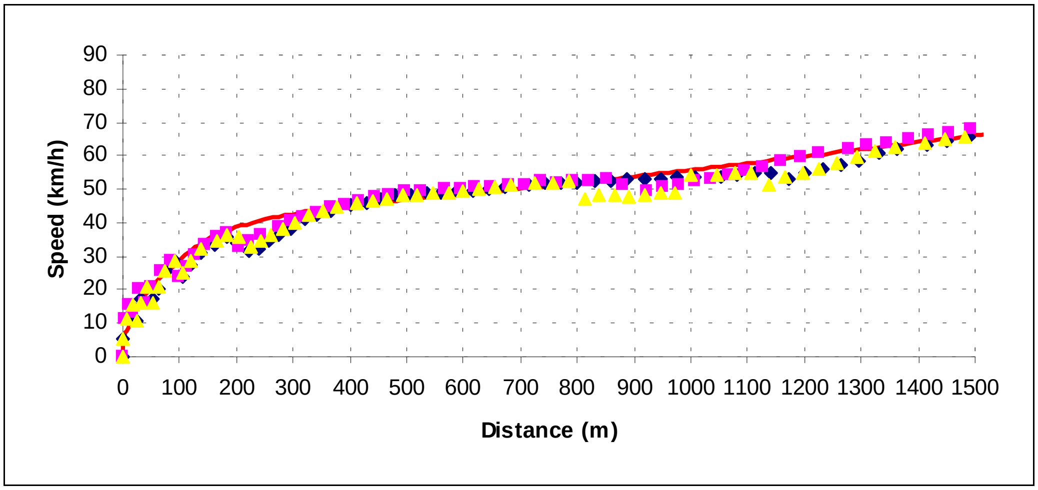


Figure B.76: Predicted and Observed Speed Profile (8-Load Configuration)

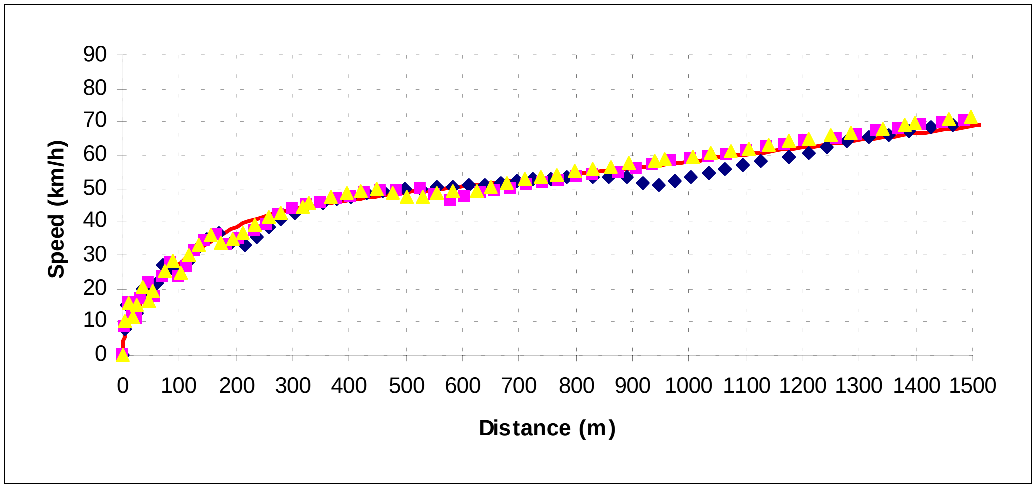


Figure B.77: Predicted and Observed Speed Profile (7-Load Configuration)

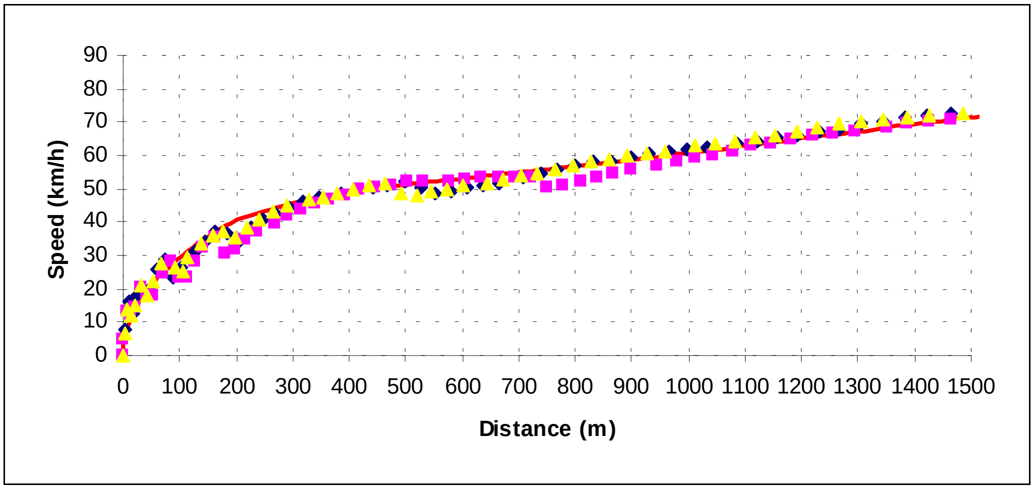


Figure B.78: Predicted and Observed Speed Profile (6-Load Configuration)

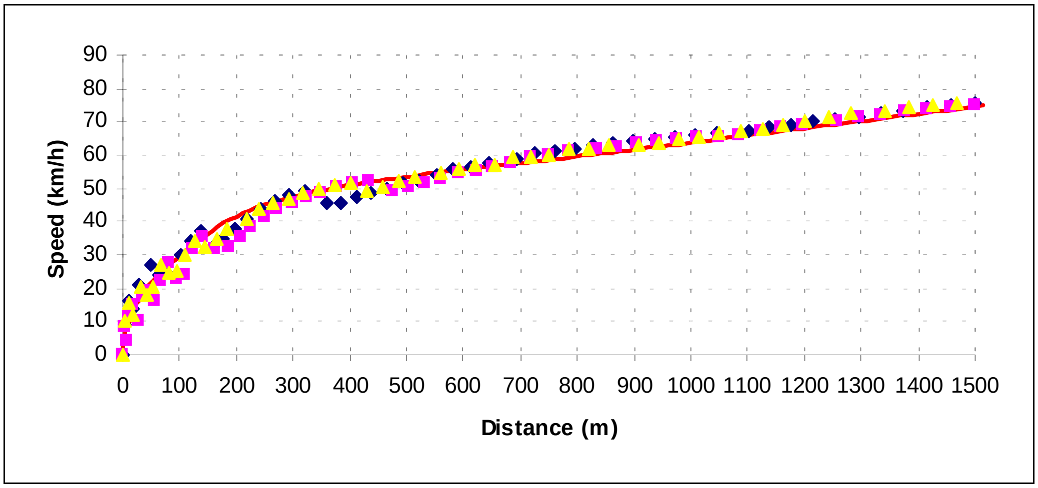


Figure B.79: Predicted and Observed Speed Profile (5-Load Configuration)

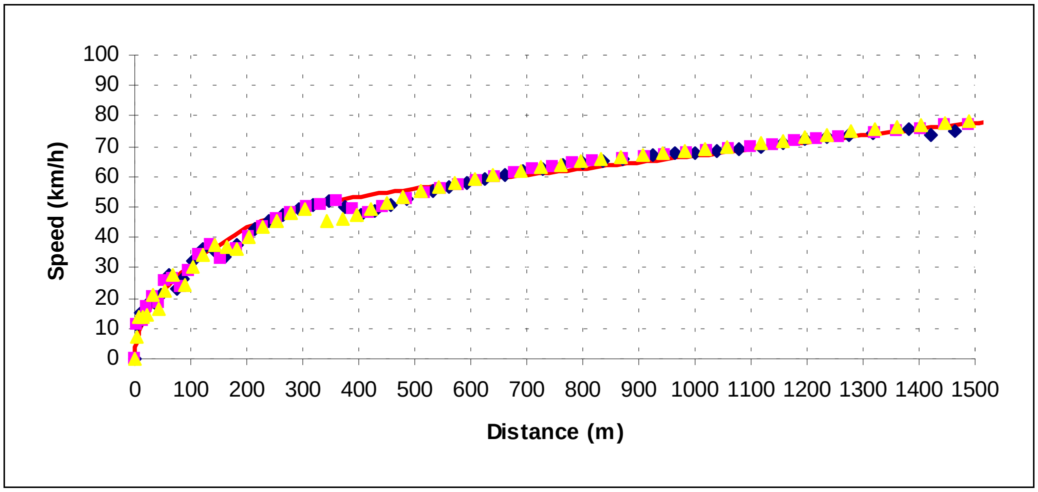


Figure B.80: Predicted and Observed Speed Profile (4-Load Configuration)

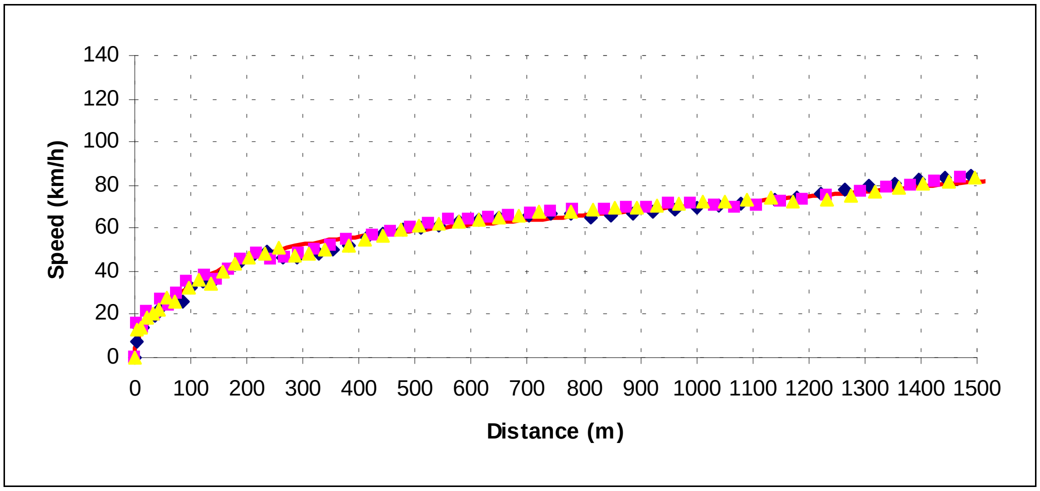


Figure B.81: Predicted and Observed Speed Profile (3-Load Configuration)

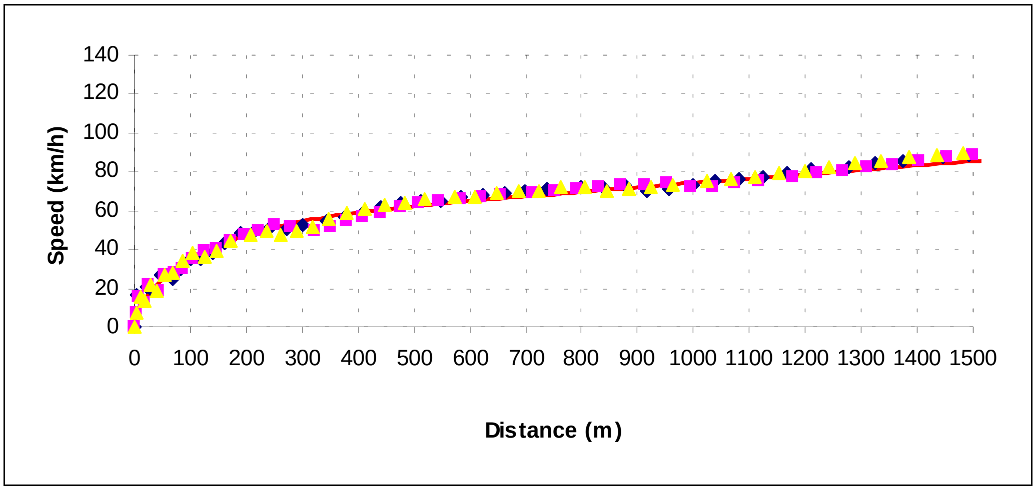


Figure B.82: Predicted and Observed Speed Profile (2-Load Configuration)

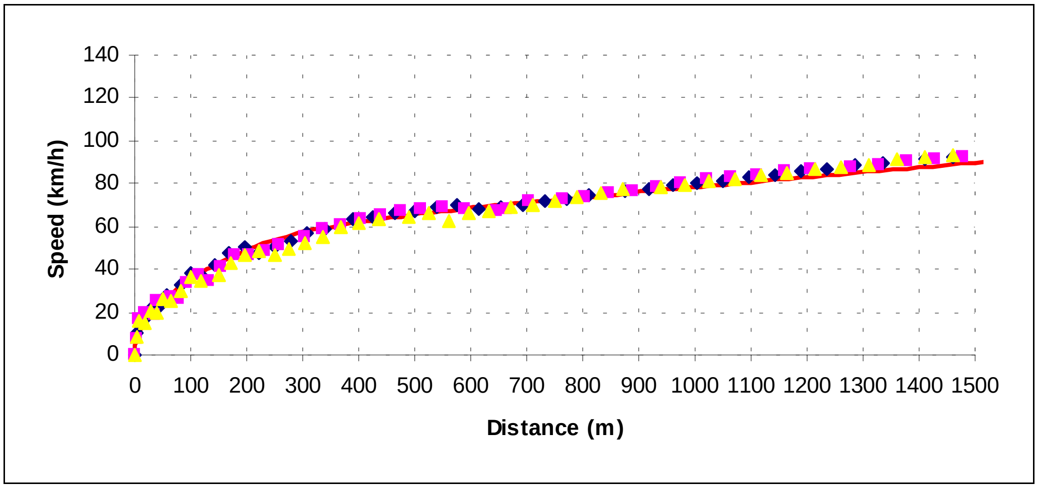


Figure B.83: Predicted and Observed Speed Profile (1-Load Configuration)

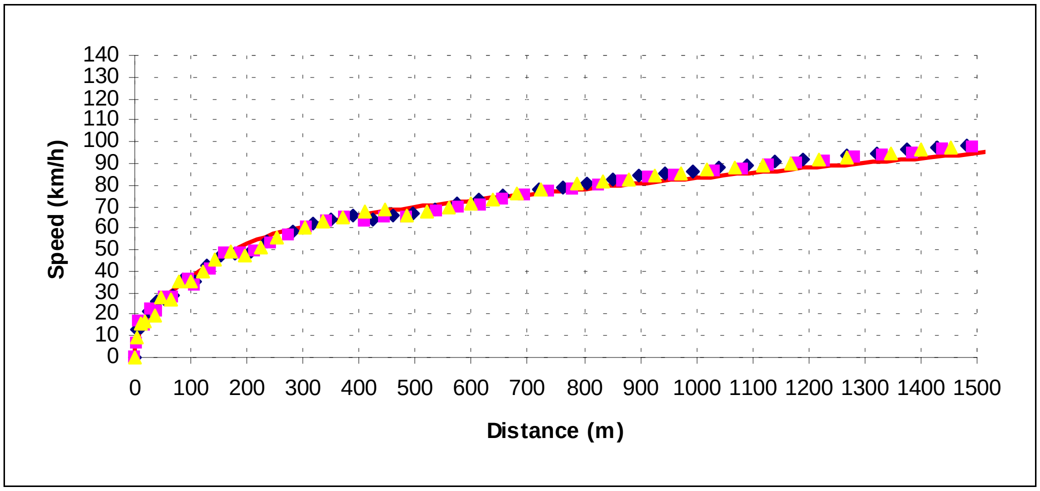


Figure B.84: Predicted and Observed Speed Profile (0-Load Configuration)

APPENDIX C

Matlab program that calculates model data and error in speed along section traveled

```
% This program calculates MSE for typical efficiency.
load 'truckinfo2_0.txt';
load 'Load_0.txt';
truckinfo = truckinfo2_0;

[m, n] = size (Load_0);
SD1 = zeros (m, n);

SD1 (:, 1) = Load_0 (:, 1); % Time (s)     These data are from GPS collected on Smart Road.
SD1 (:, 2) = Load_0 (:, 2); % Distance (m)
SD1 (:, 3) = Load_0 (:, 3); % Speed (km/h)

SD = sort (SD1, 1); % Sort data

ds = polyfit(SD (:, 2), SD (:, 3), 20);

PD = zeros (m, 2);

MinVal = 0;
ArrIndex = 0;
for i =1:m
  if ((SD (i, 1) == 0) & (i == 1)) | (SD (i, 1) > MinVal)
    MinVal = SD (i, 1);
    ArrIndex = ArrIndex + 1;
    PD (ArrIndex, 1) = SD (i, 2); % Distance (m)
    PD (ArrIndex, 2) = polyval (ds, PD(ArrIndex, 1)); % Speed (km/h)
  end
end
```

```
MaxDistFromData = max(SD(:, 2)); % Max Distance estimation

MaxTime = 200; % Process will continue until this time (s)

MI = zeros(MaxTime + 1, 1 + 9); % Size of matrix with data from model

ErrorI = zeros(MaxTime + 1, 2); % Size of matrix with error data

MI (1, 1) = 0; % Time (s)
MI (1, 2) = 0;  % Distance (m)
MI (1, 3) = 0;  % Speed (km/h)
MI (1, 4) =0; % Acceleration (m/s2)
MI (1, 6) = 0.0596; % Grade
MI (1, 7) = 0;  % Ra (N)
MI (1, 8) = 9.8066 * truckinfo(15) * (truckinfo(13) * (MI (1, 3)) + truckinfo(14)) * truckinfo(5)/1000; %Rr (N)
MI (1, 9) = 9.8066*truckinfo(5)*MI (1, 6); % Rg (N)
MI (1, 10) = MI (1, 7) + MI (1, 8) + MI (1, 9); % R (N)

if MI (1, 3) < 1
   Ft = 3600*truckinfo(8)*truckinfo(4);
else
   Ft = 3600*truckinfo(8) * truckinfo(4)/MI (1, 3);
  end
   MI (1, 5) = min(Ft, 9.8066*truckinfo(7)*truckinfo(5)*truckinfo(9));  % F (N)
  %MI (1, 5) = 9.8066*truckinfo(7)*truckinfo(5)*truckinfo(9);  % F (N)


i = 1;
   MI (i + 1, 1) = i; % Time (s)
   MI (i + 1, 2) = MI (i, 2) + MI (i, 3)/3.6*(MI (i + 1, 1) - MI (i, 1)); % Distance (m)
```

```
while (i <= MaxTime + 1) & (MI (i + 1, 2) <= 1500)
   MI (i + 1, 3) = MI (i, 3) + MI (i, 4)*(MI (i + 1, 1) - MI (i, 1))*3.6; % Speed (km/h)
   MI (i + 1, 6) = 0.0596283 + (3.328 * 10^(-6) * MI (i + 1 , 2)) + ((-3.79) * 10^(-8) * (MI (i + 1 , 2))^2) + (1.42 * 10^(-11) * (MI (i +
1, 2))^3) ;  % Grade
   MI (i + 1, 7) = truckinfo(12) * truckinfo(10) * truckinfo(11) * truckinfo(16) * (MI (i + 1, 3))^2; %Ra (N)
   MI (i + 1, 8) = 9.8066 * truckinfo(15) * (truckinfo(13) * (MI (i + 1, 3)) + truckinfo(14)) * truckinfo(5)/1000; %Rr (N)
   MI (i + 1, 9) = truckinfo(5) * MI (i + 1, 6) * 9.8066; %Rg (N)
   MI (i + 1, 10) = MI (i + 1, 7) + MI (i + 1, 8) + MI (i + 1, 9); % R (N)
   if MI (i + 1, 3) < 1
      Ft = 3600*truckinfo(8)*truckinfo(4);
   else
      Ft = 3600*truckinfo(8) * truckinfo(4)/MI (i + 1, 3);
   end
   MI (i + 1, 5) = min(Ft, 9.8066*truckinfo(7)*truckinfo(5)*truckinfo(9));  % F (N)
   MI (i + 1, 4) = (MI (i + 1, 5) - MI (i + 1, 10))/truckinfo(5); % Acceleration (m/s2)
   ErrorI (i, 1) = MI(i + 1, 3) - interp1 (PD (1:ArrIndex, 1), PD (1:ArrIndex, 2), MI(i + 1, 2));
   ErrorI (i, 2) = (MI(i + 1, 3) - interp1 (PD (1:ArrIndex, 1), PD (1:ArrIndex, 2), MI(i + 1, 2)))^2;

   i = i + 1;
   MI (i + 1, 1) = i; % Time (s)
   MI (i + 1, 2) = MI (i, 2) + MI (i, 3)/3.6*(MI (i + 1, 1) - MI (i, 1)); % Distance (m)

end
MaxIndex = i - 1;

MSErr = 1/MaxIndex * sum (ErrorI(:, 2));  % Mean square error

i = 1;
while (i <= ArrIndex) & (PD(i, 1) <= 1500)
    i = i + 1;
end
```

```
ArrIndex = i - 1;
plot (MI(1:MaxIndex, 2), ErrorI (1:MaxIndex, 1));
xlabel ('Distance [m]');
ylabel ('Error');
grid

fid = fopen ('outHP350a.dat', 'w');
fprintf (fid, '%6.5f %6.5f %6.5f %6.5f %6.5f %6.5f %6.5f %6.5f %6.5f %6.5f\n', MI'); % Results from model
status = fclose(fid);

fid = fopen ('outHP350b.dat', 'w');
fprintf (fid, '%6.5f %6.5f\n', ErrorI'); % The first column contains error and the second square error
fprintf (fid, '%6.5f\n', MSErr'); % Mean square error
status = fclose(fid);
```

Error comparison for two models

Truck with power of 260 kW (350 hp)

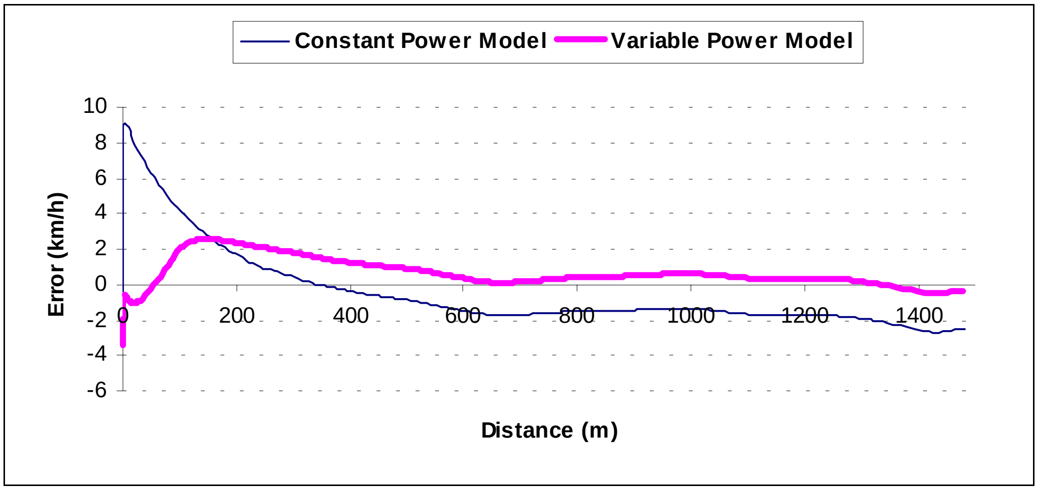


Figure C.1: Comparison of error versus distance traveled (9-Load Configuration)

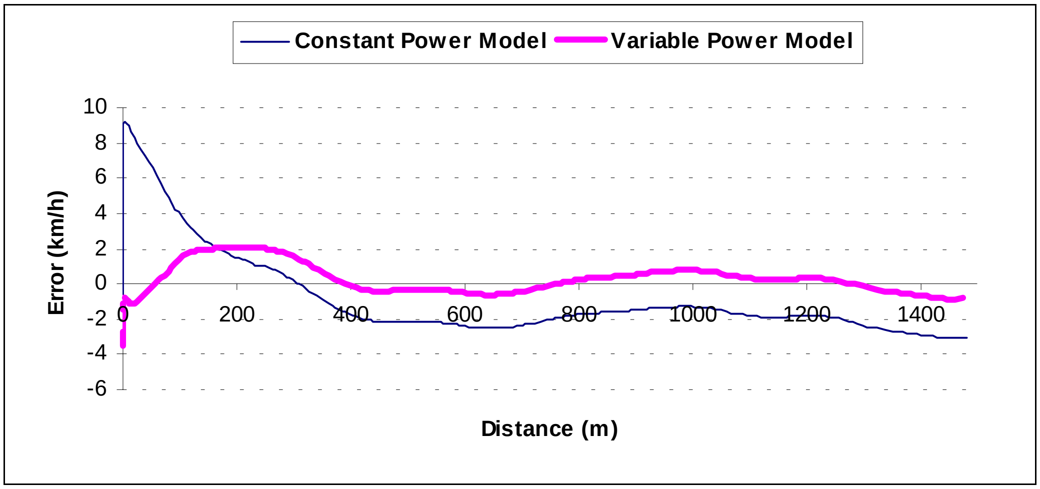


Figure C.2: Comparison of error versus distance traveled (8-Load Configuration)

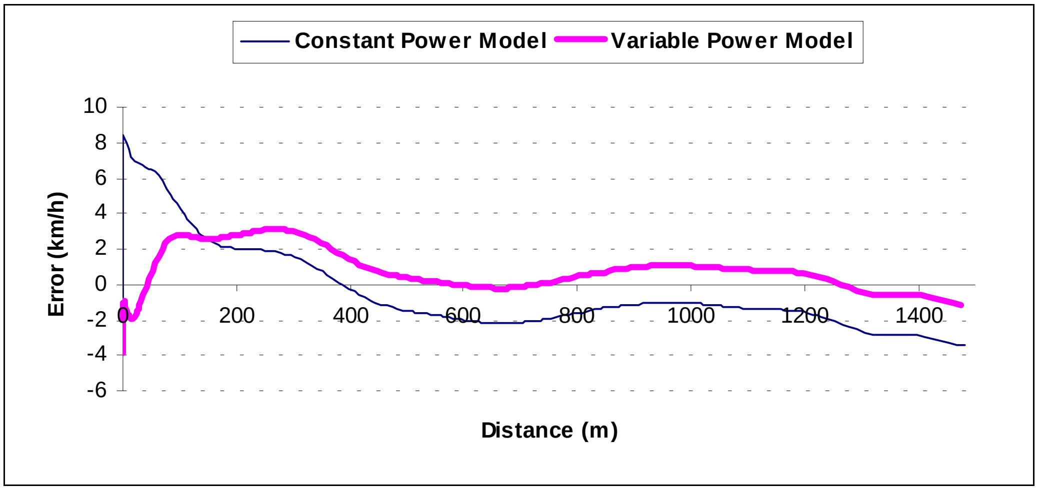


Figure C.3: Comparison of error versus distance traveled (7-Load Configuration)

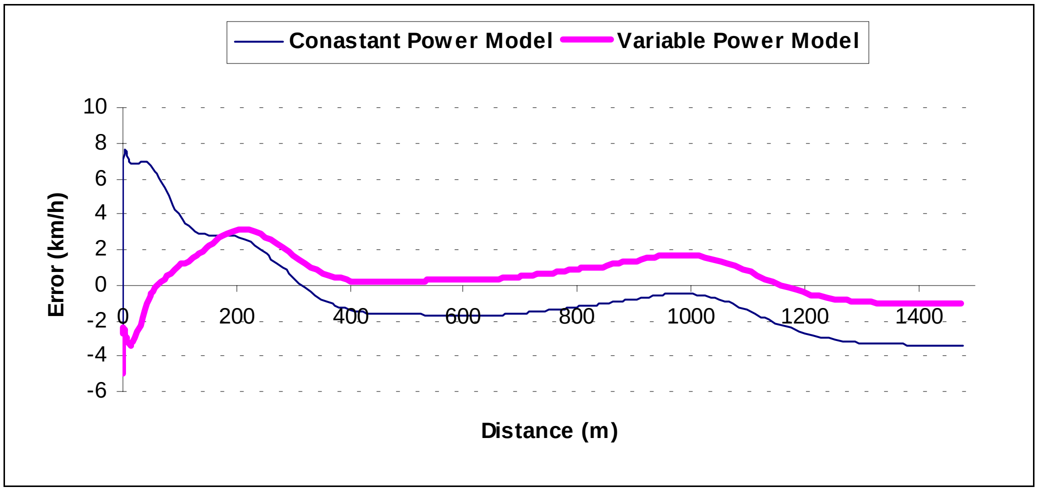


Figure C.4: Comparison of error versus distance traveled (6-Load Configuration)

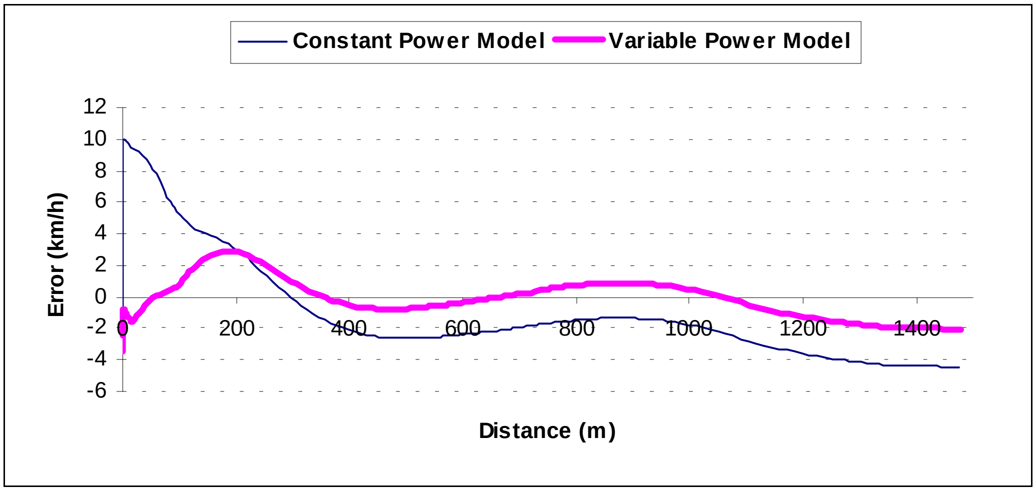


Figure C.5: Comparison of error versus distance traveled (5-Load Configuration)

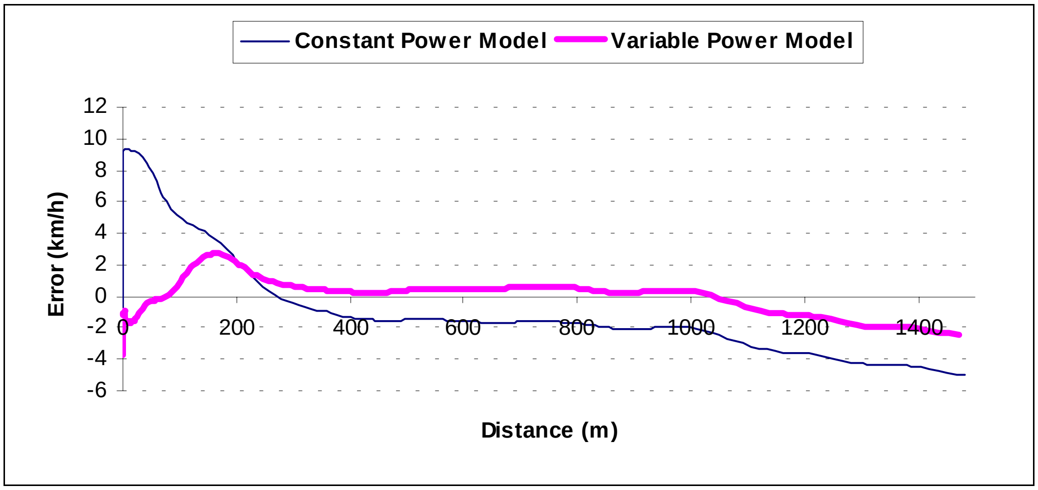


Figure C.6: Comparison of error versus distance traveled (4-Load Configuration)

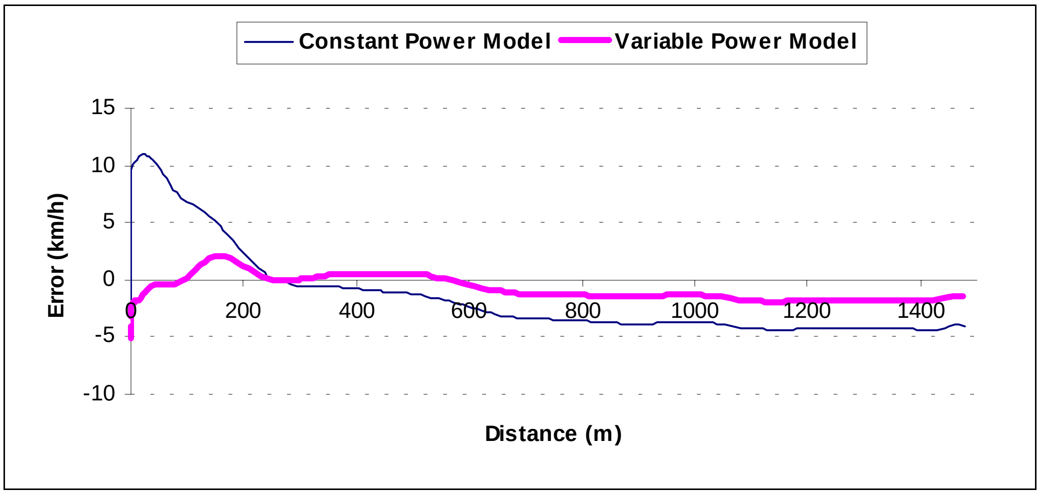


Figure C.7: Comparison of error versus distance traveled (3-Load Configuration)

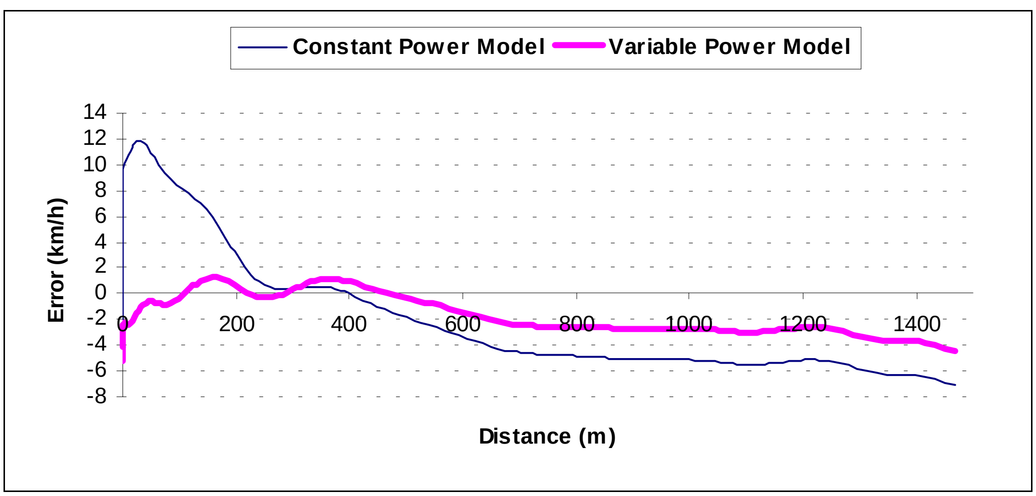


Figure C.8: Comparison of error versus distance traveled (2-Load Configuration)

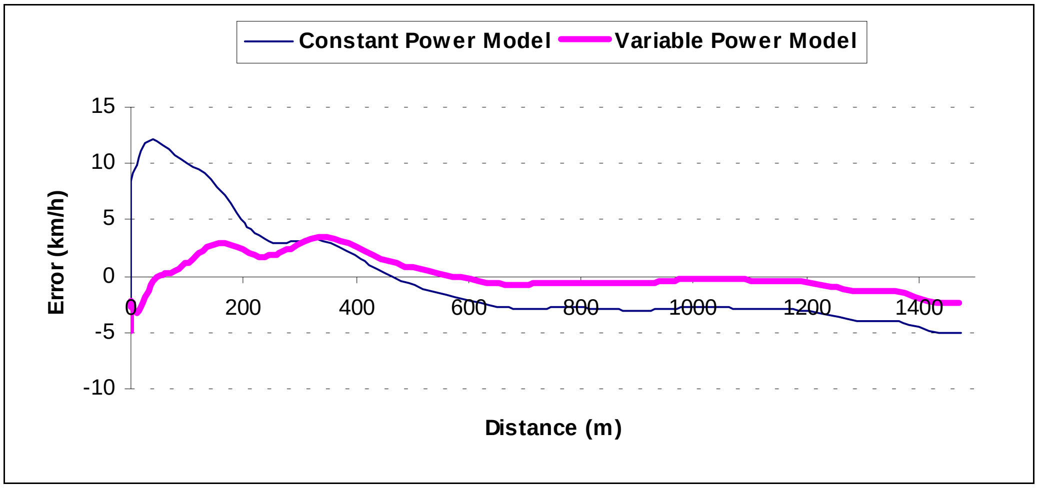


Figure C.9: Comparison of error versus distance traveled (1-Load Configuration)

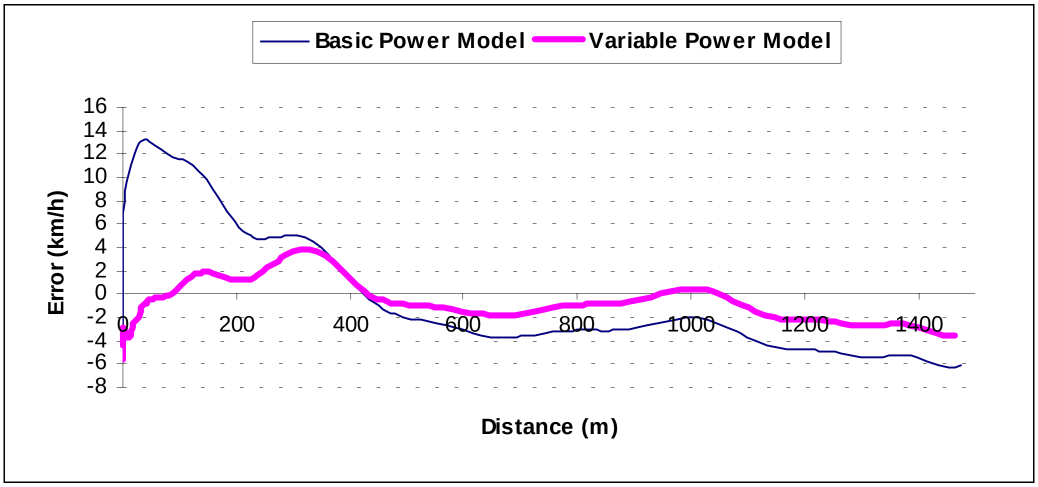


Figure C.10: Comparison of error versus distance traveled (0-Load Configuration)

Truck with power of 320 kW (430 hp)

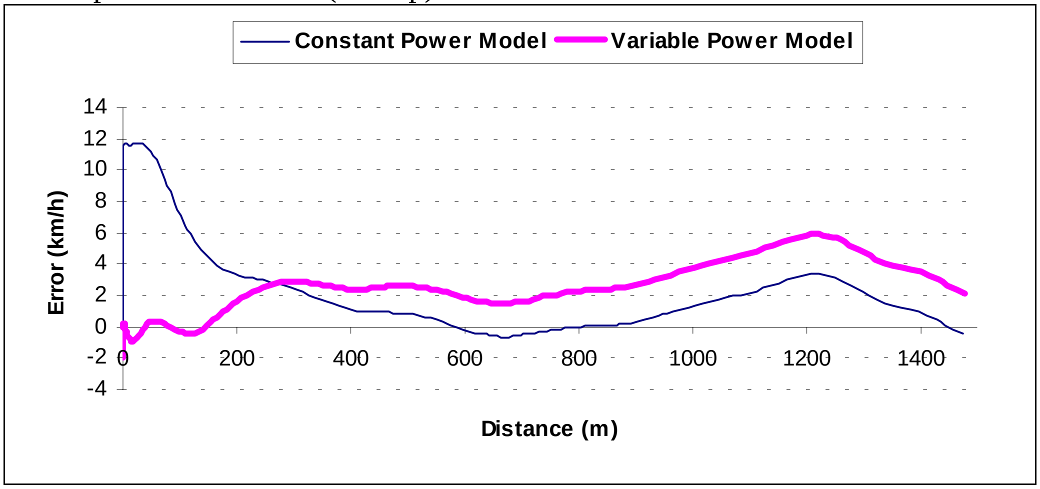


Figure C.11: Comparison of error versus distance traveled (9-Load Configuration)

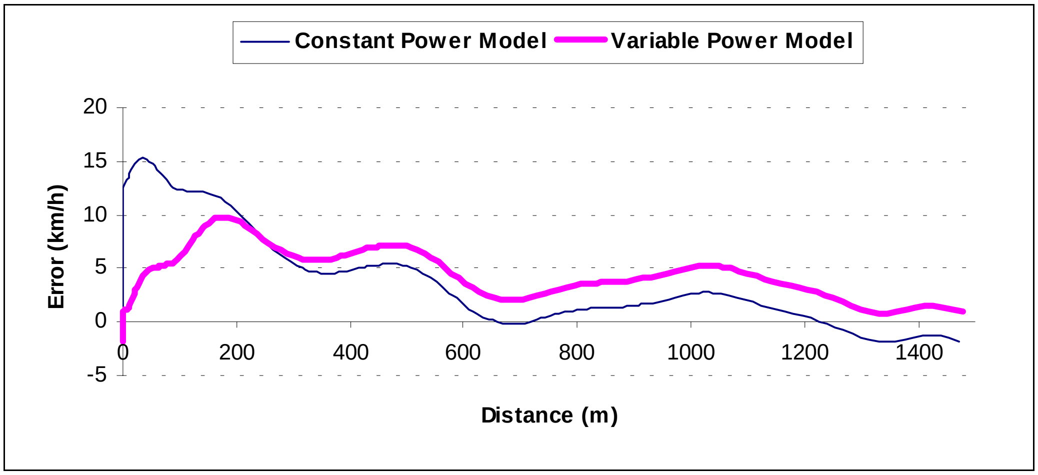


Figure C.12: Comparison of error versus distance traveled (8-Load Configuration)

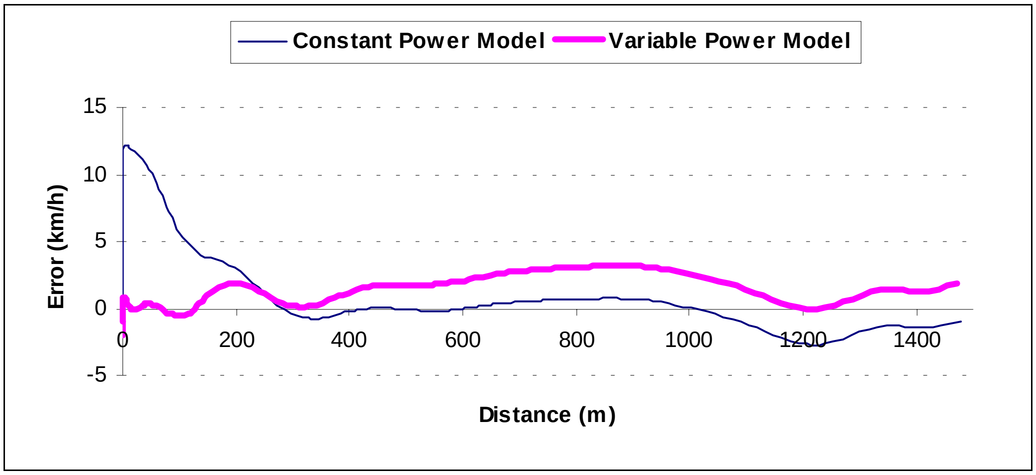


Figure C.13: Comparison of error versus distance traveled (7-Load Configuration)

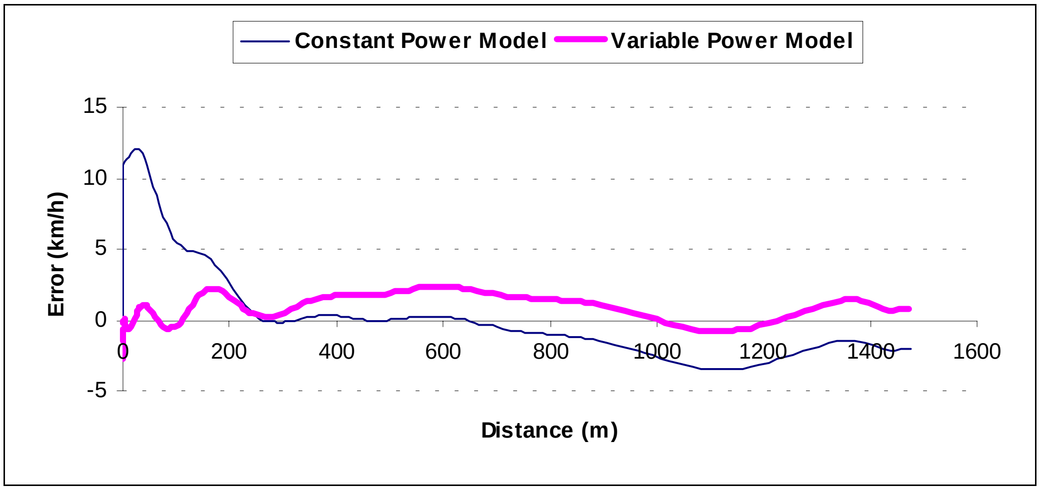


Figure C.14: Comparison of error versus distance traveled (6-Load Configuration)

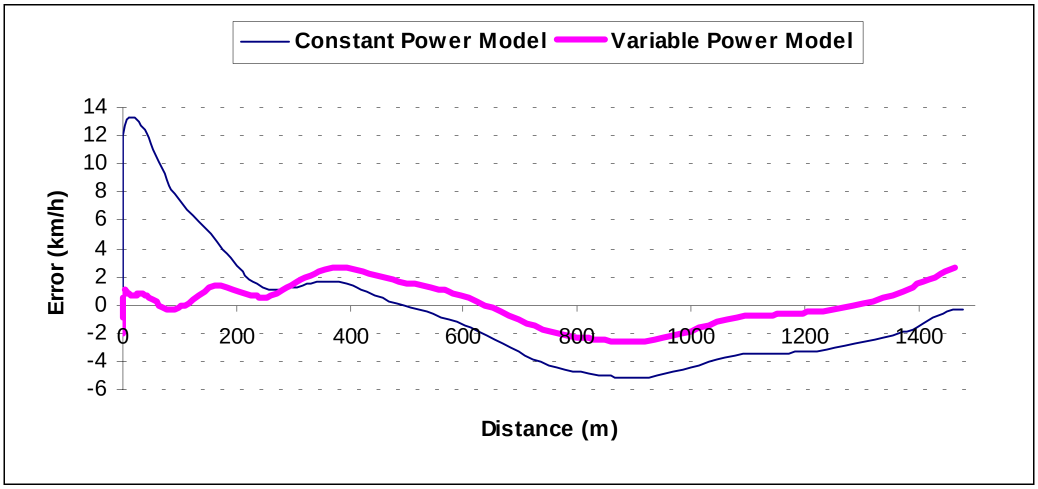


Figure C.15: Comparison of error versus distance traveled (5-Load Configuration)

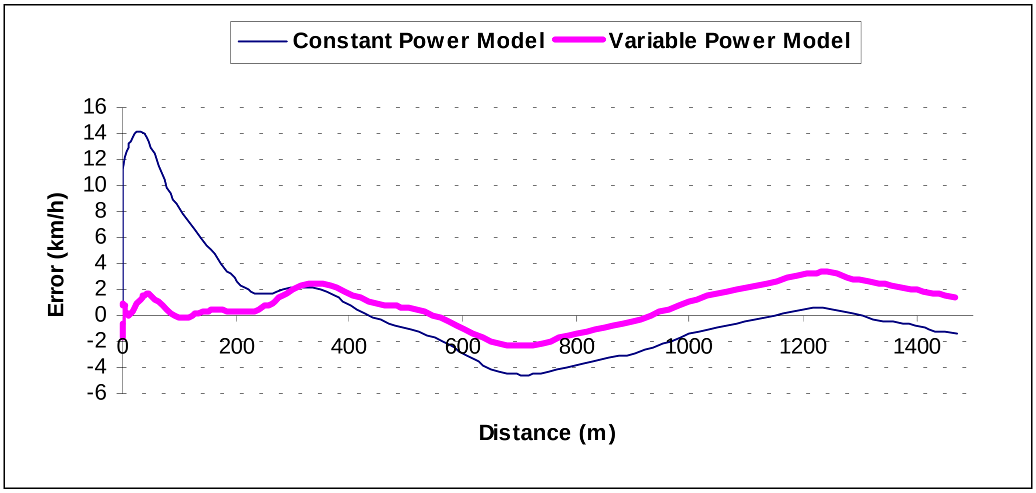


Figure C.16: Comparison of error versus distance traveled (4-Load Configuration)

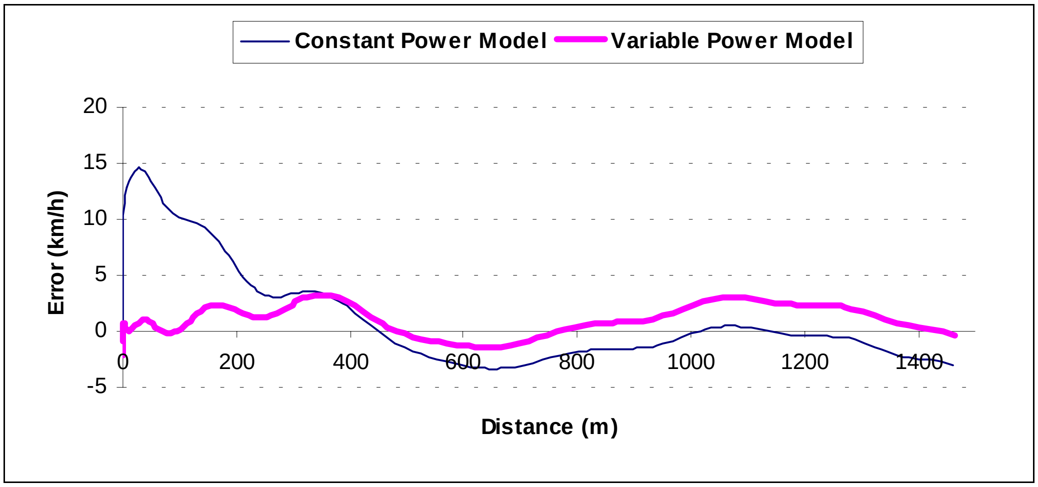


Figure C.17: Comparison of error versus distance traveled (3-Load Configuration)

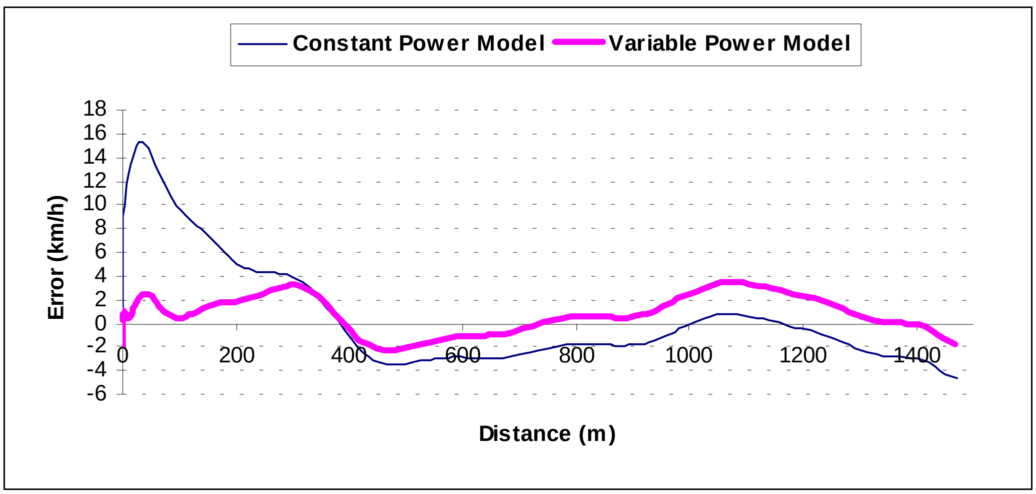


Figure C.18: Comparison of error versus distance traveled (2-Load Configuration)

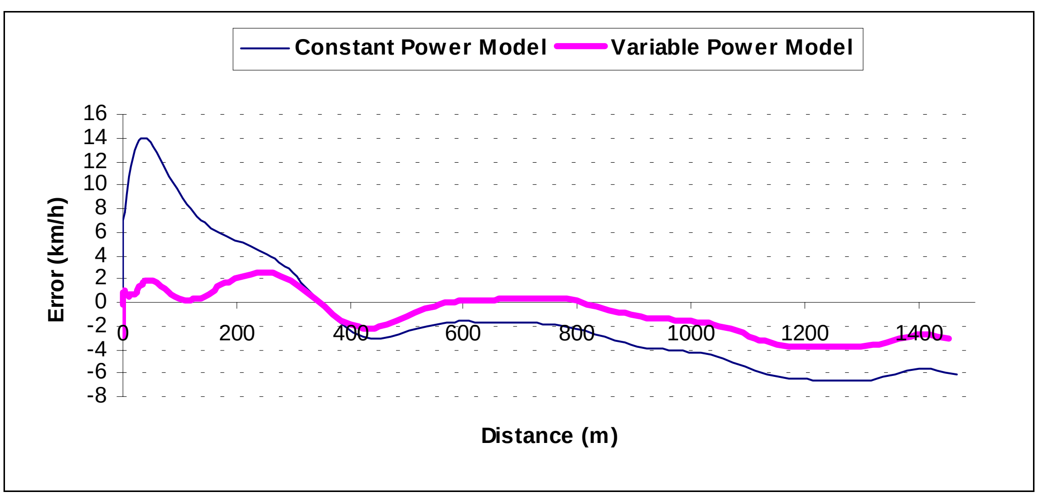


Figure C.19: Comparison of error versus distance traveled (1-Load Configuration)

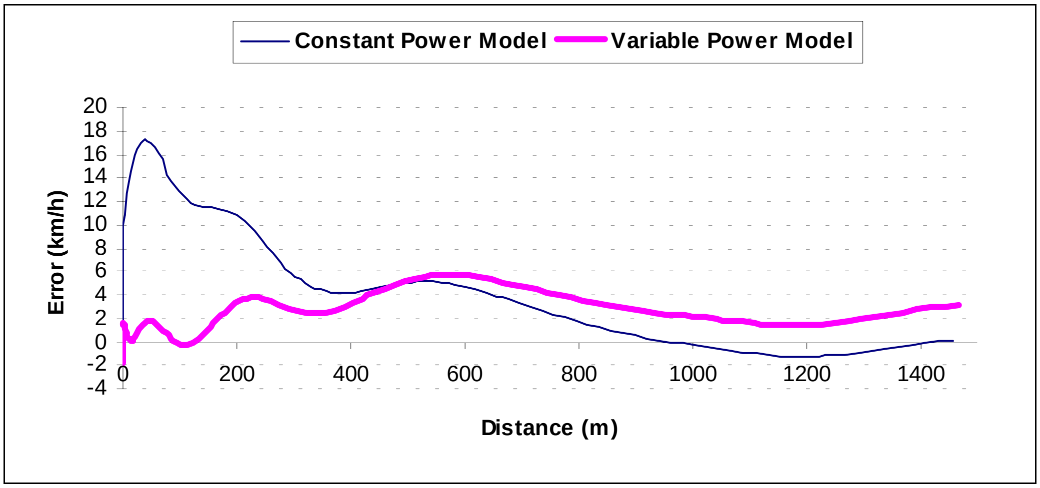


Figure C.20: Comparison of error versus distance traveled (0-Load Configuration)

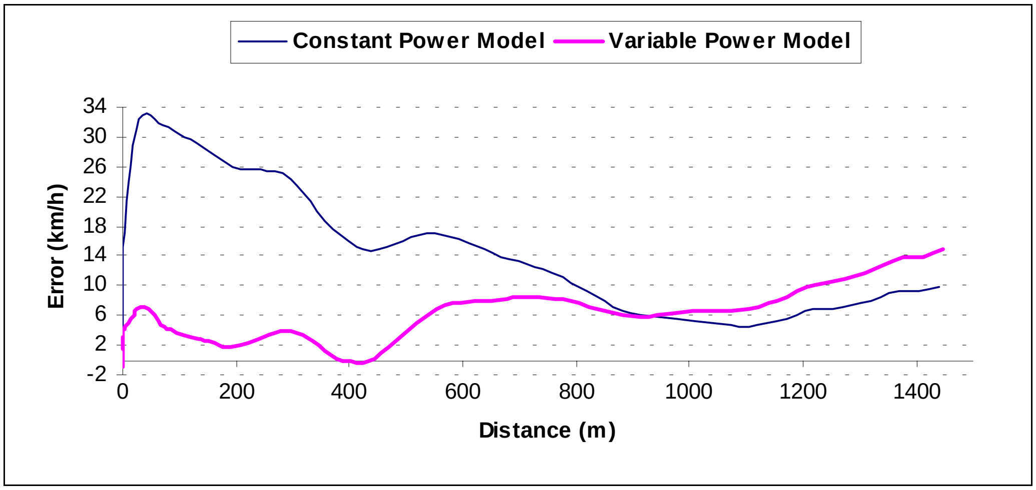


Figure C.21: Comparison of error versus distance traveled (Truck Configuration)

Truck with power of 350 kW (470 hp)

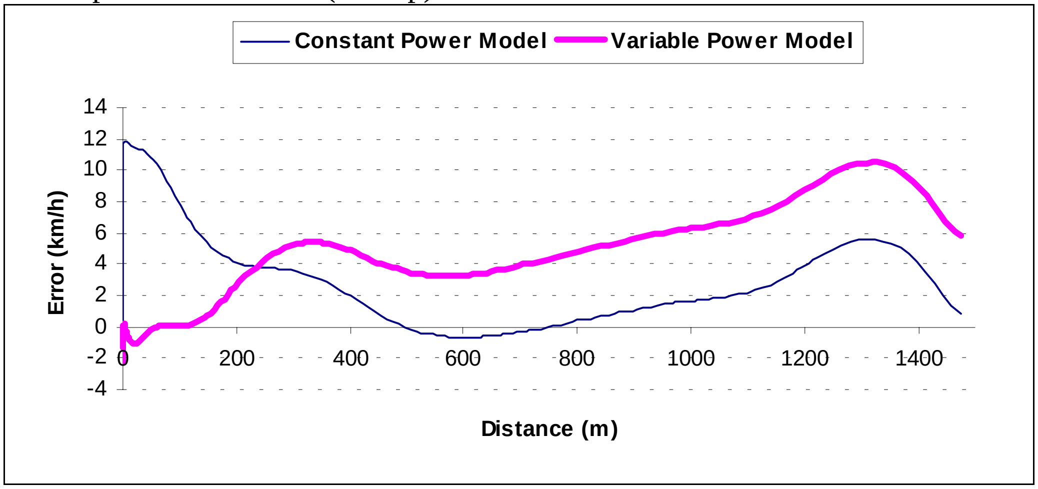


Figure C.22: Comparison of error versus distance traveled (9–Load Configuration)

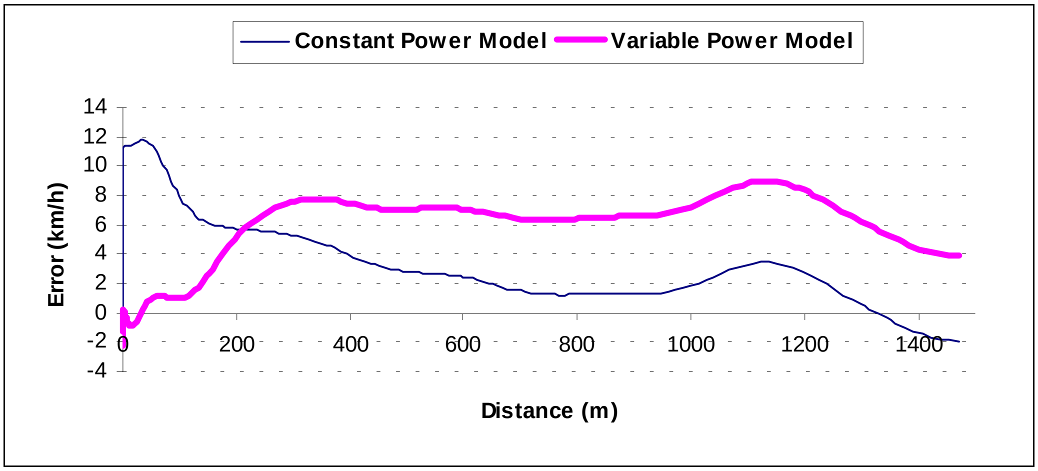


Figure C.23: Comparison of error versus distance traveled (8–Load Configuration)

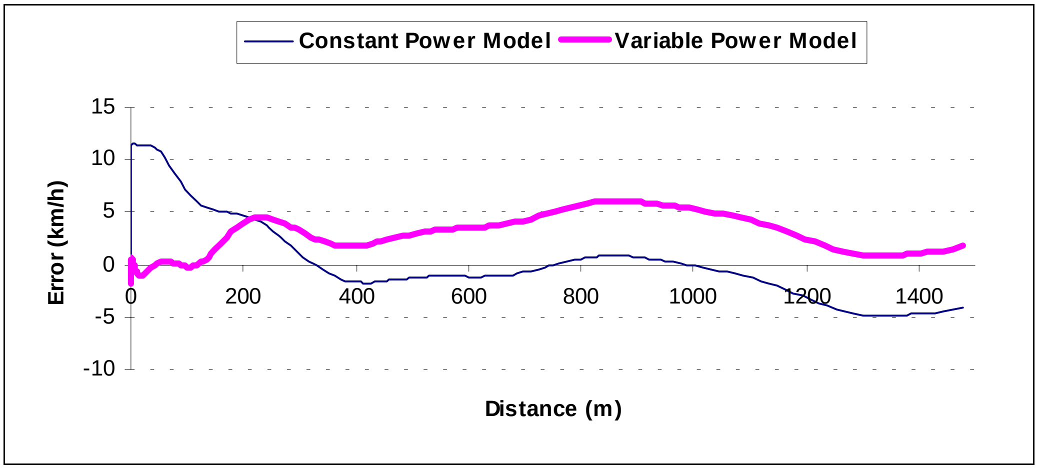


Figure C.24: Comparison of error versus distance traveled (7–Load Configuration)

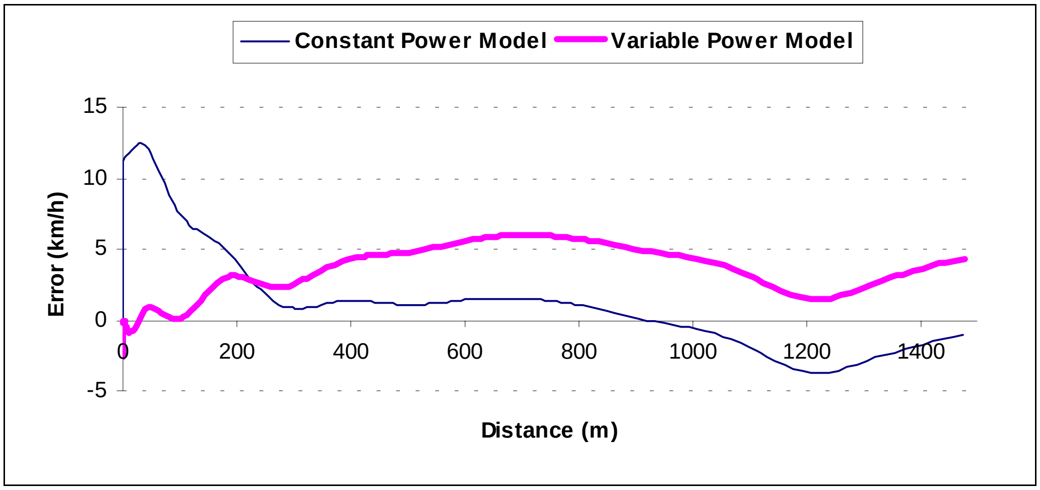


Figure C.25: Comparison of error versus distance traveled (6–Load Configuration)

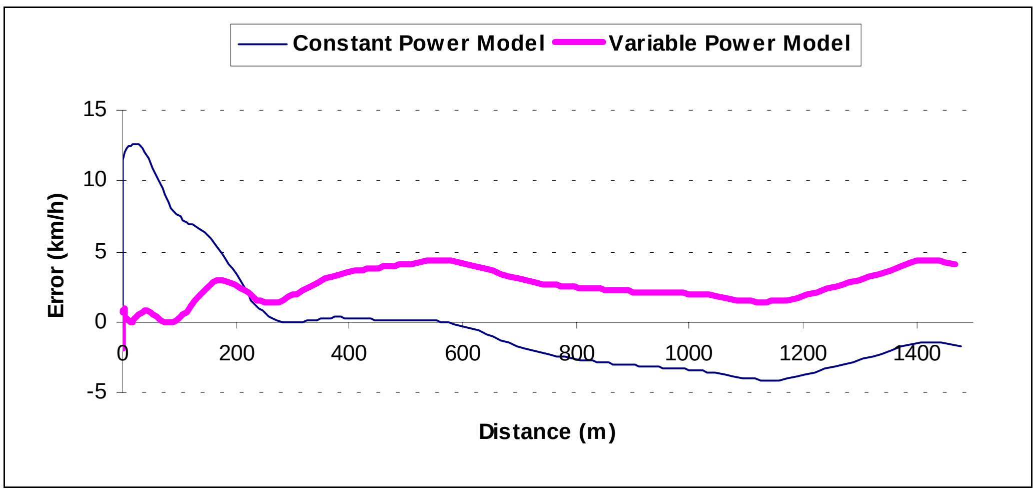


Figure C.26: Comparison of error versus distance traveled (5–Load Configuration)

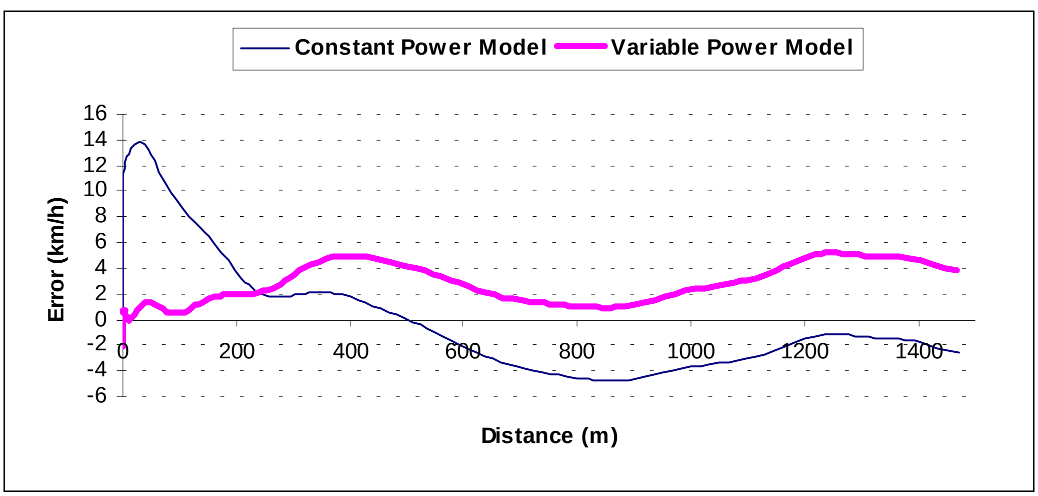


Figure C.27: Comparison of error versus distance traveled (4–Load Configuration)

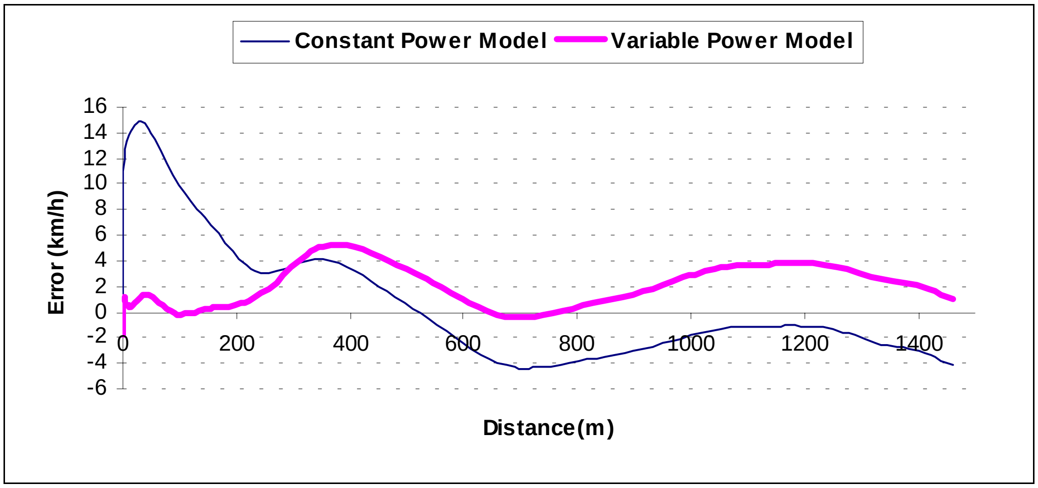


Figure C.28: Comparison of error versus distance traveled (3–Load Configuration)

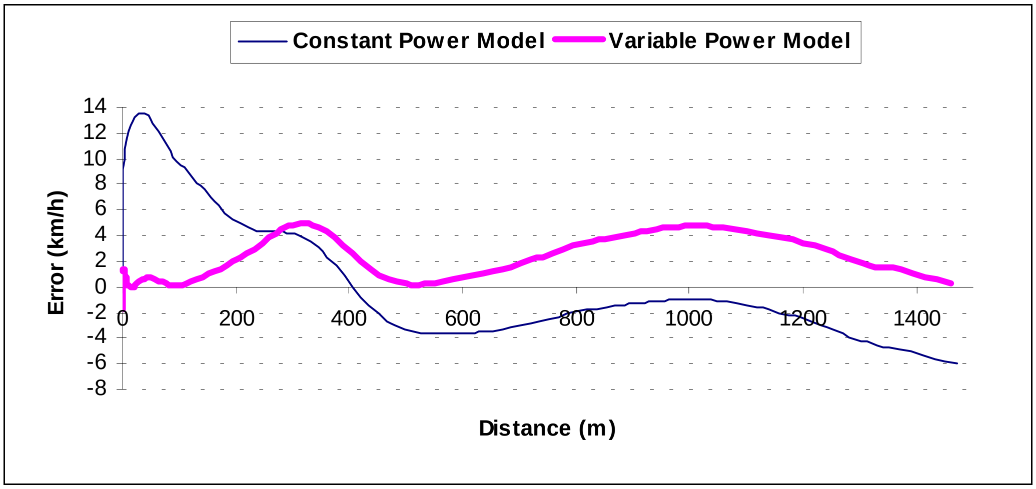


Figure C.29: Comparison of error versus distance traveled (2–Load Configuration)

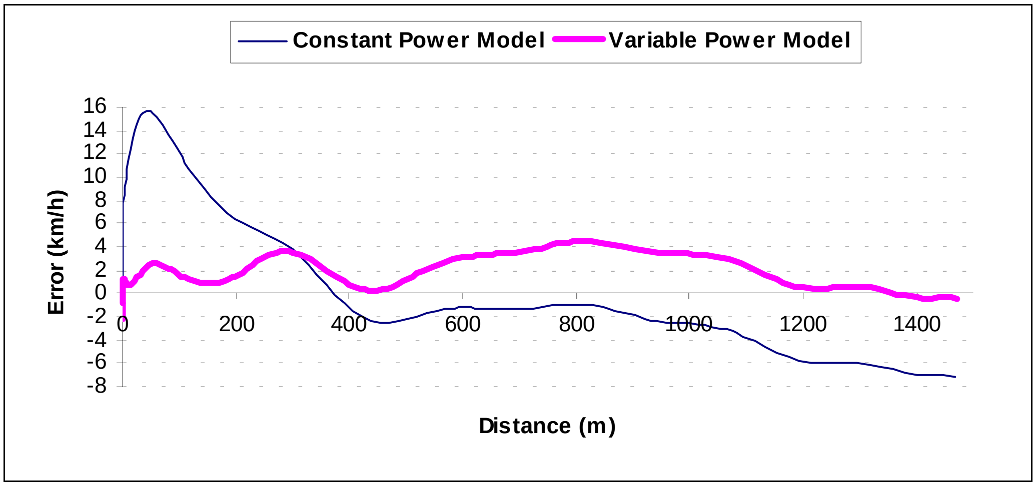


Figure C.30: Comparison of error versus distance traveled (1–Load Configuration)

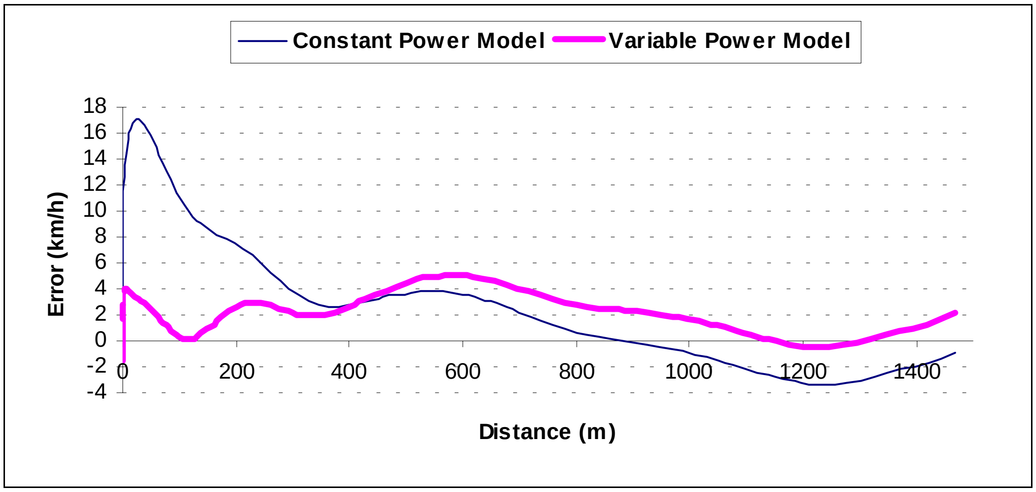


Figure C.31: Comparison of error versus distance traveled (0–Load Configuration)

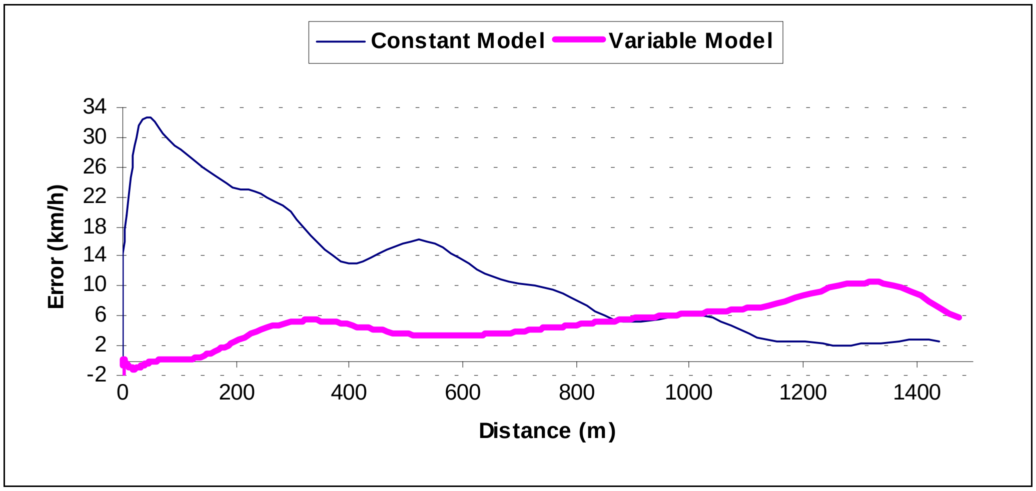


Figure C.32: Comparison of error versus distance traveled (Truck Configuration)

Truck with power of 375 kW (500 hp)

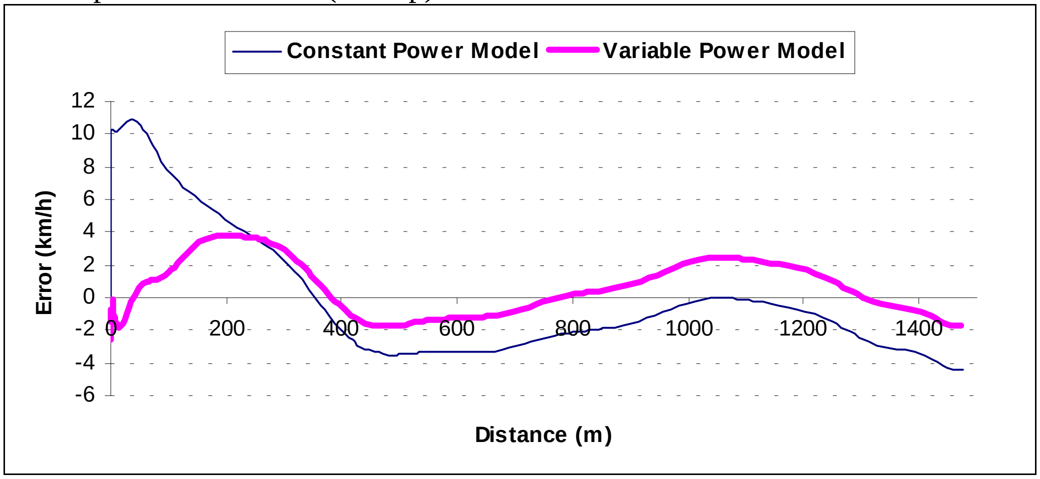


Figure C.33: Comparison of error versus distance traveled (9–Load Configuration)

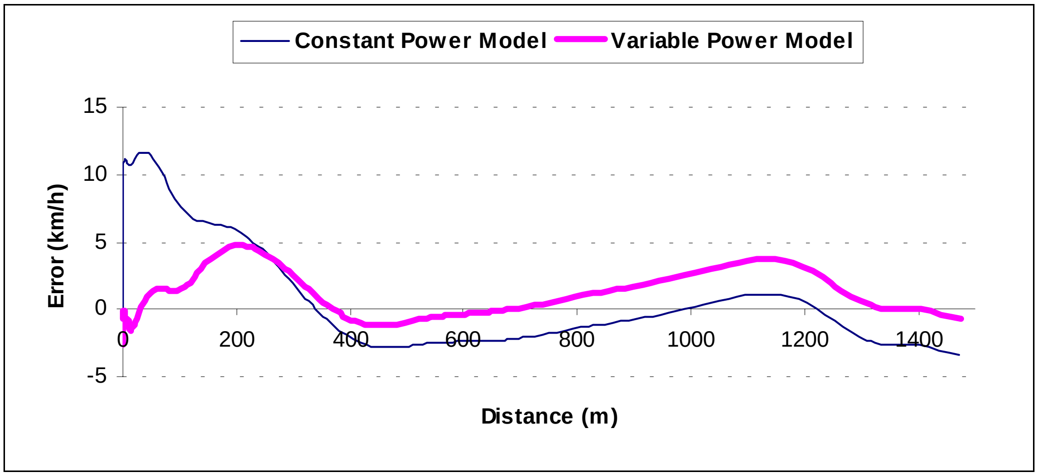


Figure C.34: Comparison of error versus distance traveled (8–Load Configuration)

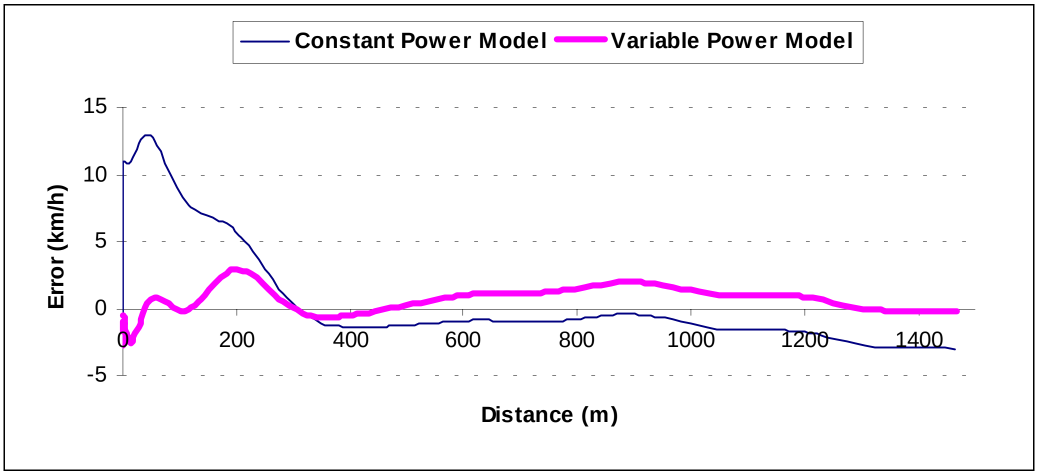


Figure C.35: Comparison of error versus distance traveled (7–Load Configuration)

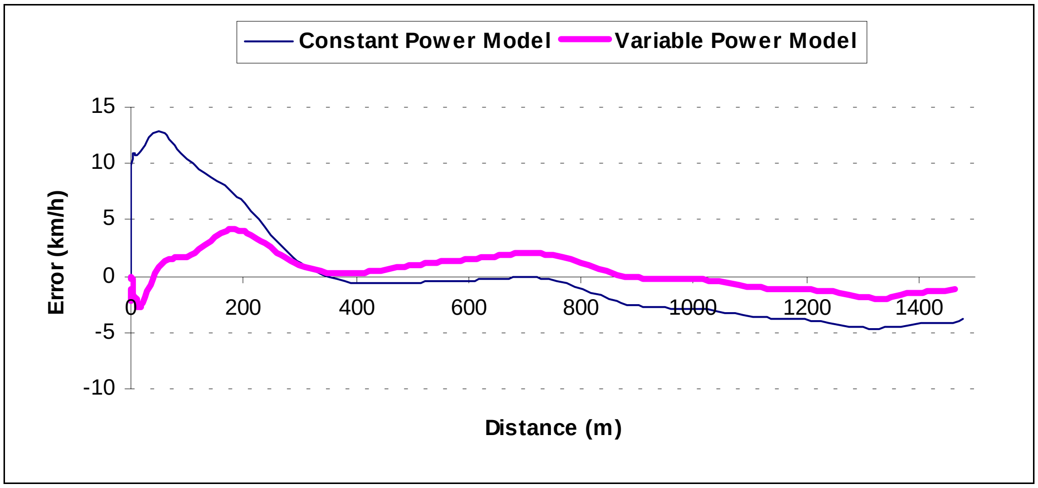


Figure C.36: Comparison of error versus distance traveled (6–Load Configuration)

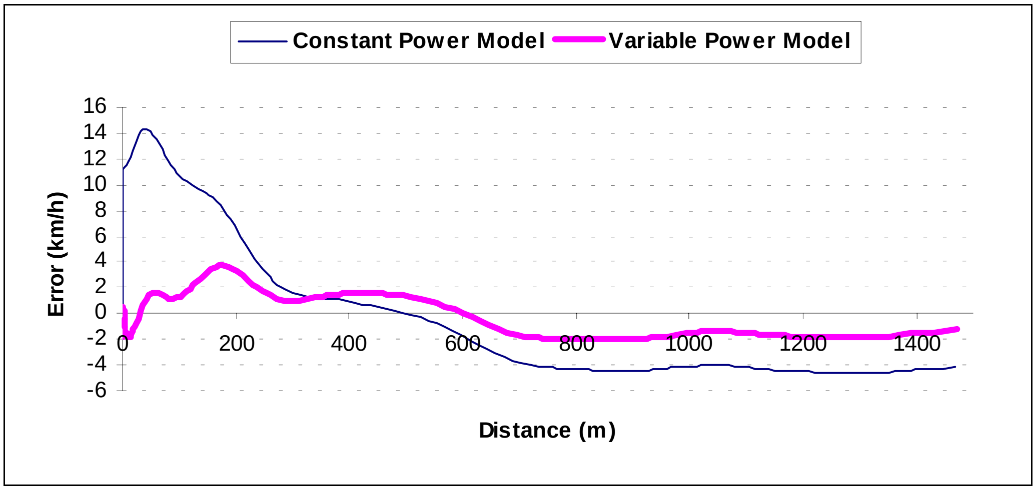


Figure C.37: Comparison of error versus distance traveled (5–Load Configuration)

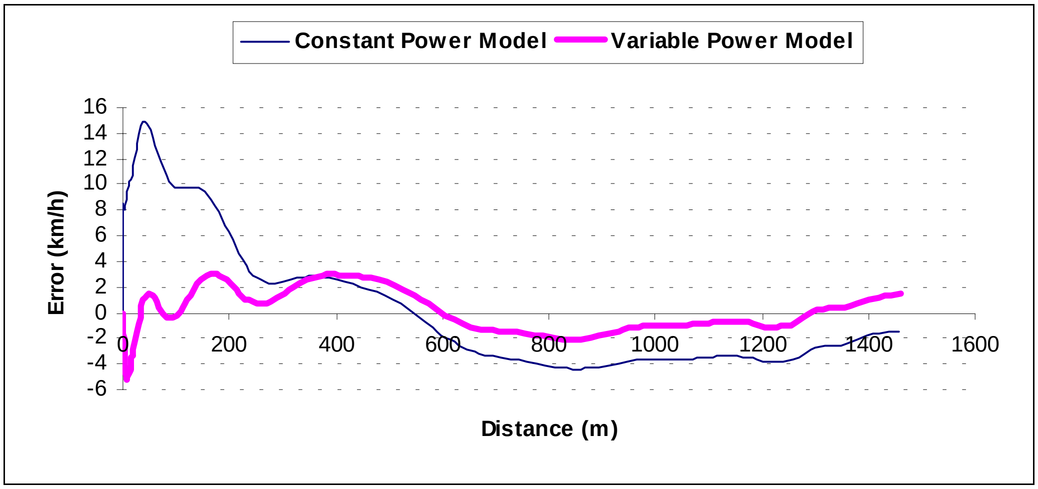


Figure C.38: Comparison of error versus distance traveled (4–Load Configuration)

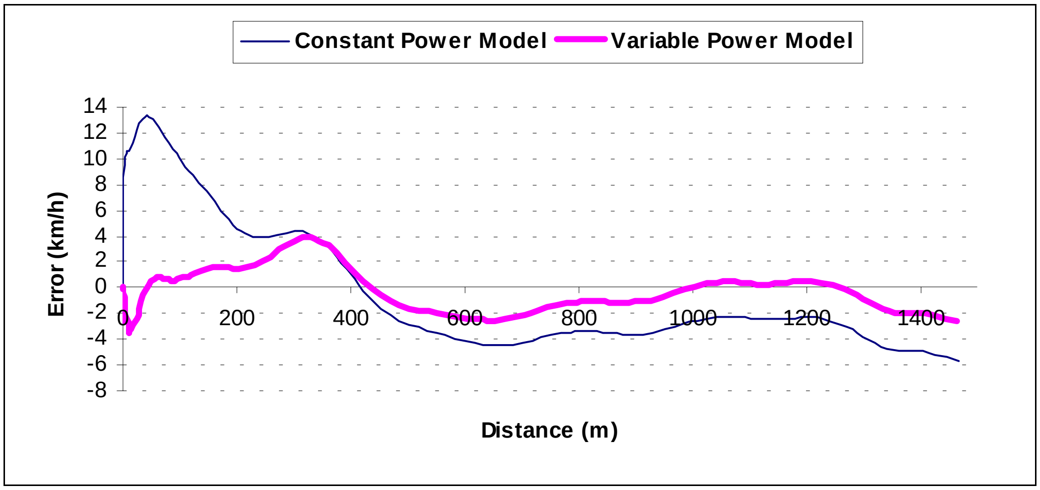


Figure C.39: Comparison of error versus distance traveled (3–Load Configuration)

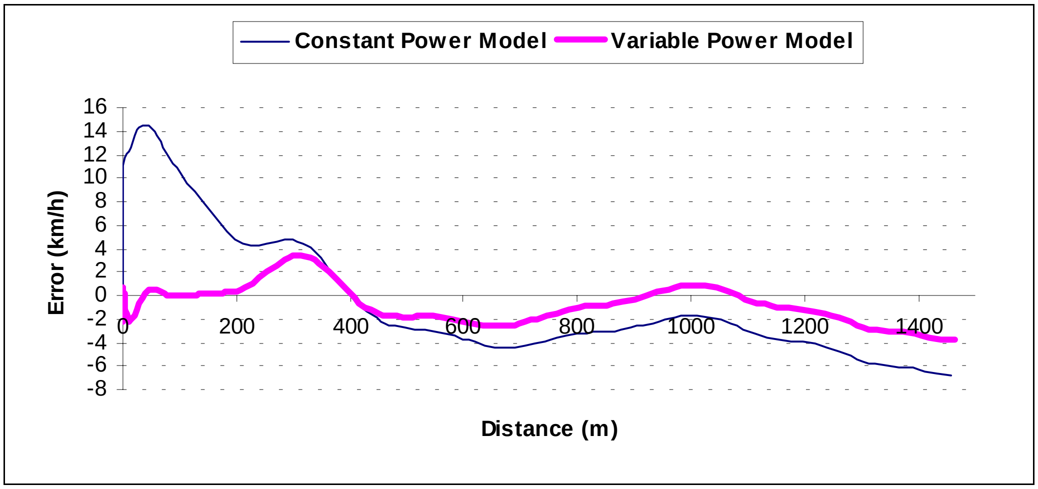


Figure C.40: Comparison of error versus distance traveled (2–Load Configuration)

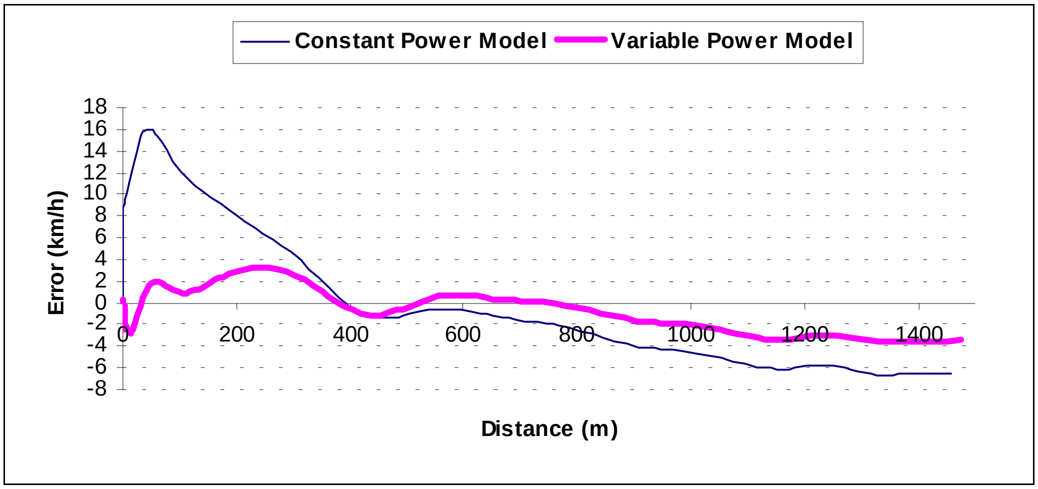


Figure C.41: Comparison of error versus distance traveled (1–Load Configuration)

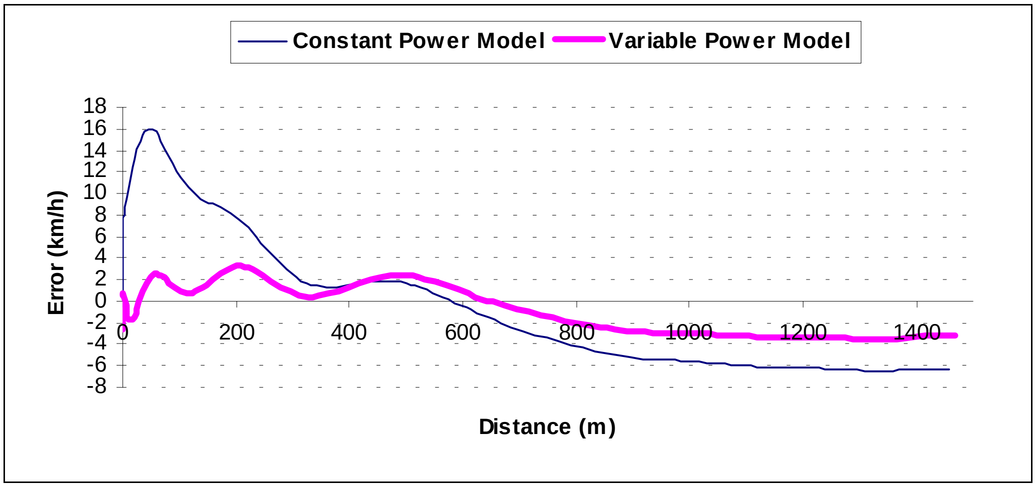


Figure C.42: Comparison of error versus distance traveled (0–Load Configuration)

APPENDIX D

Mean mass variations for vehicle class 9 by DOW, direction, season and month for 3-year period

Table D.1: Mean mass (kg) variations by DOW, direction, season, and month for 1998 year

DOW	1	mean = 24402.59	DOW	2	mean = 25045.53	DOW	3	mean = 24630.88
Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1	
Month	4		Month	4		Month	4	
DOW	1	mean = 24110.36	DOW	2	mean = 25401.81	DOW	3	mean = 26132.61
Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1	
Month	5		Month	5		Month	5	
DOW	1	mean = 24906.04	DOW	2	mean = 25251.59	DOW	3	mean = 25694.21
Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1	
Month	6		Month	6		Month	6	
DOW	1	mean = 24764.09	DOW	2	mean = 25932.14	DOW	3	mean = 25677.29
Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2	
Month	7		Month	7		Month	7	
DOW	1	mean = 25342.98	DOW	2	mean = 26127.12	DOW	3	mean = 26072.81
Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2	
Month	8		Month	8		Month	8	
DOW	1	mean = 25233.22	DOW	2	mean = 26043.7	DOW	3	mean = 25935.51
Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2	
Month	9		Month	9		Month	9	

Table D.1: Mean mass (kg) variations by DOW, direction, season, and month for 1998 year (Continued)

DOW	4	mean = 24714.06	DOW	5	mean = 24439.52	DOW	6	mean = 25326.92	DOW	7	mean = 26455
Direction	2		Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1		Season	1	
Month	4		Month	4		Month	4		Month	4	
DOW	4	mean = 25170.91	DOW	5	mean = 24750.33	DOW	6	mean = 26013.22	DOW	7	mean = 26791.64
Direction	2		Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1		Season	1	
Month	5		Month	5		Month	5		Month	5	
DOW	4	mean = 25299.33	DOW	5	mean = 24669.53	DOW	6	mean = 24832.06	DOW	7	mean = 30476.64
Direction	2		Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1		Season	1	
Month	6		Month	6		Month	6		Month	6	
DOW	4	mean = 25473.51	DOW	5	mean = 25154.02	DOW	6	mean = 26438.37	DOW	7	mean = 27108.28
Direction	2		Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2		Season	2	
Month	7		Month	7		Month	7		Month	7	
DOW	4	mean = 25740.5	DOW	5	mean = 25131.54	DOW	6	mean = 26574.23	DOW	7	mean = 27594.96
Direction	2		Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2		Season	2	
Month	8		Month	8		Month	8		Month	8	
DOW	4	mean = 25659.65	DOW	5	mean = 25275.92	DOW	6	mean = 26714.76	DOW	7	mean = 27569.38
Direction	2		Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2		Season	2	
Month	9		Month	9		Month	9		Month	9	

Table D.2: Mean mass (kg) variations by DOW, direction, season, and month for 1999 year

DOW	1	mean = 26475.16	DOW	2	mean = 27266.18	DOW	3	mean = 27418.97
Direction	1		Direction	1		Direction	1	
Season	2		Season	2		Season	2	
Month	9		Month	9		Month	9	
DOW	1	mean = 23772.86	DOW	2	mean = 24500.36	DOW	3	mean = 24800.69
Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1	
Month	4		Month	4		Month	4	
DOW	1	mean = 23752.37	DOW	2	mean = 24525.66	DOW	3	mean = 24352.73
Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1	
Month	5		Month	5		Month	5	
DOW	1	mean = 23729.78	DOW	2	mean = 24486.53	DOW	3	mean = 24339.2
Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1	
Month	6		Month	6		Month	6	
DOW	1	mean = 24594.5	DOW	2	mean = 25539.87	DOW	3	mean = 25285.89
Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2	
Month	7		Month	7		Month	7	
DOW	1	mean = 24901.68	DOW	2	mean = 25893.4	DOW	3	mean = 25919.54
Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2	
Month	8		Month	8		Month	8	
DOW	1	mean = 24920.86	DOW	2	mean = 25535.04	DOW	3	mean = 26219.75
Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2	
Month	9		Month	9		Month	9	

Table D.2: Mean mass (kg) variations by DOW, direction, season, and month for 1999 year (Continued)

DOW	4	mean = 27440.94	DOW	5	mean = 27446.99	DOW	6	mean = 29210.68	DOW	7	mean = 28527.09
Direction	1		Direction	1		Direction	1		Direction	1	
Season	2		Season	2		Season	2		Season	2	
Month	9		Month	9		Month	9		Month	9	
DOW	4	mean = 24773.06	DOW	5	mean = 24044.16	DOW	6	mean = 25241.91	DOW	7	mean = 25796.55
Direction	2		Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1		Season	1	
Month	4		Month	4		Month	4		Month	4	
DOW	4	mean = 24150.79	DOW	5	mean = 23243.3	DOW	6	mean = 24933.49	DOW	7	mean = 25713.93
Direction	2		Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1		Season	1	
Month	5		Month	5		Month	5		Month	5	
DOW	4	mean = 23907.81	DOW	5	mean = 23424.46	DOW	6	mean = 24954.35	DOW	7	mean = 25501.9
Direction	2		Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1		Season	1	
Month	6		Month	6		Month	6		Month	6	
DOW	4	mean = 25233.86	DOW	5	mean = 24895.98	DOW	6	mean = 25940.82	DOW	7	mean = 27077.76
Direction	2		Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2		Season	2	
Month	7		Month	7		Month	7		Month	7	
DOW	4	mean = 25624.33	DOW	5	mean = 24929.64	DOW	6	mean = 26421.19	DOW	7	mean = 26910.36
Direction	2		Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2		Season	2	
Month	8		Month	8		Month	8		Month	8	
DOW	4	mean = 25513.88	DOW	5	mean = 25675.3	DOW	6	mean = 27170.89	DOW	7	mean = 26707.09
Direction	2		Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2		Season	2	
Month	9		Month	9		Month	9		Month	9	

Table D.3: Mean mass (kg) variations by DOW, direction, season, and month for 2000 year

DOW	1	mean = 26194.73	DOW	2	mean = 26686.89	DOW	3	mean = 26812.68
Direction	1		Direction	1		Direction	1	
Season	1		Season	1		Season	1	
Month	5		Month	5		Month	5	
DOW	1	mean = 26164.75	DOW	2	mean = 26590.6	DOW	3	mean = 26938.7
Direction	1		Direction	1		Direction	1	
Season	1		Season	1		Season	1	
Month	6		Month	6		Month	6	
DOW	1	mean = 26774.46	DOW	2	mean = 26406.86	DOW	3	mean = 26646.86
Direction	1		Direction	1		Direction	1	
Season	2		Season	2		Season	2	
Month	7		Month	7		Month	7	
DOW	1	mean = 26721.41	DOW	2	mean = 27185.62	DOW	3	mean = 27109.17
Direction	1		Direction	1		Direction	1	
Season	2		Season	2		Season	2	
Month	8		Month	8		Month	8	
DOW	1	mean = 26622.78	DOW	2	mean = 27002.57	DOW	3	mean = 27142.55
Direction	1		Direction	1		Direction	1	
Season	2		Season	2		Season	2	
Month	9		Month	9		Month	9	
DOW	1	mean = 23629.88	DOW	2	mean = 25319.09	DOW	3	mean = 25453.69
Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1	
Month	4		Month	4		Month	4	
DOW	1	mean = 22950.27	DOW	2	mean = 24195.2	DOW	3	mean = 23823.47
Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1	
Month	5		Month	5		Month	5	

Table D.3: Mean mass (kg) variations by DOW, direction, season, and month for 2000 year (Continued)

DOW	1	mean = 25947.11	DOW	2	mean = 25551.83	DOW	3	mean = 25527.11
Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1	
Month	6		Month	6		Month	6	
DOW	1	mean = 24022.27	DOW	2	mean = 24648.42	DOW	3	mean = 24241.67
Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2	
Month	7		Month	7		Month	7	
DOW	1	mean = 24707.33	DOW	2	mean = 25555.53	DOW	3	mean = 25609.45
Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2	
Month	8		Month	8		Month	8	
DOW	1	mean = 24115.41	DOW	2	mean = 24885.67	DOW	3	mean = 25071.14
Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2	
Month	9		Month	9		Month	9	

Table D.3: Mean mass (kg) variations by DOW, direction, season, and month for 2000 year (Continued)

DOW	4	mean = 26727.36	DOW	5	mean = 26196.84	DOW	6	mean = 27739.85	DOW	7	mean = 28183.45
Direction	1		Direction	1		Direction	1		Direction	1	
Season	1		Season	1		Season	1		Season	1	
Month	5		Month	5		Month	5		Month	5	
DOW	4	mean = 27359.68	DOW	5	mean = 26440.04	DOW	6	mean = 27995.37	DOW	7	mean = 28135.16
Direction	1		Direction	1		Direction	1		Direction	1	
Season	1		Season	1		Season	1		Season	1	
Month	6		Month	6		Month	6		Month	6	
DOW	4	mean = 26376.6	DOW	5	mean = 26427.14	DOW	6	mean = 27979.98	DOW	7	mean = 27892.42
Direction	1		Direction	1		Direction	1		Direction	1	
Season	2		Season	2		Season	2		Season	2	
Month	7		Month	7		Month	7		Month	7	
DOW	4	mean = 27142.15	DOW	5	mean = 26059.08	DOW	6	mean = 27783.88	DOW	7	mean = 27908.82
Direction	1		Direction	1		Direction	1		Direction	1	
Season	2		Season	2		Season	2		Season	2	
Month	8		Month	8		Month	8		Month	8	
DOW	4	mean = 26711.98	DOW	5	mean = 26199.52	DOW	6	mean = 27613.71	DOW	7	mean = 27964.32
Direction	1		Direction	1		Direction	1		Direction	1	
Season	2		Season	2		Season	2		Season	2	
Month	9		Month	9		Month	9		Month	9	
DOW	4	mean = 24612.71	DOW	5	mean = 24315.79	DOW	6	mean = 25875.99	DOW	7	mean = 26656.88
Direction	2		Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1		Season	1	
Month	4		Month	4		Month	4		Month	4	
DOW	4	mean = 23484.01	DOW	5	mean = 22494.42	DOW	6	mean = 23165.8	DOW	7	mean = 23270.63
Direction	2		Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1		Season	1	
Month	5		Month	5		Month	5		Month	5	

Table D.3: Mean mass (kg) variations by DOW, direction, season, and month for 2000 year (Continued)

DOW	4	mean = 25051.59	DOW	5	mean = 24264.78	DOW	6	mean = 25243.53	DOW	7	mean = 25494.08
Direction	2		Direction	2		Direction	2		Direction	2	
Season	1		Season	1		Season	1		Season	1	
Month	6		Month	6		Month	6		Month	6	
DOW	4	mean = 24811.77	DOW	5	mean = 24609.67	DOW	6	mean = 24687.27	DOW	7	mean = 24805.91
Direction	2		Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2		Season	2	
Month	7		Month	7		Month	7		Month	7	
DOW	4	mean = 25101.74	DOW	5	mean = 24781.33	DOW	6	mean = 25817.69	DOW	7	mean = 26477.83
Direction	2		Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2		Season	2	
Month	8		Month	8		Month	8		Month	8	
DOW	4	mean = 24965.09	DOW	5	mean = 24155.96	DOW	6	mean = 25866.31	DOW	7	mean = 25942.31
Direction	2		Direction	2		Direction	2		Direction	2	
Season	2		Season	2		Season	2		Season	2	
Month	9		Month	9		Month	9		Month	9	

Table D.4: Data Legend

DOW (Day of Week)	Legend
Monday	1
Tuesday	2
Wednesday	3
Thursday	4
Friday	5
Saturday	6
Sunday	7

Direction	Legend
Northbound	1
Southbound	2

Season	Legend
Spring	1
Summer	2

Month	Legend
April	4
May	5
June	6
July	7
August	8
September	9

Output results from SAS

Results for DOW

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                       Number of observations    168

                              The SAS System                            183
                                            10:42 Wednesday, April 11, 2001

                             The GLM Procedure

Dependent Variable: averageGVW

                                            Sum of
Source                      DF         Squares   Mean Square  F Value  Pr > F

Model                        6      67962288.9    11327048.1     8.40  <.0001

Error                      161     217066495.1     1348239.1

Corrected Total            167     285028784.0


          R-Square     Coeff Var      Root MSE    averageGVW Mean

          0.238440      4.519961      1161.137           25689.09


Source                      DF       Type I SS   Mean Square  F Value  Pr > F

dow                          6     67962288.87   11327048.15     8.40  <.0001
                              The SAS System                            184
                                            10:42 Wednesday, April 11, 2001

                             The GLM Procedure

Dependent Variable: averageGVW

Source                      DF     Type III SS   Mean Square  F Value  Pr > F

dow                          6     67962288.87   11327048.15     8.40  <.0001
                              The SAS System                            185
                                            10:42 Wednesday, April 11, 2001

                             The GLM Procedure

Level of            ----------averageGVW---------
dow           N             Mean          Std Dev

1            24       24948.2022       1116.70987
2            24       25649.0499        890.43597
3            24       25702.3565       1007.00586
4            24       25460.3050       1051.29071
5            24       24959.3849       1138.40712
6            24       26230.9269       1372.80950
7            24       26873.4332       1448.41531

                              The SAS System                            186
                                            10:42 Wednesday, April 11, 2001
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Frequency

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      22500  23500  24500  25500  26500  27500  28500  29500  30500
                           averageGVW Midpoint
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Results for DIRECTION

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The SAS System         18:04 Tuesday, April 24, 2001   6

                                        The GLM Procedure

                                     Class Level Information

                                 Class          Levels    Values

                                 direction           2    1 2


                          Number of observations    168
The SAS System         18:04 Tuesday, April 24, 2001   7

                                        The GLM Procedure

Dependent Variable: averageGVW

                                                 Sum of
Source                      DF          Squares     Mean Square    F Value    Pr > F

Model                        1      116898490.6     116898490.6     115.42    <.0001

Error                      166      168130293.4       1012833.1

Corrected Total            167      285028784.0


R-Square     Coeff Var      Root MSE    averageGVW Mean

0.410129      3.917601      1006.396           25689.09
Source                      DF        Type I SS     Mean Square    F Value    Pr > F
direction                    1      116898490.6     116898490.6     115.42    <.0001

Source                      DF      Type III SS     Mean Square    F Value    Pr > F
direction                    1      116898490.6     116898490.6     115.42    <.0001

The SAS System         18:04 Tuesday, April 24, 2001   8

                                        The GLM Procedure

Level of              ----------averageGVW---------
direction       N             Mean          Std Dev

1              42       27133.9031        733.95305
2             126       25207.4911       1080.90378

The SAS System         18:04 Tuesday, April 24, 2001   9
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            22500    23500    24500    25500    26500    27500    28500    29500    30500

                                          averageGVW Midpoint
```

Results for YEAR

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The SAS System         18:04 Tuesday, April 24, 2001  11
                                  The GLM Procedure

                     Class Level Information

Class         Levels    Values

year               3    1998 1999 2000
                          Number of observations    168
The SAS System         18:04 Tuesday, April 24, 2001  12

                                  The GLM Procedure

Dependent Variable: averageGVW

                                         Sum of
Source                      DF          Squares     Mean Square    F Value    Pr > F
Model                        2        3170219.7       1585109.8       0.93    0.3974

Error                      165      281858564.3       1708233.7

Corrected Total            167      285028784.0

R-Square     Coeff Var      Root MSE    averageGVW Mean

0.011122      5.087739      1306.994           25689.09

Source                      DF        Type I SS     Mean Square    F Value    Pr > F

year                         2      3170219.683     1585109.842       0.93    0.3974

Source                      DF      Type III SS     Mean Square    F Value    Pr > F

year                         2      3170219.683     1585109.842       0.93    0.3974
                  The SAS System         18:04 Tuesday, April 24, 2001  13

                                  The GLM Procedure

Level of            ----------averageGVW---------
year          N             Mean          Std Dev

1998         42       25716.1609       1120.17057
1999         49       25482.5213       1320.81870
2000         77       25805.7858       1389.21371

The SAS System         18:04 Tuesday, April 24, 2001  14
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             22500     23500     24500     25500     26500     27500     28500     29500     30500

                                             averageGVW Midpoint
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Results for SEASON

The SAS System 18:04 Tuesday, April 24, 2001 22

The GLM Procedure

Class Level Information

Class	Levels	Values
season	2	1 2

Number of observations 168

The SAS System 18:04 Tuesday, April 24, 2001 23

The GLM Procedure

Dependent Variable: averageGVW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	29548219.0	29548219.0	19.20	<.0001
Error	166	255480565.0	1539039.5		
Corrected Total	167	285028784.0			

R-Square	Coeff Var	Root MSE	averageGVW Mean
0.103667	4.829210	1240.580	25689.09

Source	DF	Type I SS	Mean Square	F Value	Pr > F
season	1	29548218.97	29548218.97	19.20	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
season	1	29548218.97	29548218.97	19.20	<.0001

The SAS System 18:04 Tuesday, April 24, 2001 24

The GLM Procedure

Level of season	N	----------averageGVW--------- Mean	Std Dev
1	77	25233.1765	1385.99968
2	91	26074.8705	1102.95027

The SAS System 18:04 Tuesday, April 24, 2001 25

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    Frequency

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                                              averageGVW Midpoint
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Results for MONTH

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The SAS System         18:04 Tuesday, April 24, 2001  17

                                        The GLM Procedure

                  Class Level Information

Class         Levels    Values

month              6    4 5 6 7 8 9
                         Number of observations    168
The SAS System         18:04 Tuesday, April 24, 2001  18

                                        The GLM Procedure

Dependent Variable: averageGVW

                                               Sum of
Source                      DF          Squares     Mean Square    F Value    Pr > F

Model                        5      43986049.4       8797209.9       5.91    <.0001

Error                      162     241042734.5       1487918.1

Corrected Total            167     285028784.0

R-Square     Coeff Var      Root MSE    averageGVW Mean

0.154321      4.748328      1219.802           25689.09

Source                      DF       Type I SS     Mean Square    F Value    Pr > F

month                        5     43986049.43      8797209.89       5.91    <.0001

Source                      DF     Type III SS     Mean Square    F Value    Pr > F

month                        5     43986049.43      8797209.89       5.91    <.0001
The SAS System         18:04 Tuesday, April 24, 2001  19

                                        The GLM Procedure

Level of            ----------averageGVW---------
month         N             Mean          Std Dev

4            21       24943.2439        800.51186
5            28       25034.5971       1537.58711
6            28       25649.2054       1510.83588
7            28       25694.5588       1079.07463
8            28       26112.3323        926.50284
9            35       26349.1505       1189.99400

The SAS System         18:04 Tuesday, April 24, 2001  20
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    Frequency

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                                              averageGVW Midpoint
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Results for DOW x DIRECTION

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                       Number of observations    168

                              The SAS System                              356
                                            10:42 Wednesday, April 11, 2001

                             The GLM Procedure

Dependent Variable: averageGVW

                                         Sum of
Source                      DF          Squares   Mean Square  F Value  Pr > F

Model                       13      187106578.1    14392813.7    22.64  <.0001

Error                      154       97922205.9      635858.5

Corrected Total            167      285028784.0


          R-Square     Coeff Var      Root MSE    averageGVW Mean

          0.656448      3.104070      797.4073           25689.09


Source                      DF        Type I SS   Mean Square  F Value  Pr > F

dow*direction               13      187106578.1    14392813.7    22.64  <.0001

                              The SAS System                              357
                                            10:42 Wednesday, April 11, 2001

                             The GLM Procedure

Dependent Variable: averageGVW

Source                      DF      Type III SS   Mean Square  F Value  Pr > F
dow*direction               13      187106578.1    14392813.7    22.64  <.0001

                              The SAS System                              358
                                            10:42 Wednesday, April 11, 2001

                             The GLM Procedure

Level of     Level of              ----------averageGVW---------
dow          direction      N             Mean          Std Dev

1            1              6       26492.2108        262.77835
1            2             18       24433.5327        738.24028
2            1              6       26856.4525        346.16213
2            2             18       25246.5824        592.82196
3            1              6       27011.4863        272.22857
3            2             18       25265.9799        737.33583
4            1              6       26959.7852        419.57457
4            2             18       24960.4783        620.82204
5            1              6       26461.5997        504.67078
5            2             18       24458.6466        785.18152
6            1              6       28053.9098        585.20823
6            2             18       25623.2659        940.82127
7            1              6       28101.8773        240.26231
7            2             18       26463.9518       1453.00152

                              The SAS System                              359
                                            10:42 Wednesday, April 11, 2001
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                           averageGVW Midpoint
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Results for DOW x DIRECTION, YEAR

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                      Number of observations    168

                             The SAS System                             529
                                           10:42 Wednesday, April 11, 2001

                            The GLM Procedure

Dependent Variable: averageGVW
                                      Sum of
Source                      DF       Squares   Mean Square  F Value  Pr > F
Model                       15   207653241.1    13843549.4    27.19  <.0001

Error                      152    77375542.9      509049.6

Corrected Total            167   285028784.0


R-Square     Coeff Var      Root MSE    averageGVW Mean

0.728534      2.777354      713.4771           25689.09


Source                      DF     Type I SS   Mean Square  F Value  Pr > F

dow*direction               13   187106578.1    14392813.7    28.27  <.0001
year                         2    20546663.0    10273331.5    20.18  <.0001

                             The SAS System                             530
                                           10:42 Wednesday, April 11, 2001

                            The GLM Procedure

Dependent Variable: averageGVW

Source                      DF   Type III SS   Mean Square  F Value  Pr > F

dow*direction               13   204483021.4    15729463.2    30.90  <.0001
year                         2    20546663.0    10273331.5    20.18  <.0001

                             The SAS System                             531
                                           10:42 Wednesday, April 11, 2001

                            The GLM Procedure

Level of     Level of            ----------averageGVW---------
dow          direction      N            Mean          Std Dev

1            1              6      26492.2108        262.77835
1            2             18      24433.5327        738.24028
2            1              6      26856.4525        346.16213
2            2             18      25246.5824        592.82196
3            1              6      27011.4863        272.22857
3            2             18      25265.9799        737.33583
4            1              6      26959.7852        419.57457
4            2             18      24960.4783        620.82204
5            1              6      26461.5997        504.67078
5            2             18      24458.6466        785.18152
6            1              6      28053.9098        585.20823
6            2             18      25623.2659        940.82127
7            1              6      28101.8773        240.26231
7            2             18      26463.9518       1453.00152

                             The SAS System                             532
                                           10:42 Wednesday, April 11, 2001
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                              The GLM Procedure

             Level of            ----------averageGVW---------
year            N             Mean           Std Dev

1998           42       25716.1609       1120.17057
1999           49       25482.5213       1320.81870
2000           77       25805.7858       1389.21371

                               The SAS System                              533
                                            10:42 Wednesday, April 11, 2001

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                              averageGVW Midpoint
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Results for DOW x DIRECTION, YEAR, MONTH

Number of observations 168

The SAS System 703
10:42 Wednesday, April 11, 2001

The GLM Procedure

Dependent Variable: averageGVW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	20	229940776.7	11497038.8	30.68	<.0001
Error	147	55088007.3	374748.3		
Corrected Total	167	285028784.0			

R-Square	Coeff Var	Root MSE	averageGVW Mean
0.806728	2.382984	612.1669	25689.09

Source	DF	Type I SS	Mean Square	F Value	Pr > F
dow*direction	13	187106578.1	14392813.7	38.41	<.0001
year	2	20546663.0	10273331.5	27.41	<.0001
month	5	22287535.6	4457507.1	11.89	<.0001

The SAS System 704
10:42 Wednesday, April 11, 2001

The GLM Procedure

Dependent Variable: averageGVW

Source	DF	Type III SS	Mean Square	F Value	Pr > F
dow*direction	13	181504202.3	13961861.7	37.26	<.0001
year	2	19114217.2	9557108.6	25.50	<.0001
month	5	22287535.6	4457507.1	11.89	<.0001

The SAS System 705
10:42 Wednesday, April 11, 2001

The GLM Procedure

Level of dow	Level of direction	N	----------averageGVW--------- Mean	Std Dev
1	1	6	26492.2108	262.77835
1	2	18	24433.5327	738.24028
2	1	6	26856.4525	346.16213
2	2	18	25246.5824	592.82196
3	1	6	27011.4863	272.22857
3	2	18	25265.9799	737.33583
4	1	6	26959.7852	419.57457
4	2	18	24960.4783	620.82204
5	1	6	26461.5997	504.67078
5	2	18	24458.6466	785.18152
6	1	6	28053.9098	585.20823
6	2	18	25623.2659	940.82127
7	1	6	28101.8773	240.26231

7	2	18	26463.9518	1453.00152

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                              The SAS System                              706
                                            10:42 Wednesday, April 11, 2001

                             The GLM Procedure
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Level of year	N	averageGVW Mean	averageGVW Std Dev
1998	42	25716.1609	1120.17057
1999	49	25482.5213	1320.81870
2000	77	25805.7858	1389.21371

Level of month	N	averageGVW Mean	averageGVW Std Dev
4	21	24943.2439	800.51186
5	28	25034.5971	1537.58711
6	28	25649.2054	1510.83588
7	28	25694.5588	1079.07463
8	28	26112.3323	926.50284
9	35	26349.1505	1189.99400

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                              The SAS System                              707
                                            10:42 Wednesday, April 11, 2001

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                              averageGVW Midpoint
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Results for DOW x DIRECTION, YEAR, SEASON

Number of observations 168

The SAS System 1051
10:42 Wednesday, April 11, 2001

The GLM Procedure

Dependent Variable: averageGVW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	221905333.9	13869083.4	33.18	<.0001
Error	151	63123450.0	418036.1		
Corrected Total	167	285028784.0			

R-Square	Coeff Var	Root MSE	averageGVW Mean
0.778537	2.516854	646.5571	25689.09

Source	DF	Type I SS	Mean Square	F Value	Pr > F
dow*direction	13	187106578.1	14392813.7	34.43	<.0001
year	2	20546663.0	10273331.5	24.58	<.0001
season	1	14252092.8	14252092.8	34.09	<.0001

The SAS System 1052
10:42 Wednesday, April 11, 2001

The GLM Procedure

Dependent Variable: averageGVW

Source	DF	Type III SS	Mean Square	F Value	Pr > F
dow*direction	13	188570030.0	14505386.9	34.70	<.0001
year	2	19502438.3	9751219.2	23.33	<.0001
season	1	14252092.8	14252092.8	34.09	<.0001

The SAS System 1053
10:42 Wednesday, April 11, 2001

The GLM Procedure

Level of dow	Level of direction	N	----------averageGVW--------- Mean	Std Dev
1	1	6	26492.2108	262.77835
1	2	18	24433.5327	738.24028
2	1	6	26856.4525	346.16213
2	2	18	25246.5824	592.82196
3	1	6	27011.4863	272.22857
3	2	18	25265.9799	737.33583
4	1	6	26959.7852	419.57457
4	2	18	24960.4783	620.82204
5	1	6	26461.5997	504.67078
5	2	18	24458.6466	785.18152
6	1	6	28053.9098	585.20823
6	2	18	25623.2659	940.82127
7	1	6	28101.8773	240.26231
7	2	18	26463.9518	1453.00152

The SAS System 1054
10:42 Wednesday, April 11, 2001

The GLM Procedure

Level of year	N	----------averageGVW--------- Mean	Std Dev
1998	42	25716.1609	1120.17057
1999	49	25482.5213	1320.81870
2000	77	25805.7858	1389.21371

Level of season	N	----------averageGVW--------- Mean	Std Dev
1	77	25233.1765	1385.99968
2	91	26074.8705	1102.95027

The SAS System 1055
10:42 Wednesday, April 11, 2001

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         22500  23500  24500  25500  26500  27500  28500  29500  30500

                              averageGVW Midpoint
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VITA

Name	Ivana Lucic
Place and Year of Birth	Belgrade, Yugoslavia, 1967
Education	Faculty of Traffic and Transportation Engineering, University of Belgrade, Bachelor of Science, 1993
Experience	Yugoslav Airlines, Belgrade, Yugoslavia, 1994-1999
Publication	Rakha H., Lucic I., Demarchi S., Setti J., and Van Aerde M. (2001), *Vehicle Dynamics Model for Predicting Maximum Vehicle Acceleration Levels*, Accepted for publication in the ASCE Journal of Transportation Engineering.