A POLICY-ORIENTED COST MODEL FOR SHIPPING COMMODITIES BY TRUCK

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16. Abstract
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A Policy-Oriented Cost Model for Shipping Commodities by Truck

Abstract: Surprisingly, transportation planners and policy makers do not have the ability to estimate the cost of shipping a quantity of a commodity between two locations for broad categories of goods. Costs of shipping are important components in mode, route, and location choice processes. Good knowledge of costs can aid public sector decision makers in determining the economic benefits of infrastructure improvements or determining the impacts on the private sector of various policies and operational strategies. Shipping costs relate to logistics practices of businesses, and these practices have been changing rapidly in recent years. In this study, we inventory cost models that have been used in the past and evaluate the availability of data sets containing shipment cost information. We then build a cost model for shipping various commodities and commodity groups by truck and present several examples to show how the model can address issues of interest to carriers, shippers, and governments.

INTRODUCTION

Freight can be broadly defined as the movement of goods from one place to another. The United States freight transportation network consists of hundreds of thousands of miles of transportation infrastructure and hundreds of thousands of transportation facilities devoted to five different modes of transport: road, rail, air, water, and pipeline. Increases in population, economic activity, and global trade have put tremendous pressure on this network in recent years. Indeed, it appears that the U.S. is now reaching a crossroads with respect to transportation planning that calls for drastic action. With the majority of transportation infrastructure in the public domain, the best chance for change lies with federal, state, and local policy makers. During the next few years, it is crucial for elected and non-elected public officials to adopt wise policies that will chart a favorable course for the U.S. transportation system in the 21st century.

Transportation policies are usually judged in terms of their environmental, social, and economic impacts. Economic impact usually dominates policy analysis, with environmental and social impacts playing a secondary role. Yet, even economic analysis of transportation policy is often incomplete. In particular, the impact of a proposed project or policy on private sector shipping costs is rarely studied. Instead, most analyses focus on the jobs created by an infrastructure project; the public sector infrastructure and maintenance costs of the project or policy; and the impact on traffic congestion. Meanwhile, the discussion of costs borne by private sector shipping companies is muted. The purpose of the current study is to develop a methodology that will allow private sector shipping costs to become a larger part of the equation in transportation policy analysis.

Freight transportation costs are of interest to at least three kinds of institutions—carriers, shippers, and governments. Carriers need to know freight transportation costs because they are the providers of transportation services. Shippers need to have a handle on freight transportation costs in order to better understand decisions regarding facility location and supply chain management. Finally, governments need to be able to estimate freight transportation costs if they are to formulate sound transportation policies. Surprisingly, these costs have played only a minor role in transportation planning and policy analysis. Shipping costs are an important component of mode, route, and location choice decision making processes in the freight industry. Good knowledge of shipping costs is therefore vital to the formulation of effective public policy. For example, it is important for policy makers to know how potential changes in truck flows, sizes, and weights could affect shipping costs. It is also important for transportation officials to know how proposed infrastructure improvements or construction projects affect shipping costs for different economic sectors.

In order to raise the profile of private sector shipping costs in freight transportation policy analysis, there needs to be a method for estimating the cost of shipping commodities between any two locations. At the moment, there are a few tools developed by academic researchers that can estimate the cost of shipping individual commodities between any two locations. However, to the authors' knowledge, no tools are designed to estimate the costs of shipping broad categories of cargo that correspond to various sectors of the U.S. economy. Thus, a policy-oriented methodology for estimating shipping costs is still missing.

In this study, we inventory freight cost models that have been used in the past and evaluate the availability of data sets containing shipment cost information. We then develop a methodology for estimating shipping costs for one freight transportation mode—trucking. U.S. Census figures indicate that shipments by truck were valued at about USD $6235 billion in 2002. This represents 75% of the total value of all shipments made within the U.S. The main objective is to build a model that can estimate the cost of shipping a certain quantity of a specific commodity or commodity group by truck from any origin to any destination inside the United States. The model can also be used to estimate general shipping costs for different economic sectors, with significant ramifications for public policy. The field-testing of the model and expansion of the model to include at least one additional mode of transportation—rail, air, or water—is left to a future study.

This paper is organized as follows. Section 2 reviews the literature relevant to the current study. In Section 3, we evaluate the availability of data sets containing shipment cost information. Section 4 introduces the concept of commodity aggregation as a way to model shipping costs from a public policy perspective. A mathematical model of shipping costs in the trucking industry is presented in Section 5. In Section 6, we illustrate the use of the cost model in various hypothetical scenarios. Final conclusions are made in Section 7.

LITERATURE REVIEW

A literature review was conducted to determine what research has already been done on freight planning and other topics related to freight cost modeling.

Berwick and Dooley (1997) built a truck cost model for motor vehicle owners and/or operators. A spreadsheet simulation model was developed to estimate truck costs for different truck configurations, trailer types, and trip movements. A shipper may need to know product unit costs to determine the transportation cost per item. Alternatively, a lessor (shipper) may want total trip costs while the owner/operator may want per hour or per mile costs. The trucking industry has a perfect competition environment due to its non-homogeneity, limited entry barriers, large number of firms, and virtually perfect information. Furthermore, its small independent truckers are mainly price takers. Therefore, cost tracking and control are essential for survival of the owner/operator. However, the authors point out that owner/operators may have less knowledge of the full cost of their operation than shippers, larger trucking companies, and logistics firms. Cost information is important because it allows shippers to reconcile freight rates with trucking costs. This may assure revenue adequacy for the truckers, without sacrificing efficiency in the shippers' industry. Current cost estimates may be beneficial to both parties (lessor and trucker) in negotiating a lease agreement. Sustainability for the independent trucker may reduce search costs, improve quality for the lessor, and reduce turnover.

Recent changes in manufacturing practice and supply chain management have lowered inventories and created a move toward just-in-time inventory management. These new changes have increased the need for quality transportation. With owner/operators moving 30 to 40 percent of all intercity freight (Griffin and Rodriguez, 1992), the importance of understanding the costs borne by owner/operators cannot be understated. The model proposed by Berwick and Dooley (1997) was the first effort to understand such costs.

Berwick and Dooley point out that change in trailers and combinations of trailers continue to affect the cost structure of the trucking industry. New safety requirements have affected the costs for truckers. Safety costs such as anti-lock braking systems and air ride suspension have added to the price of a new tractor and trailer. However, safety features may reduce risk (insurance) costs because of fewer crashes and less damage to products hauled. The use of cell phones and other technological changes also may create more changes in the trucking industry. The authors develop a spreadsheet model that contains several sheets. One of them contains decisions and exogenous variables, another one has performance measures, and the remaining sheets contain data and sensitivity analysis calculations, and linkages for the costing and revenue associated with particular truck movement. Fixed costs in this model include equipment costs, depreciation, return on investment, license fees insurance and sales tax, and management and overhead costs, while the variable costs include labor, fuel, tires, and maintenance and repair costs.

Berwick and Farooq (2003) continue the work of Berwick and Dooley. They argue that, while the spreadsheet costing model developed in 1996 was useful, it lacked the functionality of a stand-alone model or software product. Thus, a new visual basic model was developed to be a stand-alone product to be utilized by transportation professionals and researchers.

William and Allen (1996) find that the cost per mile of operating a motor vehicle is a key parameter in many transportation studies. They defined the auto operating cost as a result of dividing the sum of annual cost of maintenance, oil, and tires by average miles driven vehicle per year.

Forkenbrock (1999) defines private costs as the direct expenses incurred by providers of fright transportation. Such costs consist of operating costs, as well as investments in capital facilities while the external costs include: accident; emissions; noise; and unrecovered costs associated with the provision, operation, and maintenance of public facilities. Freight trucking creates certain adverse impacts. These impacts are referred to as external costs because they are not borne by those who generate these costs. Internalizing external costs makes it possible to return to society an amount equal to the costs one imposes. Forkenbrock’s analysis reveals that external costs are equal to 13.2% of private costs and user fees would need to be increased about three fold to internalize these external costs. These results depend on the data of intercity truck freight transportation which accounts for a very large share of the total ton-miles of transportation.

Forkenbrock (2001) extends the above work related to external costs of intercity truck freight transportation to include rail transportation and makes a comparison between the trucking and rail transportation modes. He finds that rail external costs are USD $0.24 to $0.25 per ton-mile, well less than the $1.11 for freight trucking, but that external costs for rail generally constitute a larger amount relative to private costs—9.3% to 22.6%--than is the case for trucking (13.2%).

Ergun et al. (2007) propose an optimization model for reducing truckload transportation costs. A highly effective and extremely efficient heuristic had been designed and implemented that incorporates fast routines for checking time feasibility for a tour in the presence of dispatch time windows and for minimizing the duration of a tour by appropriately selecting a starting location and departure time.

Woensel and Curz (2009) studied the costs of transportation congestion. They show that contemporary traffic pricing typically does not reflect the external congestion costs. In order to induce road users to make the correct decision, marginal external costs should be internalized. Optimal use of a transportation facility cannot be achieved unless each additional user pays for the additional costs that he/she imposes on all other users on the facility. The main advantage of the authors' methodology is the possibility to derive the marginal congestion costs in an analytical way while taking into account the inherent stochasticity of the real world. This approach relies less on the availability of data than most other techniques.

One of the most comprehensive freight studies that has been done is described in Report 260 of the National Cooperative Highway Research Program (NCHRP 260). NCHRP is administered by the Transportation Research Board (TRB) and sponsored by various state DOTs in cooperation with the Federal Highway Administration (FHWA). NCHRP was created in 1962 as a means to conduct research in acute problem areas that affect highway planning, design, construction, operation, and maintenance nationwide. NCHRP Report 260 proposes and describes a set of freight demand forecasting techniques that together form a "user's manual." This user's manual is a guide for conducting studies that involve or require freight demand forecasts. Its development is motivated by the observation that freight oriented studies are often adversely affected by inadequate freight flow data. Indeed, in most states the collection of truck traffic flow data, and the preparation of demand forecasts is treated as an appendage to similar data collection and forecasting that is done for passenger vehicles. Thus, passenger flows have received the majority of attention, while freight flows have been largely ignored.

The limited capability for undertaking truck-oriented freight demand forecasts in both highway and non-highway modes stems more from the lack of a database rather than from any inability to devise suitable truck traffic forecasting techniques. The lack of freight flow data usually means that future truck volumes are forecasted as a percentage of aggregated traffic volumes for both existing and proposed facilities. Thus, forecasts are usually prepared using trend extension forecasting techniques rather than by relating observed volumes with present economic activities. NCHRP proposes a method that can still accomplish freight demand forecasting despite the limited freight flow data. The NCHRP user's manual presents an overall process or methodology to be followed in conducting such studies along with appropriate sub-techniques. Before attempting to apply the technique the user should first take time to fully determine the parameters and constraints both affecting and shaping the application at hand. Secondly, the user should reduce the scope of application to the maximum extent possible.

The overall freight demand forecasting technique consists of four phases: (1) traffic generation; (2) traffic distribution; (3) mode division; and (4) traffic assignment. The product of freight traffic generation and distribution is one or more commodity flow matrices. These matrices show how much of a given commodity is being shipped between any two locations. A multidimensional commodity flow matrix may differentiate cargo according to commodity class, mode, shipment origin, and shipment destination and can be reported in annual tons, annual dollar value, and annual ton-miles. One matrix represents the base case. The others, developed from the base case matrix, represent predictions for future years. If vehicular origin-destination or commodity flow data are available to the user, that data should be used as the basis of the base year commodity flow matrix. The need for additional matrices depends on the alternatives being evaluated, the extent to which the application involves alternative (1) futures (cases of increasing or decreasing commodity or vehicle flow); (2) scenarios (changes in infrastructure, rates, or services); and/or (3) conditions (when constraints or limitations are placed upon system use or revenue and cost structure).Phase 3—mode division—consists of three main components: (1) summarizing base commodity (or vehicle) flows, carrier costs, and carrier revenue/shipper costs; (2) for each alternative being considered, dividing commodity flow among competing modes using a split model, and then summarizing resulting flows, costs, and revenues; and (3) performing selected constancy tests to insure the reasonableness of the results obtained from the mode split model, and then preparing final outputs. Phase 4—traffic assignment—consists of four main components: (1) converting commodity flows into vehicle flows, if not already done in estimating carrier costs; (2) assigning the resulting traffic to modal networks; (3) estimating changes in vehicle/vessel volumes and loadings expected to occur on a segment basis; and (4) for highway segments, estimating expected changes in pavement service life on a segment basis.

The NCHRP 260 user's manual contains three sub-techniques related to the freight cost. These are (1) a truck unit costing model, (2) a shipper costing model, and (3) a freight rate estimating model. The truck unit cost sub-technique estimates the per-mile cost contributions for 16 components including insurance, fuel, and driver wages. These components are then combined to produce estimates for the truck load cost, cost per mile, and cost per ton-mile. The model has a total of 35 variables. Users must provide eight specific inputs including fuel price ($/gallon) and can interactively change any of the remaining 27 variables or use supplied default values. As unit cost varies with the carrier, mode, and time, the resulting cost estimate is very rough and is not intended to be a true cost. Indeed, today most large carriers have developed extensive costing systems for strategic planning and internal management purposes.The second cost model is a shipper costing model. In recent years, shippers have increasingly recognized that the mode offering the lowest rate may not in fact be the least cost mode, after considering other logistics costs. Thus, costs accruing to shippers typically include transport logistics (rates, loss and damage, pickup and delivery) and non-transport logistics costs (order, storage, inventory, and stock-out costs). These costs are taken into account in the shipper cost model. The third model is a rate estimating model. Completely separate from unit costs are the rates charged for specific transport services. Rates may be supplemented by charges for special or accessorial services and penalties assessed. Rates, charges, and penalties, taken together, represent carrier income. None of the above costing models directly consider issues related to public policy.

Huang and Smith (1999) mention that many state departments of transportation are becoming interested in developing statewide truck travel-demand (TTD) forecasting models. Estimates of future truck traffic are useful for making better decisions on highway improvements. Four similar TTD models are developed for Wisconsin using 1993 Commodity Flow Survey (CFS) origin-destination (O-D) data and a limited amount of truck classification count data. First, statewide zonal-level trip tables are developed from the CFS database. Then, gravity models for four trip types are calibrated to match the trip-length frequency distributions of the CFS O-D trip tables. Finally, zonal trip productions and attractions are adjusted using an iterative procedure. The four alternative TTD models differ only in the method used to assign external trips to the external stations. All of the models provide reasonable levels of goodness-of-fit to the 40 selected calibration links, as well as 104 additional count locations across the state.

Gordon and Pan (2001) propose a three step modeling structure for the non-survey freight transportation model which includes freight trip generation, freight trip distribution and freight traffic assignment. A freight origin-destination (OD) matrix of freight flows can be developed using secondary data sources. The estimated freight flows can be loaded together conventional passenger flows on the regional high way network of a large metropolitan area. GIS can potentially improve the non-survey approach in data validation, model operations, and evaluation.

Tadi and Balbach (1994) mention that trip generation rates for trucks are lower than rates for autos in the case of all land use categories except for truck terminals. This appears logical as the main activity at truck terminals relates to trucks.

García-Ródenas and Marín (2009) established a new methodology to model and to simultaneously solve the problems of calibration and O-D (origin-destination) matrix estimation for the multi-modal assignment problem with combined modes (MAPCM). A new approach called the calibration and demand adjusting model (CDAM), has been formulated based on nonlinear bi-level programming. The existence of an infinite number of solutions for any reasonable means of calibration of the MAPCM is proved. This is due to the use of a nested logit model for the modeling of the demand and the cost structure of the model. A heuristic column generation algorithm (HCGA) has been proposed to solve the bi-level model.

De Jong, Gunn, and Walker (2004) found that national model systems that can be used for forecasting future freight transport volumes and/or vehicle flows have been developed in a number of European countries. For the trip generation step, several European and national models now use input-output and related methods. Distribution in those models is also based on input-output analysis, or in gravity formulations. For modal split, many different model forms can be found in practice. But most of the large model systems use multi-modal network assignment, in which mode choice and assignment are handled simultaneously.

Internationally, the Great Britain Freight Model (GBFM) is perhaps the most comprehensive freight demand forecasting model to be developed outside the United States (GBFM, 2003). The GBFM project objective was to combine a group of existing software components and data sources into a single entity, and to develop a comprehensive model of international and domestic freight flows within Great Britain.GBFM used a path enumeration technique which is the process of defining sequences of links connecting the source (origin) to the sink (destination). By attaching the trip matrix to a route choice model, traffic can be assigned back to the underlying network, so that the assigned traffic volumes for a given link can be recorded. A basic concept of a network path freight network used in this model can be simplified to that of a "service." A service can be regarded as a wrapper for a path, where only the customer-oriented information (cost, time taken, reliability, access terminal, egress terminal) are known. Within GBFM, it is possible to define services that can be added directly to the paths within the choice set, or as hyper-links within the multimodal network. In principle, this choice model, expressed as a mapping from generalized cost *i* to probability *i*, is a straightforward process to simulate within a computer model. The approach taken has been to follow the F-Logit method established by Fowkes and Toner (1996) within the STEMM5 project, itself influenced by Cascetta's C-Logit16 Model (1995). The C-Logit/ F-Logit approach is intuitive and logical, suggesting that a route can win traffic if it is attractive (in terms of generalized cost) but not dominated by a similar, better alternative. GBFM has been designed to read data created by GIS Software18, and to generate results that can be re-interpreted as maps. Representing data in a geo-coded form (with latitude and longitude co-ordinates) is a simple way of imposing a degree of referential integrity between the components of a transport model. Simple algorithms can be built to test the distance between objects, and whether one object contains or intersects with another.

Winston (1982) and Gray (1982) discuss different kinds of freight models. Freight demand is essentially required to analyze most of the issues related to the freight transportation system. Freight demand models can be classified in different ways. Many models are built according to an aggregation flow approach that considers an aggregate and disaggregate model. In the aggregate model, the basic unit of observation is an aggregate share of a particular fright mode at the regional or non-regional level. The basic unit of observation in the disaggregate model is an individual decision maker's distinct choice of a particular freight mode for a given shipment.

Janic (2007) analyzes the full cost of a given intermodal and equivalent road transport network based on the network size, intensity of operations, technology in use, and internal and external costs of individual components of the system. Both networks are assumed of equivalent size in terms of spatial coverage, number of nodes, and the demand volume they serve. A model is developed for calculating the full costs of a given intermodal or road freight transport network. The model is applied to simplified configurations of intermodal rail-truck and equivalent road transport networks in Europe.

Zhang et al. (2003) develop a methodology for statewide intermodal transportation planning using public domain databases. The State of Mississippi is used as an example to describe the method. The commodity flow data analysis, transportation planning model, and intermodal transportation simulation model are the main components in this study. The 1997 Commodity Flow Survey (CFS), Vehicle Inventory and Use Survey (VIUS), and Cargo Density Database (CDD) were used in the study to describe freight flows coming into, going out, within and through the State of Mississippi. Geographic information systems (GIS) are used along with the transportation planning software TransCAD to model the transportation system performance. The method does not include or consider the cost of shipping commodities by truck or by any other transportation mode.

Decorla-Souza, et al. (1997) propose total cost analysis (TCA) as an alternative to benefit-cost analysis (BCA) in evaluating transportation alternatives. One advantage of TCA over traditional BCA is that the concept of "total cost" is more easily understood by the public and political decision makers than BCA concepts such as "net present worth." A second advantage is that there is no suggestion that all benefits have been considered; decision makers are free to use their own value judgments. The TCA approach is based on assessing the relative economic efficiency of alternatives by estimating the total costs of travel for various travel market segments under each alternative. The full costs of each alternative—including travel time costs and quantifiable environmental and social costs—are considered. Many amounts which are considered as benefits in benefit-cost analysis become costs in a total cost framework. In the TCA approach, the total cost differences among alternatives are traded off against their estimated non-monetized benefits or impacts to determine the relative merit of each alternative.

In conclusion, there is still no study looking at impact of public transportation policy on private sector shipping costs. However, Berwick and Dooley (1997) developed a truck costing model that can be used by shippers and owners/operators. The main objective of that model was to provide owner/operator cost information to more readily reflect the differences in equipment, product, and trip characteristics of the individual firm. In this paper, we present a policy oriented cost model for shipping various commodities at different aggregation levels by truck.

EVALUATION OF DATA SETS

Transportation, commodity flow, and transshipment analyses require different kinds of data sets. Some of the required data can be obtained through comprehensive and scientific surveys or available data sets from related departments, affiliations, associations and companies. Data sets for transportation modeling are available either publicly or privately. Most of them are available on the internet or in electronic form. A list of databases relevant to U.S. commodity flows and the trucking industry is displayed in Table 1. We now discuss these data sets in more detail.

U.S. Census Bureau Data Sets

The U.S. Census Bureau issues data, statistics, and censuses classified in different categories like geography, business, and industry. It has many transportation-related publications such as the Commodity Flow Survey, Vehicle Inventory and Use Survey, and Transportation and Warehousing. All of these data sets are compiled within the transport sector of the Bureau's economic census. The economic census is the major source of facts about the structure and functioning of the nation's economy. It provides the framework for such composite measures as the gross domestic product, input/output measures, production and price indexes, and other statistical indices that measure short-term changes in economic conditions.

Commodity Flow Survey (CFS)

The Commodity Flow Survey (CFS) for the entire U.S., individual states, regions, divisions, metropolitan areas (MAs), and reminder of state areas (ROS) is conducted every five years as part of the economic census by the U.S. Census Bureau in partnership with the Bureau of Transportation Statistics (BTS). BTS provides information and assistance for survey respondents and data users. The data from the CFS are used for public policy analysis and for transportation planning and decision-making to assess the demand for transportation facilities and services, energy use, safety risks, and environmental concerns.

TABLE 1 List of Important Truck Databases and Their Publishers

Data Base	Publisher	Description	Publisher Website
Commodity Flow Survey (CFS)	U.S. Census Bureau	Tabular results on shipment characteristics by mode of transportation, commodity, distance shipped, and shipment weight	www.census.gov (all websites should be preceded by "http://")
Vehicle Inventory and Use Survey (VIUS)	U.S. Census Bureau	Data on the physical and operational characteristics of the nation's private and commercial truck population	www.census.gov
Transportation and Warehousing	U.S. Census Bureau	Summary statistics includes number of establishments, revenues and annual payroll for different trucking and warehousing companies	www.census.gov
The North American Transborder Freight Database	Bureau of Transportation Statistics (BTS)	Contains freight flow data by commodity type and by mode of transportation for U.S. exports to and imports from Canada and Mexico	www.bts.gov
Freight Analysis Framework (FAF^2)	The Federal Highway Administration (FHWA)	Commodity origin-destination database providing tonnage and value of goods shipped by type of commodity and mode of transportation among and within 114 areas; to and from 7 international trading regions; and through the 114 areas plus 17 additional international gateways	ops.fhwa.dot.gov /freight/index.cfm
Office of Freight Management and Operations	The Federal Highway Administration (FHWA)	Data regarding highway condition and performance, cost allocation, truck size and weight limits, and the economic consequences of highway investments	ops.fhwa.dot.gov /freight/index.cfm

The CFS presents detailed tabular results on shipment characteristics by mode of transportation, commodity, distance shipped, and shipment weight reported in annual tons, annual dollar value, annual ton-miles, and miles. The 2007 CFS includes data from business establishments in the mining, manufacturing, wholesale trade, and selected retail industries. The survey also covers selected auxiliary establishments (e.g. warehouses) of retail companies. The survey coverage excludes establishments classified as farms, fisheries, governments, foreign establishments, and most establishments in the construction, transportation, service, forestry, and retail industries. The items available on the CFS website include the commodity flow survey itself, a CFS instruction guide, the CFS survey questionnaire, a shipment sampling tool which assists in identifying those data of particular interest to the user, and commodity descriptions corresponding to the five-digit SCTG (Standard Classification of Transportation Goods) commodity codes.

Vehicle Inventory and Use Survey (VIUS)

The Vehicle Inventory and Use Survey (VIUS) is another publication product of U.S. Census Bureau. This publication includes census data from the years 1997 and 2002. Prior to 1997 the survey was known as the Truck Inventory and Use Survey (TIUS).

VIUS provides data on the physical and operational characteristics of the nation's private and commercial truck population. Its primary goal is to produce national and state-level estimates of the total number of trucks. This survey was conducted every 5 years, until 2002, as part of the economic census. Recent cuts in federal government spending led to the elimination of the survey. The survey includes private and commercial trucks registered (or licensed) in the United States as of July 1 of the survey year. The survey excludes vehicles owned by federal, state, or local governments. VIUS data are of considerable value to government, business, academia, and the general public. Businesses and others make use of these data in conducting market studies and evaluating market strategies; assessing the utility and cost of certain types of equipment; calculating the longevity of products; determining fuel demands; and linking to, and better utilizing, other data sets representing limited segments of the truck population.

The VIUS product consists of 52 data releases available for the entire United States, each of the fifty states, and the District of Columbia. All files are released as .pdf files which provide general survey information, information on how to use the survey data, and program changes that impact comparability. Survey micro-data files contain un-aggregated records for individual trucks by state. Individual data records are masked to avoid disclosure. A “data dictionary” .pdf file provides a listing of each variable, a description of the variable, the survey question that was asked to obtain the data, and a list of valid responses to the question.VIUS has issued separate reports about the trucking industry in the USA, each individual state, and the District of Columbia. These reports estimate the number of trucks in a given year that fall into one or more of the following types of categories: vehicle size, truck type, number of miles traveled; and vehicle operational characteristics. The reports also include a comparative summary of truck operational characteristics—such as type of business, body type, vehicle size, and annual mileage—in different years. They also give a summary of the total truck mileage and average annual mileage by equipment type, fuel type and engine size, refueling location, maintenance, vehicle size and weight, total length, and fuel economy.

Transportation and Warehousing

The Transportation and Warehousing portion of the U.S. Census includes data sets and reports for all transportation modes—water, rail, air, pipeline, and truck. These data sets distinguish seven main types of activities: five corresponding to transportation in each of the five transportation modes and two corresponding to (A) warehousing and storage and (B) transportation support activities. A separate subsector for transportation support activities is established for many reasons. First, most transportation support activities—such as freight transportation arrangement—are inherently multimodal or have multimodal aspects. Second, there are production process similarities among the support activity industries. In addition, the data set tracks activities associated with establishments providing passenger transportation for scenic and sightseeing purposes, postal services, and courier services.

The 2002 Truck Transportation Report has summary statistics including the number of establishments, revenue, and annual payroll for different truck transportation companies. These companies are categorized according to the 2002 NAICS (North American Industry Classification System) code. It compares the 2002 data to the data from the previous (1997) study.

Bureau of Transportation Statistics (BTS)

The Bureau of Transportation Statistics (BTS) was established as a statistical agency of the United States federal government in 1992. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 created BTS to administer data collection, analysis, and reporting and to ensure the most cost-effective use of transportation-monitoring resources. BTS brings a greater degree of coordination, comparability, and quality standards to transportation data, and facilitates the closing of important data gaps**.** It provides reports and censuses related to freight and truck transportation from different departments and publications like VIUS, the 1990 and 200 versions of the Census Transportation Planning Package (CTPP), motor carrier financial and operating information, and the Commodity Flow Survey. BTS has issued many data and statistical reports such as Freight in America (2006), Freight Shipments in America (2004), America's Freight Transportation Gateways (2004), National Transportation Statistics, and North American Transborder Freight Data. All of these reports are available at the BTS website. At the BTS website, users can access reports related to commodity shipments, hazardous materials shipments, transportation by air and truck, most important commodities by weight or ton-miles, economic impact of shipment choices, and domestic freight movements by commodity, mode, value and distance.

The North American Transborder Freight Database

The North American Transborder Freight Database has been available since April 1993. It contains freight flow data by commodity type and by mode of transportation (rail, truck, pipeline, air, water, and other) for U.S. exports to and imports from Canada and Mexico. The database includes two sets of tables; one is commodity-based while the other provides geographic detail. The purpose of the database is to provide transportation information on North American trade flows. This type of information is being used to monitor freight flow changes since the signing of the North American Free Trade Agreement (NAFTA) by the United States, Canada, and Mexico in December 1992 and its entry into force on January 1, 1994. The database is also being used for trade corridor studies, transportation infrastructure planning, marketing and logistics plans and other purposes. It allows users to analyze movement of merchandise by all land modes, waterborne vessels, and air carriers.The data are available for any month since 1994 to the current year. These data can be aggregated and disaggregated geographically, by mode, and by commodity type. Flows are measured by dollar value, pounds, short tons, and metric tons.

Beginning in 1997, the North American Transborder Freight Database represents official U.S. trade with Canada and Mexico for shipments that entered or exited the United States by surface modes of transport (other than air or maritime vessel). The data from April 1993 to December 1996 included official U.S. trade with Canada and Mexico by surface modes and transshipments that moved from a third country through Canada or Mexico to the United States or from the United States to a third country through Canada or Mexico. During this time period, it was not possible to separate transshipment activity from the official trade activity at a detailed level. Due to customer requests, BTS discontinued the inclusion of transshipment activity in the North American Transborder Freight Database beginning in January 1997. This allowed customers to perform comparable trade analyses by mode of transportation.

The North American Transborder Freight Database is extracted from the Census Foreign Trade Statistics Program. Import and export data are captured from administrative records required by the Departments of Commerce and Treasury. Historically, these data were obtained from import and export paper documents that the U.S. Customs Service (Customs) collected at a port of entry or exit. However, an increasing amount of import and export statistical information is now being captured electronically.

Federal Highway Administration (FHWA)

The Federal Highway Administration (FHWA) considers freight issues in studies of highway condition and performance, cost allocation, truck size and weight limits, and the economic consequences of highway investments. FHWA consists of several offices. The Office of Transportation Policy studies issues of truck size and weight and freight bottlenecks on highways. The Office of Legislative and Governmental Affairs considers highway condition and performance. Of particular importance to this working paper is the Office of Freight Management and Operations.

Office of Freight Management and Operations

The Office of Freight Management and Operations was established in 1999 as a part of the Federal Highway Administration's Office of Operations in the US Department of Transportation (USDOT). This office promotes efficient, seamless, and secure freight flows on the U.S. transportation system and across US borders. The Office has five major program areas: freight analysis, freight professional development, freight infrastructure, freight operations and technology, and vehicle size and weight.The Freight Analysis Program (FAP) conducts research on commodity flows and related freight transportation activities, develops analytical tools, measures system performance, and examines the relationship between freight transportation improvements and the economy. The FAP produces several regular publications including the Freight Analysis Framework, Freight Congestion, Data Source, Freight Facts and Figures 2008, Freight Model Improvement Program, Freight Planning, and Freight Studies by the FHWA Policy Offices. FAP provides both original data and links to other sources of national freight transportation data such as the commodity flow survey (CFS) and the North American Transborder Freight Database.

Freight Analysis Framework (FAF^2)

The Freight Analysis Framework (FAF^2) is a commodity origin-destination database that estimates the tonnage and value of goods shipped by type of commodity and mode of transportation among and within 114 areas, as well as to and from 7 international trading regions though the 114 areas and 17 additional international gateways.

FAF^2 integrates data from a variety of sources to estimate commodity flows and related freight transportation activity among states, regions, and major international gateways. FAF^2 provides estimates for 2002 and the most recent year plus forecasts through 2035. FAF^2 also provides information on commodity flows and related transportation activity among major metropolitan areas, states, regions, and international gateways. These products include a national summary for the year 2002 (listing tonnage and value shipped by mode or commodity); similar summaries for each state for the year 2002; a 2002 origin-destination matrix with accompanying technical documentation; annual provisional estimates (again listing tonnage and value shipped by mode or commodity); annual provisional origin-destination matrix/technical documentation; a summary of the national freight forecast for the years 2002 through 2035; similar summaries for each state for the years 2002 through 2035; origin-destination forecast matrices with accompanying technical documentation for the years 2002 through 2035; and national summary maps for the years 2002 to 2035.

FAF^2 Data and Documentation-2002-2035

The FAF commodity origin-destination database estimates tonnage and value of goods shipped by type of commodity and mode of transportation among and within 114 areas, as well as to and from 7 international trading regions though the 114 areas and 17 additional international gateways. The 2002 estimate is based primarily on the commodity flow survey and other components of the economic census. Forecasts are included for 2010 to 2035 in 5 year increments.

FAF^2 Provisional Commodity Origin-Destination Data and Documentation – 2007

The FAF is based primarily on data collected every five years as part of the economic census. Recognizing that goods movement shifts significantly during the years between each economic census, the federal highway administration produces a provisional estimate of goods movement by origin, destination, and mode for the most recent calendar year. These provisional data are extracted and processed from yearly, quarterly, and monthly publicly available publications for the current year or past years and are less complete and detailed than data used for the 2002 base estimate.

FAF^2 Highway Link and Truck Data and Documentation - 2002 and 2035

The FAF estimates commodity movements by truck and the volume of long distance trucks over specific highways. Models are used to disaggregate interregional flows from the commodity origin-destination database into flows among individual counties and assign the detailed flows to individual highways. These models are based on geographic distributions of economic activity rather than a detailed understanding of local conditions. While the FAF provides reasonable estimates for national and multi-state corridor analyses, FAF estimates are not a substitute for local data to support local planning and project development.

FAF² Historical Commodity Origin-Destination Data and Documentation-1997

To provide national freight movement trend analysis, the FHWA has re-processed the 1997 commodity flow survey data and additional data by using the 2002 FAF data algorithm and methodologies. The 1997 data has the same coverage as the FAF² 2002 and 2010-2035 data. The 1997 data also maintain the same data dimension and terminologies to ensure all databases and GIS components are compatible with other FAF² products.

COMMODITY AGGREGATION

Public policy usually considers commodity groups, not individual commodities. Our freight cost model is therefore designed to consider not only the costs of shipping individual commodities, but also the costs of shipping certain groups (categories) of commodities. Each commodity group typically corresponds to an economic sector. For example, public policymakers are probably not too concerned about the impact of a new regulation on the cost of shipping grapes in particular, but they may be concerned, on a more general level, about the cost of shipping refrigerated fruits and vegetables or refrigerated goods in general. The process of collecting similar commodities together into groups for analysis is called commodity aggregation.

The concept of commodity grouping is not new. In fact, all of the major commodity coding systems—including SCTG and HS (the Harmonized System)—assign similar numerical values to commodities that share one or more characteristics. We use the SCTG (Standard Classification of Transported Goods) coding system in this study. This system uses five digits to identify individual commodities when they are transported. The first two digits indicate a broad cargo category. Each additional digit beyond the first two provides an extra degree of resolution that describes the nature of the cargo. For example, the first two digits "07" signify "other prepared foodstuffs, and fats and oils." Within this category, dairy products are given the code "071"; milk products are given the code "0711"; and items that fit the description "milk and cream, in powder, granules, or other solid forms" are assigned the numerical code "07112." This hierarchical system gives organizations the flexibility to decide the level of granularity of a particular study or survey. More expensive studies may consider 5-digit commodities; less expensive surveys may consider 2-digit commodities. Other studies may use one level of granularity to analyze certain commodities and another level to analyze other commodities. In such cases, the data collected at different granularity levels can still be merged into the same report. In this study, we consider how 5-digit cargo information in various databases (e.g. the Commodity Flow Survey) can be aggregated at a higher level for public policy purposes.

Geographical Information Systems (GIS) handle granularity by using three different methods. The first method is predominant type coding, the second one is precedence coding, and the third method is center point coding. Suppose a square is divided to many areas, and has many grid cells. In the predominant method each grid cell is assigned the value corresponding to the predominant characteristic of the area it covers, in other words, if grid cell "X" is divided between areas A and B, and the largest portion of X lies in A, the cell is assigned the value A. Each cell in the precedence coding method is assigned the value of the highest ranked category present in the corresponding area. The cell in center point coding method is assigned the category value corresponding to its center point.

This working paper recommends using the predominate method to determine commodity characteristics in the most precise level of a group of commodities, which is the 5 - digit commodities level. Even the SCTG's 5-digit commodities may include more than one commodity. If most commodities or shipped goods in a 5-digit commodity group are hazardous, the entire group would be considered hazardous. The same idea applies to the other characteristics such as fragility, perishability, etc. Everything is assumed to be constant and deterministic in 5-digit level commodities and that includes the type of carrier (contract, hired, company), trucks used for shipping, and the packaging method.

When commodities are aggregated, the characteristics of the individual, 5-digit, commodities should be averaged to determine the overall characteristics of the commodity group. These characteristics impact shipping costs. For example, shipping costs may increase substantially if the transported commodity is (A) hazardous, (B) fragile, and/or (C) perishable (i.e. requires refrigeration). The characteristics of individual commodities with respect to the above criteria are usually known when all five digits are provided. However, measures of such characteristics for aggregated commodity groups are often not known. For example, we can be confident that cotton seeds (SCTG code 03505) are not hazardous, fragile, or perishable and that fresh-cut flowers (SCTG code 03910) are fragile and perishable. On the other hand, it is more difficult to determine the characteristics of commodity group 03 as a whole, of which cotton seeds and fresh-cut flowers are both a part.

In this study, we propose the following solution to the aggregation problem. We assign a numerical value to each commodity characteristic that can impact shipping costs. This numerical assignment is done at the 5-digit commodity level. Let a_{ij} be the numerical value assigned to commodity i's j^{th} characteristic (e.g. hazard level, fragility level, perishability level, typical cargo temperature, density). Let t_i be the quantity of commodity i shipped annually (in ton-miles or tons). Also, let G be the set of all commodities in group g. Then A_{gj}, the numerical value assigned to commodity group g's j^{th} characteristic, is a weighted average of the values assigned to the individual commodities in the group:

$$A_{gj} = \frac{\sum_{i \epsilon G} (t_i a_{ij})}{\sum_{i \epsilon G} (t_i)}$$

The above expression is a simple weighted average that gives the best available estimate for a characteristic of a commodity group. We use this formula to help compute shipping costs in the freight cost model described in the following section.

COST MODEL FOR SHIPPING BY TRUCK

We now present a cost model for shipping commodities by truck. Shipping by trucks includes medium and heavy trucks as well as light trucks, pickups, and minivans. In this model, however, we assume that all transportation is performed by large trucks in class 8 (see appendix A).

The following units are used throughout this model with respect to the following quantities:

- Traveling distance: English system (miles)
- Fuel volume: English system (gallons)
- Weight: English system (lbs, tons (1 ton = 2000 lbs))
- Cargo volume: English system (ft^3)
- Temperature: English system (degrees Fahrenheit)

The model has two kinds of inputs—parameters and constants as shown in Tables 2 and 3. Parameters are model inputs that define the service to be provided—the commodity (group) that is shipped, how much is shipped, where it is to be shipped, and any additional requests. The constants define the industry environment for providing transportation services. They include the price of fuel, equipment costs, insurance costs, the current state of technology, and various regulations such as the maximum allowed driving time in a 24-hour period. The values of the constants are likely to change over time and should therefore be reviewed periodically.

The model is relatively broad in scope but still has some limitations. First, in the final form of this model we assume there is only one driver per truck. In other words, we do not account for the possibility that two or more drivers (e.g. a husband and wife) may share the same truck and thereby increase the total distance driven per day. However, we show later how to determine if another driver is necessary or not. Secondly, we do not consider multi-trailer units; we assume only one trailer per tractor. We do, however, allow a shipment to be carried by multiple trucks. Featured relations in this model are shown in Table 4.

TABLE 2 Parameters in Transportation Cost Model

Parameter	Description
X_o	Shipment origin (5-digit zip code)
X_d	Shipment destination (5-digit zip code)
X_c	Commodity (5-digit SCTG code) or commodity group (2- to 4-digit SCTG code)
X_w	Shipment weight (lbs)
X_{tw}	Truck weight (lbs)
X_{temp}	Requested cargo temperature (degrees Fahrenheit)
X_{time}	Requested maximum journey time (hrs)[1]
$X_{trailer}$	Trailer and dock type
X_{plu}	Packaging, loading, and unloading method (0 = no unloading service requested; 1 = unloading service requested)

[1]Includes time spent idling and/or resting.

The total transportation cost is a function of the parameters. This total cost is comprised of the individual costs for fuel, labor, depreciation, maintenance, loading and unloading, insurance, overhead, and extra expenses.

Total Cost $= \quad Cost(X_o , X_d , X_c , X_w , X_{temp} , X_{time} , X_{trailer} , X_{plu}) =$

$$
\begin{aligned}
&Fuel(X_o , X_d , X_c , X_w , X_{tw} , X_{temp} , X_{time} , X_{trailer} , X_{plu}) + \\
&Labor(X_o , X_d , X_c , X_w , X_{tw} , X_{temp} , X_{time} , X_{trailer} , X_{plu}) + \\
&Deprec(X_o , X_d , X_c , X_w , X_{tw} , X_{temp} , X_{time} , X_{trailer} , X_{plu}) + \\
&Maint(X_o , X_d , X_c , X_w , X_{tw} , X_{temp} , X_{time} , X_{trailer} , X_{plu}) + \\
&Load(X_o , X_d , X_c , X_w , X_{tw} , X_{temp} , X_{time} , X_{trailer} , X_{plu}) + \\
&Insur(X_o , X_d , X_c , X_w , X_{tw} , X_{temp} , X_{time} , X_{trailer} , X_{plu}) + \\
&Over(X_o , X_d , X_c , X_w , X_{tw} , X_{temp} , X_{time} , X_{trailer} , X_{plu}) + \\
&Extra(X_o , X_d , X_c , X_w , X_{tw} , X_{temp} , X_{time} , X_{trailer} , X_{plu})
\end{aligned}
$$

TABLE 3 Constants in Transportation Cost Model

Constant	Description	Estimated values as of April, 2009
C_{maxWt}	Truck capacity (lbs)	Appendix A
C_{maxVol}	Trailer inside volume (ft^3)	Appendix A
$C_{fuel\$}$	Cost of fuel ($/gal)	2. 1
C_{optSpd}	Truck speed that yields optimum fuel efficiency (miles/hr)	55
C_{maxEff}	Truck fuel efficiency while traveling with empty trailer at optimum speed for fuel efficiency (miles/gal)	7-7.5
C_{minEff}	Truck fuel efficiency while traveling with full load (by weight) at optimum speed for fuel efficiency (miles/gal)	5-6
C_{spdLim}	Official truck speed limit on highway (miles/hr)	45-65
C_{hours}	Maximum allowed driving time for a single driver in any 24-hour period (hrs)	11
C_{ref}	Refrigeration unit fuel consumption per Fahrenheit degree difference between outside temperature and requested cargo temperature per hr (gal/(degree*hr))	0.4
C_{perish}	Commodity's perishablity value (0-1)	X††
C_{idle}	Average fuel consumption during idling (gal/hr)	1
C_{wage}	Driver wage ($/mile)	0.40
C_{hthIns}	Annual cost of driver health insurance ($)	6000
$C_{pension}$	Annual cost of driver pension plan ($)	6,500
$C_{SocialMed}$	Annual cost of driver social security tax and Medicare tax ($)	7,650
C_{annual}	Distance an average truck is driven annually (miles)	120,000
C_{new}	Cost of new tractor + trailer ($)	125,000
C_{life}	Truck expected lifetime (years)	5
C_{salv}	Truck salvage value at end of expected lifetime ($)	25,000
$C_{maintGM}$	Truck general maintenance cost per mile for engine and non-engine maintenance purposes ($/mile)	X†
C_{maintT}	Truck tires maintenance cost per mile ($/mile)	X††
C_{unload}	Average truck unloading cost ($/trailer)	40
C_{trkIns}	Annual cost of full liability, collision, and theft insurance for a truck ($/truck)	5,000
C_{crgIns}	Cost of cargo damage insurance for a commodity with maximum fragility level (= 1) per mile per $10,000 in value of the commodity (pro-rated for commodities with fragility levels less than 1) ($/truck-mile)	X†††
C_{othIns}	Annual cost of other insurance for a truck ($/truck)	5,000
C_{OH}	Overhead and indirect cost ($/truck-mile)	0.17
C_{haz}	Cost of shipping a commodity with maximum hazard level (= 1) (pro-rated for commodities with hazard levels less than 1) ($/truck-mile)	X†††

TABLE 3 Constants in Transportation Cost Model (continuation)

Constant	Description	Estimated values as of April, 2009
C_{regLic}	Annual cost of vehicle registration and driver licensing ($/truck)	Appendix A (State of Indiana is used as an example)

† Varies according to total truck shipment load.

†† Varies according to total truck shipment load, and total trailer and tractor tires .

††† Theses values are according to commodity and shipper considerations.

TABLE 4 Featured Relations in Cost Model

Milwaukee approximation for heavy truck fuel consumption "Total trip distance" †

$$TFC = \begin{cases} \sum_{i=5}^{15} Wsli55 * \text{Dist (Xis} - \text{Xif)} / [\left(\frac{33{,}000}{\text{M}}\right)\left[\frac{1.536}{0.17 + \left(\frac{2.43}{\text{V}}\right)}\right]] & , \text{ speed} < 55\text{mph} \\ \sum_{i=0}^{4} Wsmi55 * \text{Dist(Xis} - \text{Xif)} / [\frac{1}{[(1.53 * 10^{-6} * \text{M}) + (2.94 * 10^{-5} + 1.94 * 10^{-13} * \text{M}) * \text{V}^2]}] & , \text{ speed} \geq 55 \text{ mph} \end{cases}$$

Total shipping cost per truck †

$$\boldsymbol{Cost(X_o, X_d, X_c, X_w, X_{temp}, X_{time}, X_{trailer}, X_{plu}) =}$$

$$\left(C_{fuel\,\$}\right)(FuelTrav + FuelRefr + FuelIdle) + LaborWage + LaborHealthIns + LaborSocialMed + LaborPension + \left(\frac{dist(X_o, X_d)}{C_{annual}}\right) AnnualDepr + \left(dist(X_o, X_d)\right)(C_{maintGM} + C_{maintT}) + (C_{unload})(X_{plu}) + TrkIns + CargIns + OthIns + (C_{OH})(dist(X_o, X_d)) + RegLic + Haz$$

† These relations built according to 2009 technologies for heavy trucks "class 8"

Model Setup

Let *Speed* be the average speed while traveling. The time spent idling, sleeping, on breaks, and at rest stops is not considered here. Depending on driver preference, *Speed* might take the value C_{optspd} , C_{spdlim} , C_{spdlim} + 10, or any other value.

Let $dist(X_o, X_d)$ be the trip distance.

Fuel

Let $density(X_c)$ be the cargo density in lbs/ft^3. This density can be derived from the commodity type X_c. Let *NumVeh* be the number of trucks needed to haul the shipment. This quantity depends on whether shipment weight or shipment volume is the determining factor. In other words, we must determine whether the cargo will "weigh out" a trailer before it "cubes out" a trailer or vice versa. Note that $\frac{X_w}{C_{maxWt}}$ gives the number of trailers required based on a consideration of shipment weight alone. Also, $\frac{X_w/density\ (X_c)}{C_{maxVol}}$ gives the number of trailers required based on a consideration of shipment volume alone. The number of trailers required based on a consideration of both shipment weight and volume is therefore the maximum of these two values rounded up to the nearest integer.

$$NumVeh\ =\ \left\lceil \max\left(\frac{X_w}{C_{maxWt}},\frac{X_w/density\ (X_c)}{C_{maxVol}}\right)\right\rceil^{\dagger}$$

In the case of palletized shipment using boxes or pallets, or a combination of both of them the pallet specification should be considered. To find out number of trucks required we need to know the number of pallets used. Let *PallCap* be the capacity of one pallet (lbs) and *NumPall* be the number of pallets required for the shipment.

$$NumPall = \left\lceil \frac{X_w}{PallCap} \right\rceil$$

Number of each kind of pallet inside any trailer depends on the inside trailer and pallet dimensions. Let *PallTra* be number of pallets that can fit inside the trailer while *PaDim1*, *PaDim2* and *PalDim3* are the pallet dimensions and *InTraDim1*, *InTrDim2* and *InTrDim3* are inside trailer dimensions. In many cases you can orient the boxes or the pallets inside the trailer in any direction to maximize number of pallets in the stack.

† $\lceil X \rceil$: Rounding X up to the nearest integer. $\lfloor X \rfloor$: Rounding X down to the nearest integer.

$$PallTra = \max\left(\begin{array}{c}\left\lfloor\frac{InTraDim\ X}{PalDim\ X}\right\rfloor \cdot \left\lfloor\frac{InTraDim\ Y}{PalDim\ Y}\right\rfloor \cdot \left\lfloor\frac{InTraDim\ Z}{PalDim\ Z}\right\rfloor, \\ \left\lfloor\frac{InTraDim\ X}{PalDim\ Y}\right\rfloor \cdot \left\lfloor\frac{InTraDim\ Y}{PalDim\ X}\right\rfloor \cdot \left\lfloor\frac{InTraDim\ Z}{PalDim\ Z}\right\rfloor\end{array}\right)$$

Number of trailers if the shipment is palletized is given by the following expression:

$$NumVeh2 = max\left\lceil\left(\frac{X_w}{C_{maxWt}}, \frac{NumPall}{PallTra}\right)\right\rceil$$

Fuel Consumed for Traveling Purposes Only

According to the current technology used in today's trucks, for a tractor plus empty trailer weighing around 20,000 lbs, the fuel efficiency is roughly 7.5 miles/gallon. For each additional 20,000 lbs of cargo hauled, the truck fuel efficiency decreases by about 1 mile/gallon.

This working paper developed its own heavy truck fuel approximation. The authors of this working paper call this formulation the Milwaukee Approximation for heavy truck fuel consumption. This approximation combines the most updated theoretical and empirical relations. The approximation has discontinuous equations and relates truck fuel consumption (mpg) to driving speed (mph).The energy required to run a truck is given in equation 1.

$$F = A + Bv + Cv^2 \ldots\ldots\ldots\ldots(1).$$

Coefficients A, B and C are defined according to Giannelli et al. (2005). Since 55 mph is the most fuel efficient driving speed according to most of the theoretical resources and the available practical data, equation 1 is used for speeds of 55 mph and above. The equation has been converted from its original units of Newtons to miles per gallon (MPG) as in equation 2. See appendix B for more details about our calculations and conversions.

$$MPG = 1 / [(1.53*10^{-6}*M) + (2.94*10^{-5}+1.94*10^{-13}*M)*V^2]\ldots\ldots\ldots\ldots(2)$$

In equation 2, M is the total truck mass in lbs, and V is the truck driving speed in mph.

To find MPG for a speed less than 55 mph, Papacostas's textbook (Transportation and Engineering Planning, 2000) has been used. Papacostas reports a relation from the early 1980s between MPG and speed when the speed is less than 35 mph. The data in Factors Affecting Fuel Economy paper (Good Year, 2003) was used to update Papacostas's relation and extend it to include driving speeds less than 55 mph as in equation 3.

$$MPG = [1/(0.17 +(2.43/V))]\ldots\ldots\ldots(3)$$

In equation 3, V is the speed in miles per hour.

The model created in this paper divides driving speeds into 16 classes, each class being a different 5-mph interval, starting with 0 mph and ending at 80 mph. Class 0 pertains to speeds from 75-80 mph, class 1 pertains to speeds from 70-75 mph, and so on so that class 15 pertains to speeds from 0-5 mph. The probability (i.e. relative amount of time) the driver drives at each of these speed classes is found using data published in the Transportation Energy Data Book edition 2008-2009 as a part of a vehicle duty cycle project (Oak Ridge, 2008). These data show the distance traveled in each speed class. A reverse Poisson distribution (with parameter depending on the average driving speed) is the most appropriate distribution that fits these data. For more details see Appendix B. The total fuel consumption for any trip is found using the relation below.

$$TFC = \begin{cases} \sum_{i=5}^{15} Wsli55 * \text{Dist}\,(\text{X}_{\text{is}} - \text{X}_{\text{if}}) \,/\, [\left(\frac{33{,}000}{\text{M}}\right)\left[\frac{1.536}{0.17 + \left(\frac{2.43}{\text{V}}\right)}\right]] & (\text{speed} < 55\text{mph}) \\ + & \\ \sum_{i=0}^{4} Wsmi55 * \text{Dist}(\text{X}_{\text{is}} - \text{X}_{\text{if}}) / \left[\frac{1}{[(1.53 * 10^{-6} * \text{M}) + (2.94 * 10^{-5} + 1.94 * 10^{-13} * \text{M}) * \text{V}^2]}\right] & (\text{speed} \geq 55\text{ mph}) \end{cases}$$

Where,

TFC : Truck fuel consumption (gallons).

M: Total truck and trailer mass (lb), M = $Xt_w + X_w$

V: Driving speed (mi/hr)

W_{sli55}: The probability of driving at speed class i, when i > 4 (less than 55 mph).

W_{smi55}: The probability of driving at speed class i, when i ≤ 4 (more than 55 mph).

Dist (X_{is}-X_{if}): The distance traveled at velocities in speed class i, which has a minimum speed of X_{is} and a maximum speed of X_{if} .

Average speed (AvgSpeed) in this model is calculated by any of the following expressions, according to the user's data and requirements. Let Dist (X_{is}-X_{if}) be the distance traveled by speed class i, which starts with speed more than X_{is} and ends by speed equal or less X_{if} mph, and Time (X_{is}-X_{if}) is the time consumed in traveling by speed class i.

$$\text{AvgSpeed}_1 = \sum_0^{15} \frac{\text{Dist}\ (\text{Xis} - \text{Xif})}{\text{Time}\ (\text{Xis} - \text{Xif})}$$

Or,

$$AvgSpeed_2 = dist(X_o, X_d)/TravTime$$

Or,

$$AvgSpeed_3 = \text{Estimated average speed for a required shipping trip given by shipping parties.}$$

Let *FuelTrav* be the fuel consumption for travelling purposes. Final fuel consumption for travelling purposes is as follows:

$$FuelTrav = TFC$$

More details are provided in appendix B, regarding the Milwaukee approximation for heavy truck fuel consumption, and calculations mentioned in this section.

We now turn our attention to indirect fuel consumption. Indirect fuel consumption includes the fuel consumed for refrigeration of perishable goods and for idling, which includes the cooling or heating of the driver cabin.

Fuel Consumed for Refrigeration Purposes Only

Refrigeration and auxiliary operations use power from the engine which causes additional consumption of fuel. An average trailer refrigeration unit consumes roughly 0.5 gallons/hour for an average shipment. Many new technologies are available for reducing this consumption. The efficiency of the prevailing technology is reflected in the constant C_{ref}.

Let *TravTime* be the time (in hours) spent traveling, not including time spent on breaks, at rest stops, and for miscellaneous idling. Then *TravTime* is given by the following expression.

$$TravTime = dist(X_o, X_d)/Speed$$

Let *NumBreaks* be the number of long breaks made by the driver for the entire journey. According to industry regulations, drivers can only drive C_{hours} hours in any 24-hour time period. After that, they must put in a total of (24 - C_{hours}) hours of non-driving time before resuming their journey. Then *NumBreaks* is given by the following expression.

$$NumBreaks = \left\lfloor \frac{TravTime}{C_{hours}} \right\rfloor$$

Let *IdleTime* be the time (in hours) spent idling during breaks, at rest stops, and for miscellaneous purposes. Then *IdleTime* is given by the following expression.

$$IdleTime = (NumBreaks)(24 - C_{hours})$$

Let *JournTime* be the total time (in hours) required to complete the journey. Then *JournTime* is given by the following expression.

$$JournTime = TravTime + IdleTime$$

Let $temp(X_o, X_d)$ be the average outdoor temperature for the journey.

Let *FuelRefr* be the total volume of fuel consumed per truck for refrigeration purposes only. Then *FuelRefr* is given by the following expression.

$$FuelRefr = (JournTime)(C_{ref})(C_{perish})|temp(X_o, X_d) - X_{temp}|$$

Fuel Consumed During Idling for Non-refrigeration Purposes

Idling is common practice for heavy duty trucks in operation in the US for one or more of the following reasons: to power climate control (e.g. heaters, air conditioners); to power electrical appliances in the sleeper compartment (e.g. refrigerators, microwave ovens, televisions); to prevent start-up problems in cold weather; to drown out noise; and to maintain brake system air pressure (Lutsey et. al 2004). Truckers have also cited that they idle their engines for reasons of safety and habit (U.S. EPA 2002). Overall, idling provides truckers comfort, security, and convenience on the road.

The authors of the "Heavy-Duty Truck Idling Characteristics – Results from a Nationwide Truck Survey" found according to their survey and data from VIUS and other resources that the truck annual fuel consumption (gal/yr) = 18,846 while the idled fuel consumption was between 2,370 and 3,440. Based on this data, the average proportion of fuel consumed for idling is roughly 0.154.

Many factors effect on the idling fuel consumption, including (1) the engine speed at idling (rpm); (2) the season; (3) whether any technology is deployed to reduce the idling; (4) driver attitude; and (5) the appliances and auxiliary equipment in the driver cabin. For case 3, an alternative power unit can be used which reduces the fuel consumption by 80%. In this model, we aggregate the above factors into a single term C_{idle}, which gives the average fuel consumption during idling (gallons/hr).

Let *FuelIdle* be the total volume of fuel consumed per truck during idling for non-refrigeration purposes. Then *FuelIdle* is given by the following expression.

$$FuelIdle = (IdleTime)(C_{idle})$$

Overall Fuel Cost

We are now ready to write an expression for the overall fuel cost per truck.

$$Fuel(X_o, X_d, X_c, X_w, X_{temp}, X_{time}, X_{trailer}, X_{plu}) =$$

$$(C_{fuel\$})(FuelTrav + FuelRefr + FuelIdle)$$

Taxes are a major component of fuel prices. Currently, the U.S. federal fuel tax is 24.4¢/gal and the State of Wisconsin fuel tax is 32.9¢/gal. In this model, taxes are already accounted for by the constant $C_{fuel\$}$.

Labor

Today's average salary for a driver is $40,000-$50,000 a year and the average annual driving mileage is 100,000 - 120,000 miles. Based on these figures, the average wage for a driver, C_{wage}, is roughly $.40 per mile. Driver health insurance costs are estimated to be $500 monthly or $6000 annually.

Let *LaborWage* be the wage (in dollars) earned by the driver for the given journey. Then *LaborWage* is given by the following expression.

$$LaborWage = \left(dist(X_o, X_d)\right)(C_{wage})$$

Let *LaborHealthIns* be the portion of the driver's annual health insurance costs (in dollars) that can be attributed to the current journey. Then *LaborHealthIns* is given by the following expression.

$$LaborHealthIns = \left(\frac{dist(X_o, X_d)}{C_{annual}}\right)(C_{hthIns})$$

Social security tax, Medicare tax, and Pension plan cost are included in this model as a part of labor cost. Social security tax and Medicare tax are withheld from employees and then matched by the employer. Total Social Security tax and Medicare tax are 15.3% on the first $106,800 of each employee's earnings paid by the employer in the year 2009. Depending on these information the total social security tax and Medicare tax $C_{SocialMed}$ in 2009 is $7,650. *LaborSocialMed* is the share of total Social Security and Medicare taxes in a specific journey

$$LaborSocialMed = \left(\frac{dist(X_o, X_d)}{C_{annual}}\right)(C_{SocialMed})$$

A pension or retirement plan is an arrangement to provide people with an income when they are no longer earning a regular income from employment. It is a tax deferred savings vehicle that allows for the tax-free accumulation of a fund for later use as a retirement income. Often retirement plans require both the employer and employee to contribute money to a fund during their employment in order to receive defined benefits upon retirement. Besides the social security tax there are different kinds of retirement plans like 401K and IRA (Individual Retirement Account). Each of these plans has different contribution limits.

The maximum contribution limit for 401K is $16,500 which applied to higher paid employee that means an employee with a total compensation package of $105,000-110,000 can contribute $16,500 in 2009, this working paper expect annual driver income as $50,000. There can be an additional contribution made by the employer. The contribution limit for employers is set at 6% of the employee's pre-tax compensation. If the employee/driver is age 50 or older, he may also be eligible to make "catch-up 401k contributions" in addition to the regular 401k limits. The maximum contribution limit for the catch up plan is $5,500 in 2009. IRA maximum contribution limit in 2009 is $5,000 and 6,000 for 50 years old or older.

A trucker driver may work for a big shipping company or work for his own, we estimated the average pension plan cost of truck driver by assuming most of truck drivers are less than 50 years old, and working for a shipping company. We assumed a truck driver contribution in his pension plan is 10% ($5,000), and employer contribution 3% ($1,500) according to 2009 instructions. The total annual estimated pension cost $C_{pension}$ is $6,500. *LaborPension* is the attribute of pension plan cost in the current journey.

$$LaborPension = \left(\frac{dist(X_o, X_d)}{C_{annual}}\right)(C_{pension})$$

We are now ready to write an expression for the overall labor cost per truck.

$$Labor(X_o, X_d, X_c, X_w, X_{temp}, X_{time}, X_{trailer}, X_{plu}) =$$

$$LaborWage + LaborHealthIns + LaborSocialMed + LaborPension$$

As we mentioned before, we assume there is only one driver for each trip in the final form of this model. However, we show here how to find out if another driver is required and if the requested maximum journey time X_{time} is reasonable or not.

Let's assume that the policy maker wants to limit the shipping trip time by X_{time}, the trip is limited by specific average driving speed, and Journey time (*JournTime*), which is calculated as shown in part 5.1.2, if *JournTime* < X_{time}, then the shipping trip requires only one driver, else if *JournTime* > X_{time}, hire another driver to eliminate the idle time, the new journey time now is *JournTime2 = TravTime* , else if *JournTime2* > X_{time}, then X_{time} is not reasonable and should be modified to accommodate with other shipping process requirements and parameters.

Depreciation

There many methods for calculating depreciation. We use the method of straight-line depreciation. This method assumes that the asset will lose an equal amount of value each year. To calculate how much the asset depreciates annually, three pieces of information are required: 1) the purchase price of the asset; 2) the asset's estimated useful life (in years); and 3) the salvage value, or estimated value of the asset at the end of its useful life. To determine how much the asset depreciates annually, subtract the salvage value from the purchase price and divide the difference by the estimated useful life. Our discussions with trucking industry professionals indicate that a new truck costs $100,000-$125,000 on average; it lasts 5-10 years; and its trade-in value after five years is approximately $25,000. These are good estimates for the values of the constants C_{new}, C_{life}, and C_{salv}.

Let *AnnualDepr* be a truck's annual depreciation in dollars. Then *AnnualDepr* is given by the following expression.

$$AnnualDepr = \left(\frac{C_{new} - C_{salv}}{C_{life}}\right)$$

Capital recovery (*CapitalRec*) is added to the depreciation in this work, capital recovery represents the income sufficient to recover the amount of the original investment plus returns and profits.

$$CapitalRec = (C_{new} - C_{salv})(A/P,i,n) + C_{salv}\,(i)$$

(A/P,i,n) can be found from any engineering economy text book, where I is annual interest rate, and n = 5.The current journey represents a small fraction of the truck's annual activities. We are now ready to write an expression for the depreciation cost per truck that is attributable to the current journey.

$$Deprec(X_o, X_d, X_c, X_w, X_{temp}, X_{time}, X_{trailer}, X_{plu}) =$$

$$\left(\frac{dist\,(X_o, X_d)}{C_{annual}}\right)(AnnualDepr + CapitalRec)$$

Maintenance

The engine and transmission systems are the main truck components that receive maintenance. Other maintenance expenses include replacement tires, replacement lights, and trailer repair. A truck's engine is overhauled every 500,000 miles on average. Thus, the engine is overhauled every 4-5 years. Some operators prefer to trade in their truck every 4-5 years instead of overhauling the engine at considerable expense. The maintenance cost per truck that is attributable to the current journey can be written as follows. The tires in this model are divided to two kinds, tractor's tires and trailer's tires. The total tire's cost is the cost of the tire price and tire wear make up cost.

In this model and its case studies, $C_{maintGM}$ is a truck general maintenance cost per mile for engine and non-engine maintenance purposes, C_{maintT} is a truck tires maintenance cost per mile. The total maintenance cost is the summation of $C_{maintGE}$ & $C_{maintT..}$ Faucett and Associate formulas, 1991 have been used in this model to estimate the general maintenance cost. General maintenance cost for engine and non-engine purposes are directly related to gross vehicle weight GVW. Let's *PercentLoad* be a percent time the truck is loaded, and *PercentEmpty* be the percent time the truck is empty, Faucett and Associate formulas for loaded truck maintenance per mile *LoadTruckMaint* and empty truck maintenance per mile *EmpTruckMaint* are as follows:

$$LoadTruckMaint = ((\text{GVW-58,000})/1{,}000) \times WeightAdjMainCost) \times PercentLoad$$

$$EmpTruckMaint = ((\text{58,000-GVW})/1{,}000) \times WeightAdjMainCost) \times PercentEmpty$$

Where *WeightAdjMainCost* is weight adjusted maintenance cost. Total general maintenance cost is as follows:

$$C_{maintGM} = BaseCost + LoadTruckMaint + EmpTruckMaint$$

Where *BaseCost* is base cost and estimated to be 9 cents in 1991 and *WeightAdjMainCost* is 0.097 per mile in 1991. After including the inflation rates (1991 – 2009), *BaseCost* in 2009 is estimated to be 14.8 Cent ($0.148), and for *WeightAdjMainCost* 0.16 cent ($0.0016).

Service cost (*BaseCost*, *WeightAdjMainCost)* is a directly affected by the technology used in the truck, maintenance efficiency, preventive maintenance, and driving attitude of truck driver.

The tire cost and wear are function of weight. Faucett and Associate, 1991, found that the tire life is not affected by weight, if the weight per tire is less than 3,500 Ib. Increasing the weight by 1% per tire above the 3,500 Ib increases tire wear by 0.7%. Heggeness, 1996, estimated tractor tire cost (*TractorTireCost*) at $400 and wear (*TractorTireMile*) was estimated to be 100,000 miles on average. When consider the inflation rates from 1996-2009, the tractor tire estimated cost is $550. For a trailer tire the estimated cost (*TrailerTireCost*) in 1996 was $262, and $360 in 2009, the wear (*TrailerTireMile*) is estimated at 204,500 miles.

NumTractorTires is total number of tractor tires and *NumTrailerTires* is the total trailer tires, the total tiers is *TotTiers* = *NumTractorTires* + *NumTrailerTires*, it is required to check if the tire is overloaded or not by dividing the gross vehicle weight by total tires. (GVW/ TotTiers) > 3500. In the overload case, extra cost should be added to the tractor and trailer tire mileage cost, due to the increasing in the wear rate of the tire.

Let extra tire cost due to overload for tractor and trailer, *TractorTireExtraCost* and *TrailerTireExtraCost*, then,

$$TractorTireExtraCost = [\,((\text{GVW}/TotTire)-3500) / 3500] \times 100 \times 0.007 \times TractorTireCostMile$$

$$TrailerTireExtraCost = [\,((\text{GVW}/TotTire)-3500) / 3500] \times 100 \times 0.007 \times TrailerTireCostMile$$

Where,

$$TractorTireCostMile = TractorTireCost/TractorTireMile$$
$$TrailerTireCostMile = TrailerTireCost/TrailerTireMile$$

Loaded tractor tire cost and loaded trailer tire cost can be estimated from the following relations:

$$LoadTractorTireCost = TractorTireCostMile + TractorTireExtraCost$$
$$LoadTrailerTireCost = TrailerTireCostMile + TrailerTireExtraCost$$

Empty tractor tire is *EmpTractorTireCost* and equals *TractorTireCostMile*. Empty trailer tire cost is *EmpTrailerTireCost* and equals *TrailerTireCostMile*.

Let *PercentLoad* be percent time the truck is loaded, and *PercentEmpty* be the percent time the truck is empty, then the total tractor tire cost *TotTractorTireCost* and total trailer tire cost *TotTrailerTireCost* can be found as follows:

$$TotTractorTireCost = (LoadTractorTireCost \times PercentLoad) + (EmpTractorTierCost \times PercentEmpty)$$

$$TotTrailerTireCost = (LoadTrailerTireCost \times PercentLoad) + (EmpTrailerTierCost \times PercentEmpty)$$

The total tire cost per mile C_{maintT} is:

$$C_{maintT} = TotTractorTireCost + TotTrailerTireCost$$

$$Maint(X_o, X_d, X_c, X_w, X_{temp}, X_{time}, X_{trailer}, X_{plu}) = \big(dist(X_o, X_d)\big)(C_{maintGM} + C_{maintT})$$

Loading and Unloading

Loading and unloading refers to the services of transferring cargo between the inside of the trailer and any place or point of rest on a wharf or terminal. Truck loading consists of moving cargo over the wharf or terminal facility to the truck from a place of rest, elevating the cargo onto the truck and stowing the cargo in the truck, but shall not include sorting or grading or otherwise selecting the cargo for the convenience of the trucker or the consignee. Truck unloading consists of removing cargo from the body of the truck, and moving it over the wharf or terminal facility to a place of rest.

Drivers are usually not responsible for loading their vehicles. They may, however, participate in unloading at the destination. Unloading palletized cargo using a forklift costs about $ 40 per truck and it consumes about 20 minutes. Unloading non-palletized cargo by hand consumes 2-3 hrs and is far more costly. In this model, we only consider the former scenario.

We are now ready to write an expression for the loading and unloading cost per truck for the current shipment.

$$Load(X_o, X_d, X_c, X_w, X_{temp}, X_{time}, X_{trailer}, X_{plu}) =$$

$$(C_{unload})(X_{plu})$$

Insurance

There are two types of insurance: truck and cargo. Truck insurance covers the truck itself and the damage it can cause. It includes the following kinds of insurance: full liability, physical damage, collision, fire, and theft insurance. Cargo insurance covers the shipment in the event that goods are damaged in transit.

Let *TrkIns* be the cost of truck insurance per truck that is attributable to the current journey. Then *TrkIns* is given by the following expression.

$$TrkIns = \left(\frac{dist(X_o, X_d)}{C_{annual}}\right)(C_{trkIns})$$

Let $value(X_c)$ be the dollar value of 100 lbs of commodity X_c.

Let *Value* be the dollar value of the cargo hauled per truck. Then *Value* is given by the following expression.

$$Value = \left(\frac{(value(X_c))(X_w/NumVeh)}{100}\right)$$

Let $frag(X_c)$ be the cargo fragility level on a 0-1 scale, where 0 = not fragile and 1 = extremely fragile. The cargo fragility level can be derived from the commodity type X_c.

Let *CargIns* be the cargo insurance cost per truck. Then *CargIns* is given by the following expression.

$$CargIns = \big(dist(X_o, X_d)\big)(frag(X_c))(Value)(C_{crgIns}/10000)$$

Let *OthIns* be the cost of all other kinds of insurance not included above that is attributable to the current journey. Then *OthIns* is given by the following expression.

$$OthIns = \left(\frac{dist(X_o, X_d)}{C_{annual}}\right)(C_{othIns})$$

We are now ready to write an expression for the total insurance cost per truck that is attributable to the current journey.

$$Insur(X_o, X_d, X_c, X_w, X_{temp}, X_{time}, X_{trailer}, X_{plu}) =$$

$$TrkIns + CargIns + OthIns$$

Indirect Costs

Indirect cost includes all costs which are not classified as direct labor or materials, some of the items which may be included as indirect costs are management and administration staff, property taxes, utilities, advertising, communication equipment, rental of facilities, insurance of facilities, etc. Different methods are used to allocate overhead cost, in this model overhead cost is allocated over trucks.

This cost varies according to different shippers and truckers considerations and estimations. Dooley, Bertram, and Wilson (1988) weighted average this cost per truck as $10,721 annually. After considering inflation, this cost is estimated to be in today's dollar (2009) about $20,327 per truck. The indirect (overhead) C_{OH} in this model is calculated per driven mile. C_{OH} in 2009 according to Dooley average is 20,327 / 120000 = $0.17 per mile. The indirect (overhead) C_{OH} cost per truck that is attributable to the current journey is given by the following expression,

$$Over(X_o, X_d, X_c, X_w, X_{temp}, X_{time}, X_{trailer}, X_{plu}) =$$

$$(C_{OH})(dist(X_o, X_d))$$

Extra Costs

Extra expenses include highway user and licensing fees and additional costs for transporting hazardous cargo. Individual long-haul truckers pay a truck registration fee for the right to haul freight on U.S. roads. The cost is roughly $2500 per year. An additional cost of $0.50 to $1 per mile is typically added to the shipping cost when hazardous cargo is moved.

Let *RegLic* be the truck registration and licensing cost that is attributable to the current journey. Then *RegLic* is given by the following expression.

$$RegLic = \left(\frac{dist(X_o, X_d)}{C_{annual}}\right)(C_{regLic})$$

Let $haz(X_c)$ be the cargo hazard level on a 0-1 scale, where 0 = non-hazardous and 1 = extremely hazardous. The cargo hazard level can be derived from the commodity type X_c.

Let *Haz* be the additional cost per truck associated with a hazardous shipment. Then *Haz* is given by the following expression.

$$Haz = (C_{haz})(haz(X_c))(dist(X_o, X_d))$$

We are now ready to write an expression for the extra cost borne per truck for the current journey.

$$Extra(X_o, X_d, X_c, X_w, X_{temp}, X_{time}, X_{trailer}, X_{plu}) =$$

$$RegLic + Haz$$

Overall Shipping Costs

The total cost per truck for the shipment is equal to the sum of the component costs.

$Cost(X_o, X_d, X_c, X_w, X_{tw}, X_{temp}, X_{time}, X_{trailer}, X_{plu}) =$

$Fuel(X_o, X_d, X_c, X_w, X_{tw}, X_{temp}, X_{time}, X_{trailer}, X_{plu}) +$

$Labor(X_o, X_d, X_c, X_w, X_{tw}, X_{temp}, X_{time}, X_{trailer}, X_{plu}) +$

$Deprec(X_o, X_d, X_c, X_w, X_{tw}, X_{temp}, X_{time}, X_{trailer}, X_{plu}) +$

$Maint(X_o, X_d, X_c, X_w, X_{tw}, X_{temp}, X_{time}, X_{trailer}, X_{plu}) +$

$Load(X_o, X_d, X_c, X_w, X_{tw}, X_{temp}, X_{time}, X_{trailer}, X_{plu}) +$

$Insur(X_o, X_d, X_c, X_w, X_{tw}, X_{temp}, X_{time}, X_{trailer}, X_{plu}) +$

$Over(X_o, X_d, X_c, X_w, X_{tw}, X_{temp}, X_{time}, X_{trailer}, X_{plu}) +$

$Extra(X_o, X_d, X_c, X_w, X_{tw}, X_{temp}, X_{time}, X_{trailer}, X_{plu})$

The overall cost of transporting the entire shipment equals *NumVeh* multiplied by the above quantity.

CASE STUDIES

Case One: Shipping Crops

The first case study is about shipping 45,000 lb of corn from farm to elevator and from elevator to food plant. These three businesses are located in the same state. The distance from farm to elevator is 10 miles, while the distance from elevator to the food plant is 30 miles. Corn is classified under the cereal grains category in SCTG coding system. Corn's three-digit SCTG code is 022 and includes just one commodity at the five-digit level. Corn's five-digit code is 02200. The three-digit and five-digit codes are the same in this case. As we mentioned in Section 4, the "predominate" method would be used to determine the characteristics of the shipment of corn, but it is unnecessary in this case.

According to *Iowa farm and rural life poll, 2007 Survey Report on Grain Storage and Transportation*, semi-trailer trucks are used to ship grains with total capacity about 1,370 bushels.

Let's assume the truck used in this case is three-axle ten-tire truck, and attached to eight-tire trailer to ship corn from farm to elevator. This trailer is 48 feet long, 96 inches wide and 102 inches high. This truck gross weight is 80,000 lb and 33,000 lb empty. Corn is shipped loose from farm to elevator. The corn shipping unit is a bushel. A bushel is an imperial and U.S. customary unit of dry volume. Each bushel is 1.244 cubic foot or 2150.42 cubic inches. Each corn bushel at 15.5% moisture by weight is 56 lb. Farm bushel price is estimated to be $4.2 and the elevator price is $5. The farm per lb price is $0.075. This shipment is neither fragile nor hazardous, and doesn't require a refrigeration unit. Only one truck is required for this shipment. Average travel speed for this trip is 40 mi/hr. Total shipping cost for this case is $62.74; variables parameters and constants used in this case study are shown on Table 5. In case 1-b we consider shipping corn from elevator to food plant. The same constants, parameters and variables as in case 1-a are used in this case except for the total trip distance and the corn price per lb; see above for more details. The total shipping rate in case 1-b is $108.21. More detailed computations for these case studies are shown in Table 6. The same weight and characteristics of other grains like soybean gives the same rate as in case 1-a and case 1-b.

TABLE 5 Constants, Parameters, and Variables used in The Case Study 1-a

Constant/Parameter/Variables	Estimated values
C_{maxWt}	48000
C_{maxVol}	3,264
$C_{fuel\$}$	2.1
C_{optSpd}	55
C_{maxEff}	7.5
C_{minEff}	6
C_{spdLim}	55
C_{hours}	11
C_{ref}	0.4
C_{perish}	0
C_{idle}	1
C_{wage}	0.4
C_{hthIns}	6000
C_{annual}	120,000
C_{new}	125,000
C_{life}	5
C_{salv}	25,000
$C_{maintGM}$	0.184
C_{maintT}	0.00729
C_{unload}	40
C_{trkIns}	5,000
C_{crgIns}	0
C_{othIns}	5000
C_{haz}	0
C_{OH}	0.17
C_{regLic}	$965.75
$C_{pension}$	6,500
$C_{SocialMed}$	7,650
X_c *(density-Ib/ft3)*	45.016
X_w	45000
X_{temp}	39.200
X_{plu}	1.000
X_{tw}	33000
Speed	64.33
$dist(X_o,X_d)$	10.000
$temp(X_o, X_d)$	33.100
Value (X_c)	7.500
Empty GVW (X_{tw})	33000
M	78000
Total GVW (M)	78000

TABLE 5 Constants, Parameters, and Variables used in The Case Study 1-a (continuation)

Constant/Parameter/Variables	Estimated values
Percent Load	0.50
Percent Empty	0.50
Tractor tire	10
Trailor tire	12
Total Tire	22
TractorTire Cost	550.00
TractorTire Mile	100000
Tractor TireCostMile	0.0055
TractorTire ExtraCost	0.00005
LoadTractorTireCost	0.0056
LoadTractorTireCost x Percent Load	0.00278
EmptyTractorTireCost	0.00550
EmptyTractorTireCost x Percent Empty	0.00275
TotalTractor TireCost	0.0055
TrailorTire Cost	360.00
TrailorTire Mile	204500
TrailorTireCostMile	0.00176
TrailorTire ExtraCost	0.00002
LoadTrailerTireCost	0.00178
LoadTrailerTireCost x Percent Load	0.00089
EmptyTrailorTireCost	0.00176
EmptyTrailorTireCost x Percent Empty	0.00088
TotalTrailorTireCost	0.0018
WeightAdjMainCost	0.00160
LoadTruckMain	0.01600
EmptyTruckMain	0.02000
BaseCost	0.148
Interest rate	0.100
A/P,0.1,5	0.264
Captal recovery	38880.000

TABLE 6 Case Studies Shipping Rates in Details

Case	Description	Shipping rate ($)	Fuel ($)	Labor ($)	Depr ($)	Maint. ($)	L/UnL ($)	Insurance ($)	Indirect ($)	Extra ($)
Case 1-a	Shipping corn from farm to elevator	62.74	7.64	5.68	4.91	1.91	40	0.82	1.7	0.08
Case 1-b	Shipping corn from elevator to food plant	108.21	22.93	17.04	14.72	5.74	40	2.45	5.1	0.24
Case 2-a	Shipping brake discs 10 miles trip distance	62.63	7.55	5.68	4.91	1.90	40	0.82	1.7	0.08
Case 2-b	Shipping brake discs 200 miles trip distance	492.67	150.92	113.58	98.13	38.09	40	16.33	34	1.61
Case 2-c	Shipping brake discs 1000 miles trip distance	2330.66	781.91	567.92	490.67	190.44	40	81.67	170	8.05
Case 2-d	Shipping motor vehicle parts, 10000 miles trip distance	2330.66	781.91	567.92	490.67	190.44	40	81.67	170	8.05
Case 3-a	Shipping milk 200 miles trip distance, 52 ̊F land temperature	515.46	173.35	113.58	98.13	38.44	40	16.33	34	1.61
Case 3-b	Shipping milk 200 miles trip distance, 28 ̊F land temperature	512.99	170.89	113.58	98.13	38.44	40	16.33	34	1.61
Case 3-c	Shipping milk 200 miles trip distance, 92 ̊F land temperature	577.09	234.99	113.58	98.13	38.44	40	16.33	34	1.61
Case 3-d	Shipping Diary 200 miles trip distance, 52 ̊F land temperature	515.09	172.99	113.58	98.13	38.44	40	16.33	34	1.61

Case Two: Shipping Auto Products

SCTG divided commodities to different groups and levels according to their types and properties. A commodity at the two- digit level is aggregated from finer levels. Three-digit level groups are childs of a two-digit level group. Each three-digit level breaks down to four-digit level groups to include less commodities with less number of common characteristics and properties. The finest level is five digits, where each 5-digit number represents a specific commodity. As we discussed earlier in Section 4, the "predominate" method is used to determine the characteristics by the 5-digit level. In this paper we define the main shipping characteristics by hazard level, fragility level, perishability level, and typical cargo temperature. The first three characteristics were determined by using binary codes (1,0). 1 implies the commodity possesses the characteristics and 0 it does not. For the cargo temperature, 0 is given to room temperature, 1 for (-18 ºC/-0.4 ºF), and for any temperature in between a value from 0-1 is proportionally calculated. Aggregated commodities' shipping characteristics are determined by averaging each characteristic in a finer level for each aggregated commodity group. The weighted average value is assigned as illustrated in Section 4.

Some aggregated commodity groups have commodities with the same shipping characteristics. Shipping rates will be the same for any commodity in five-digit level and three-digit level within these groups. In this case we discus one of these aggregated commodity groups. Shipping the same weight of brake discs or any kind of gear boxes costs the same. This is because both of them belong to motor vehicle parts category in SCTG and have the same shipping characteristics. Both of them are neither hazardous nor fragile nor perishable. These characteristics apply on all commodities of this category as in Table 7. Brake's 5-digit code is 36401. Let's assume a shipment of brake discs, and the brake disc dimensions are 15″ inches diameter and 1.4″ inches thick. A brake disc average weight is 20.2 lb, and each brake price is about $200. A trailer with the following internal dimensions 630″ x 97″ x 99 ″ is used for this shipment. The shipment is containerized. The container weight empty is 107 lb, and its dimensions are 48″x40″x45.5″. Each container holds 31 brake discs with 626.2 lb of brakes weight. We considered the shipping distances of 10,200, and 1000 miles. Shipping at an aggregated level (like 3-digit) gives the same cost as a 5-digit level. Shipping rates and its details are shown in Table 6.

TABLE 7 Motor Vehicle Parts' STGC Codes and Its Shipping Characteristics.

5Digit	Motor vehicle parts	2Digit	3Digit	4Digit	Haz	Frag	Perish	Ton-Miles 3Digit
36401	Brakes	36	364	3640	0	0	0	25,847
36402	Gear boxes (except parts, see 36409)	36	364	3640	0	0	0	25,847
36403	Road wheels	36	364	3640	0	0	0	25,847
36404	Metal stampings such as bumper, fender, door, hood, trim, and hub cap	36	364	3640	0	0	0	25,847
36409	Other parts for motor vehicles, including seat belts and seat covers (except parts for motorcycles, mopeds and armored fighting vehicles, see 36351 and 36391; and except engines and engine parts, see 341xx; pumps for liquids, see34310; filters, see 34999; tires, see 24310; glass, see 313xx; lighting and signaling equipment, see 35992; ignition and starting equipment, see 35991; windshield wiper sand defrosters, see 35992; seats, see 39029; and catalytic converters, see 34999)	36	364	3640	0	0	0	25,847

Case Three: Shipping Dairy Products

Dairy products are perishable. A refrigeration unit is required to keep these products edible and nutritious, and to maintain their physical characteristics. We start in this case by shipping milk from dairy plant to vendors. Milk is packed in different sized cardboard or plastic containers. Diary shipping containers are used to ship milk product containers. The shipping container weight is 107 lb and it dimensions are 48″ x 40″ x 45.5″. 650 lbs of milk can fit into each shipping containers. Five-axle ten-tire truck attached to eight-tire trailer is used in this case. Trailer inside dimensions are 630" x 97" x 99". Sixty shipping containers fit inside the trailer, and the total shipment weight is 45,420 lb. Total trip distance is 200 miles. The required shipping temperature for milk is 39.2 °F. Let's assume three different atmospheric conditions for shipping milk from trip's origin to its final destination. 52 °F, 28 °F, and 92 °F are used as different shipping atmospheric conditions. C_{perish} is 0.56 at 39.2 °F shipping temperature.

The shipping rates for these different temperatures are higher than the shipping rates we studied earlier, for the same trip distance as in Table 6. This increase is from fuel for the refrigeration unit. Shipping in moderate temperature reduces the fuel consumption for refrigeration. However, to avoid freezing the milk cargo while shipping in below freezing conditions, the refrigeration unit should heat the trailer. Using new auxiliary energy saving equipments reduces the refrigeration unit fuel consumption. Table 8 shows the fuel consumption for travelling and refrigeration for each case.

TABLE 8 Case 3 Fuel Consumption.

Case Study	Travelling fuel consumption (gallons)	Refrigeration fuel consumption (gallons)
Shipping milk, 200 mile trip, 52 ̊F shipping temp	73.16	9.32
Shipping milk, 200 mile trip, 28 ̊F shipping temp	73.16	8.22
Shipping milk, 200 mile trip, 92 ̊F shipping temp	73.16	38.74

Now let's consider shipping diary in general from plant to vendors, diary category group number in SCTG at three digit level is 071, and that includes seven commodities. Diary commodities list and its shipping characteristics are shown in Table 9. The shipping characteristics for diary are the same except for the shipping temperature. Shipping temperature for ice cream should be very low, while shipping temperature for milk powder is room temperature. For shipping commodities at three-digit level we should weight the average of the shipping temperatures assigned for each individual commodity in this group, as we discussed before in Section 4. Weighted average for any shipping characteristics is used to get an average shipping rate at aggregated levels.

Due to confidentiality issues, the lack of data for entire nation at 5-digit level led us to use data provided from Wisconsin. These data are for commodities shipped from and to Wisconsin in tonnage, up to level 4 in STCC code. We reassembled these data to be at the 5-digit level in SCTG code as shown on Table 9. In this case the weighted average is used to assign a value for shipping temperature for diary group products at the three-digit level.

$$A_{gj} = \frac{\sum_{i\epsilon G} (t_i a_{ij})}{\sum_{i\epsilon G} (t_i)}$$

Where:

a_{ij} : The numerical value assigned to commodity i's j^{th} characteristic.

t_i: The quantity of commodity i shipped annually (in ton-miles or tons).

G: The set of all commodities in group g.

A_{gj}: The numerical value assigned to commodity group g's j^{th} characteristic, is a weighted average of the values assigned to the individual commodities in the group.

The assigned value for diary shipping temperature A_{DShT} = 0.579, from the data we have. More than 90% of the shipped commodities in this group are milk. Milk plays the major role in determining the shipping characteristics for his groups at any aggregated level. Shipping rates are as shown in Table 6.

TABLE 9 STGC Diary Commodities.

5Digit	Dairy products (except beverages and preparations)	3Digit	Haz.	Frag.	Perish.	Temp. (ºC/ ºF)	Temp. Value	Ton-Miles 3Digit†	Fraction of Total 3Digit Ton-Miles (%)
07111	Milk and cream, unconcentrated and unsweetened	071	0	0	0	(4/39.2)	0.59	20,111	91.63
07112	Milk and cream, in powder, granules, or other solid forms	071	0	0	0	(21/69.8)	0	20,111	2.01
07119	Other milk and cream	071	0	0	0	(4/39.2)	0.59	20,111	3.65
07120	Cheese and curds	071	0	0	0	(4/39.2)	0.59	20,111	1.56
07130	Ice cream, ice milk, sherbets, and ices (excludes frozen yogurt, see 07199, and ice cream and ice milk mixes, see 06399)	071	0	0	0	(-18/-0.4)	1	20,111	0.12
07191	Butter and other fats and oils derived from milk	071	0	0	0	(4/39.2)	0.59	20,111	0.51
07199	Other dairy products, (excludes mixtures of butter and vegetable oil, see 0743x, preparations based on milk, see 06399, eggnog and flavored milk drinks, see 07899)	071	0	0	0	(4/39.2)	0.59	20,111	0.51

† As in Commodity Flow Survey (2002)

CONCLUSION AND FUTURE WORK

In this study, we have studied the problem of estimating the cost of shipping commodities by truck between a given origin and destination inside the United States. We have taken an inventory of cost models that have been used in the past and evaluated the availability of data sets containing shipment cost information. We have also built a cost model for shipping various commodities and commodity groups by truck and have presented several examples showing how the model can address several issues of interest to carriers, shippers, and governments.

Our next task is to test the truck transportation cost model and compare the freight rates we obtain from it with actual freight rates. This validation process will be undertaken to improve our cost models according to the test results. We will also adopt regression methods to increase the forecasting capability of the model. Also, a user-friendly excel spreadsheet will be created to accommodate changes in model parameters and constants, and to increase the model's flexibility and predictability. After that, other freight transportation modes (rail, air, and/or water) will be considered, and then all transportation modes models will be combined to form a complete transportation model with forecasting and estimation capabilities that qualify it to give good transportation modes choices through a fright trip from its origin to destination.

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APPENDICES

Appendix A: Trucks/Vehicle Classifications

The single unit and combination trucks are divided into 17 classes reflecting differences in the number of cargo carrying units and the number and types of axles. The 20 vehicle classes used for this study are:

- Automobiles and motorcycles.
- Pickups, vans and other light 2-axle, four tire vehicles.
- 2-, 3-, and 4- or more axle single unit trucks.
- 3-, 4-, 5-, 6-, and 7- or more axle tractor-semitrailer trucks with two categories of 5-axle vehicles, one with standard tandem axles and one with split tandem axles.
- 3-, 4-, 5-, and 6- or more axle truck-trailer combinations.
- 5-, 6-, 7-, and 8- or more axle twin trailer/semitrailer combinations.
- Triple trailer combinations.
- Buses.

TABLE A1 Vehicle Class Categories

VC	Acronym	Description
1	AUTO	Automobiles and Motorcycles
2	LT4	Light trucks with 2-axles and 4 tires (Pickup Trucks, Vans, Minivans, etc.)
3	SU2	Single unit, 2-axle, 6 tire trucks (includes SU2 pulling a utility trailer)
4	SU3	Single unit, 3-axle trucks (includes SU3 pulling a utility trailer)
5	SU4+	Single unit trucks with 4- or more axles (includes SU4+ pulling a utility trailer)
6	CS3	Tractor-semitrailer combinations with 3-axles
7	CS4	Tractor-semitrailer combinations with 4-axles
8	CS5T	Tractor-semitrailer combinations with 5-axles, two rear tandem axles
9	CS5S	Tractor-semitrailer combinations with 5-axles, two split (>8 feet) rear axles
10	CS6	Tractor-semitrailer combinations with 6-axles
11	CS7+	Tractor-semitrailer combinations with 7- or more axles
12	CT34	Truck-trailers combinations with 3- or 4-axles
13	CT5	Truck-trailers combinations with 5-axles
14	CT6+	Truck-trailers combinations with 6- or more axles
15	DS5	Tractor-double semitrailer combinations with 5-axles
16	DS6	Tractor-double semitrailer combinations with 6-axles
17	DS7	Tractor-double semitrailer combinations with 7-axles
18	DS8+	Tractor-double semitrailer combinations with 8- or more axles
19	TRPL	Tractor-triple semitrailer or truck-double semitrailer combinations
20	BUS	Buses (all types)

TABLE A2 Vehicle Classes by Weight (in 10,000 Pound Increments)

VC	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Auto	X														
LT4	X	X													
SU2	X	X	X	X	X	X									
SU3		X	X	X	X	X	X	X							
SU4+			X	X	X	X	X	X	X	X					
CS3		X	X	X	X	X	X	X							
CS4			X	X	X	X	X	X	X						
CS5T					X	X	X	X	X	X	X				
CS5S					X	X	X	X	X	X	X				
CS6					X	X	X	X	X	X	X	X	X		
CS7+								X	X	X	X	X	X	X	
CT3,4	X	X	X	X	X	X	X	X	X						
CT5			X	X	X	X	X	X	X	X	X				
CT6+					X	X	X	X	X	X	X	X	X	X	
DS5						X	X	X	X	X	X				
DS6							X	X	X	X	X	X	X		
DS7							X	X	X	X	X	X	X	X	X
DS8+								X	X	X	X	X	X	X	X
TRPL							X	X	X		X	X	X		X
BUS		X	X	X	X										

The SCAG HDT model represents heavy-duty trucks only, that is, trucks that are over 8,500 pounds. The primary use of this model is for air quality purposes and so it uses the weight-based classification system. These are:

• Light-heavy (8,500 to 14,000 pounds).

• Medium-heavy (14,000 to 33,000 pounds).

• Heavy-heavy (greater than 33,000 pounds).

The PSRC truck model also classifies trucks based on weight but these categories also are loosely correlated to other defining characteristics of trucks for other purposes. These are:

• **Light Trucks –** Four or more tires, two axles, and less than 16,000 pounds (this also includes nonpersonal use of cars and vans);

• **Medium Trucks –** Single unit, six or more tires, two to four axles and 16,000 to 52,000 pounds; and

• **Heavy Trucks –** Double or triple unit, combinations, five or more axles, and greater than 52,000 pounds.

The San Joaquin Valley truck model in central California is designed to generate truck volumes based on truck classes that the California Air Resources Board defines asmedium-heavy and heavy-heavy duty for regulatory purposes (more than 14,000 pounds gross vehicle weight rating). These are:

• **Medium-Heavy Duty Trucks –** GVW rating between 14,001 and 33,000 pounds; and

• **Heavy-Heavy Duty Trucks –** GVW rating of 33,001 pounds and more. Where GVW is the gross vehicle weight.

The current Maricopa Association of Governments (MAG) truck model is based on GVW as well that includes three classes – light (less than 8,000 pounds), medium (8,000 to 28,000pounds), and heavy (greater than 28,000 pounds). As the vehicle classification counts are based on FHWA classes, and due to the difficulty in correlating the GVW classes to FHWA classes, the new MAG truck model will include three groups of trucks. These are based on the FHWA classification system, as shown below:

• Class 3 – 2-axle, 4-tire commercial vehicles (“Light”);

• Classes 5-7 – 3+ axle, 6+ tire, single unit commercial vehicles (“Medium”); and

• Classes 8-13 – 3+ axle, 6+ tire, combination unit commercial vehicles (“Heavy”).

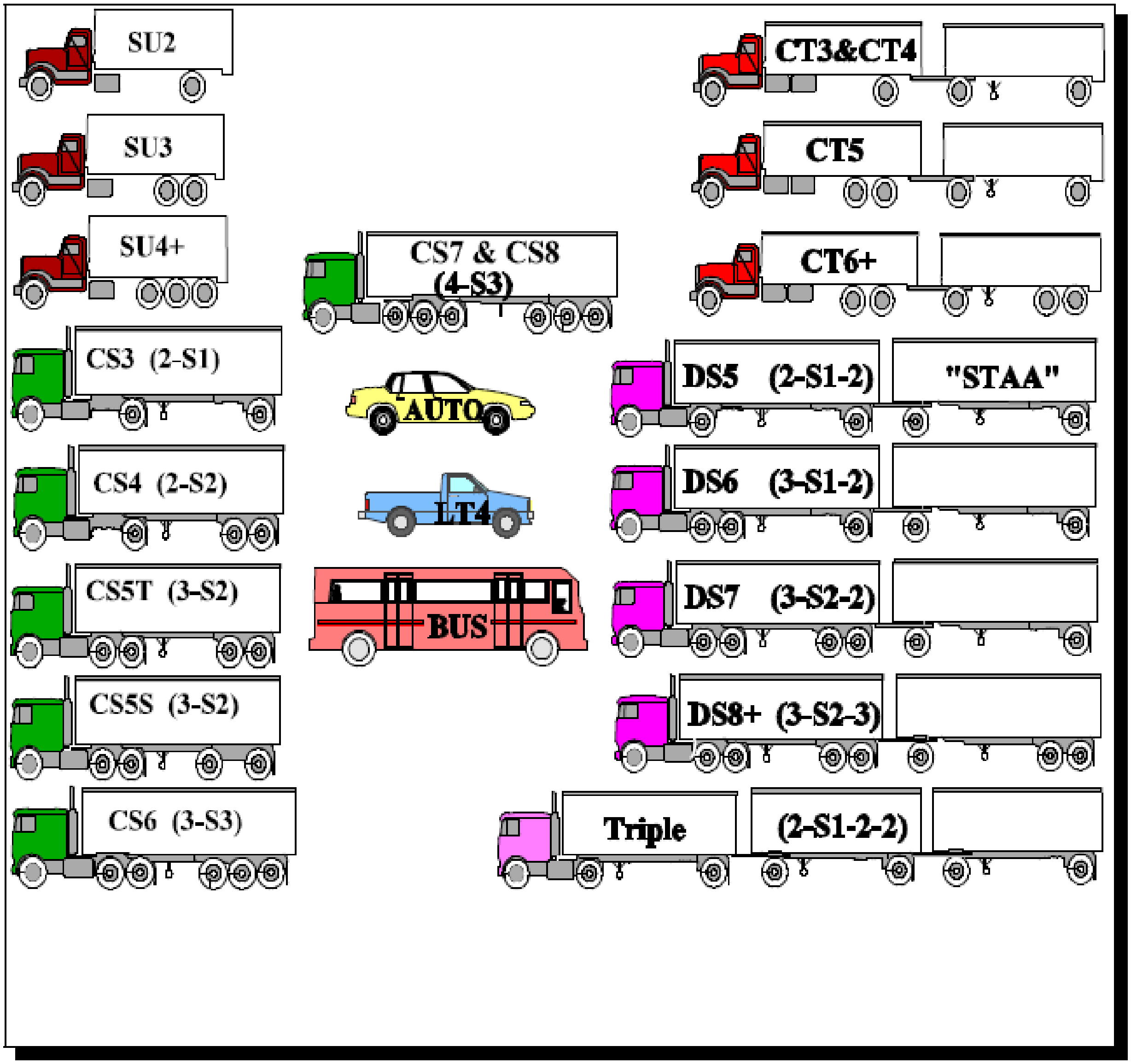

FIGURE A1 Vehicle Classes

Table A3 Indiana Truck Registration Fees

Truck Registration Transactions (By declared gross weight)	Full Fees	Half Fees
Truck: 7,000 pounds or less • **Valid for one year.** • **May bear special recognition and personalized license plates.**	$30.05	Not available
Truck: 7,001 to 9,000 pounds • **Valid for one year.** • **May bear special recognition and personalized license plates.**	$50.05	Not available
Truck: 9,001 to 10,000 pounds • **Valid for one year.** • **May bear special recognition and personalized license plates.**	$80.05	Not available
Truck: 10,001 to 11,000 pounds • **Valid for one year.** • **May bear special recognition and personalized license plates.**	$84.75	Not available
Truck: 11,001 to 16,000 pounds • **Valid for one year.**	$144.75	$75.25
Truck: 16,001 to 20,000 pounds • **Valid for one year.**	$184.75	$95.25
Truck: 20,001 to 23,000 pounds • **Valid for one year.**	$244.75	$125.25
Truck: 23,001 to 26,000 pounds • **Valid for one year.**	$244.75	$125.25
Truck: 26,001 to 30,000 pounds • **Valid for one year.**	$304.75	$155.25
Truck: 30,001 to 36,000 pounds • **Valid for one year.**	$422.75	$214.25
Truck: 36,001 to 42,000 pounds • **Valid for one year.**	$515.75	$260.75
Truck: 42,001 to 48,000 pounds • **Valid for one year.**	$636.75	$321.25
Truck: 48,001 to 54,000 pounds • **Valid for one year.**	$739.75	$372.75
Truck: 54,001 to 60,000 pounds • **Valid for one year.**	$819.75	$412.75

Table A3 Indiana Truck Registration Fees (continuation)

Truck Registration Transactions (By declared gross weight)	Full Fees	Half Fees
Truck: 60,001 to 66,000 pounds • **Valid for one year.**	$867.75	$436.75
Truck: 66,001 pounds or more • **Valid for one year.**	$965.75	$485.75
Other Truck Registration Transactions	Full Fees	Half Fees
Replaced registration • **To replace a lost, stolen, or destroyed registration.** • **Valid until next renewal date.**	$6	Not available
Amended registration • **To change the registration holder's name, address, or personal information.** • **Valid until next renewal date.**	$6	Not available
Replaced license plate or sticker • **To replace a lost, stolen, or destroyed plate or sticker.** • **Valid until next renewal date.**	$10	Not available
License plate transfer • **To transfer a plate from one vehicle to another vehicle.** • **Valid until next renewal date.**	$10.75	Not available

Appendix B: Milwaukee Approximation for Heavy Truck Fuel Consumption

There is no clear relationship between fuel consumption and heavy trucks' driving speeds. The available theoretical relations are valid for specific technologies and some of them became obsolete due to new technologies. Some theoretical relations have congruent results with practical data for specific ranges of driving speeds. However, applying these relations beyond these specific ranges leads to an obvious contradiction with practical data. On the other hand, we should know that the practical relations depend on the truck type, model, and technology and don't rely on equations.

There are many factors affecting the relationship between truck fuel consumption and driving speed, like the proficiency of truck driver and terrain. All of the above make it hard to come up with reliable correlation between truck fuel consumption and speed. This approximation combines the most updated theoretical and practical relations. The approximation is made up of discontinuous equations relating to truck fuel consumption (mpg) to driving speeds (mph).

Running a truck requires energy to overcome the aero drag force and tire rolling resistance force. The total force can be expressed as in equation 1

$$F = A + Bv + Cv^2 \text{ ....(1).}$$

Giannelli in his paper "Heavy-duty diesel vehicle fuel consumption modeling based on road load and power train parameters" updated the A,B and C coefficients and redefined them as in tableB1.

TABLE B1 A, B, and C Road Load Parameters Developed From Petrushov.

Vehicle classification	A (kW*s/m)	B ($kW*s^2/m^2$)	C ($kW*s^3/m^3$)
8500 to 14000 lbs (3.855 to 6.350 tonne)	$\frac{0.0996M}{2204.6}$	0	$1.47 + \frac{5.22\ X\ 10^{-5}M}{2205}$
14000 to 33000 lbs (6.350 to 14.968 tonne)	$\frac{0.0875M}{2204.6}$	0	$1.93 + \frac{5.90\ X\ 10^{-5}M}{2205}$
>33000 lbs (>14.968 tonne)	$\frac{0.0661M}{2204.6}$	0	$2.89 + \frac{4.21\ X\ 10^{-5}M}{2205}$
Buses	$\frac{0.0643M}{2204.6}$	0	$3.22 + \frac{5.06X\ 10^{-5}M}{2205}$

Where:

$$A = C_{R0} Mg$$

B=0

$$C = \frac{C_D A_f \rho_{air}}{2} + C_{R2} Mg$$

Most of the data resources emphasize 55 mph as the most efficient speed that can give the higher mpg. This approximation considers equation 1 for 55 mph speed and above.

Equation1 is divided and multiplied by many factors to convert it from Newton to MPG, this includes the truck engine losses. Equation 2 shows the relation between MPG and speed mph for speeds more than or equal 55 mph.

$$MPG = 1 / [(1.53*10^{-6}*M) + (2.94*10^{-5}+1.94*10^{-13}*M)*V^2]\text{…………}(2)$$

Where M is the total truck mass in lb, and V is Truck driving speed in mph.

For speed less than 55 mph, this approximation uses truck's fuel consumption equation mentioned in Papacostas's textbook (Transportation and Engineering Planning,2000). This relation considers 1970's trucks' technologies and it is valid for speed less than 35 mph. This approximation assumes the speed range (35-54) is more related to this equation rather than equation 1 mentioned above. Papacosta's equation for tracks is shown in equation 3.

$$MPG = [1/(0.17 +(2.43/V))]\text{………}(3)$$

Where, V is the speed in mile per hour.

To update equation 3, the data given in Factors Affecting Fuel Economy paper (Good year, 2003) had been used. From this paper the most efficient fuel consumption speed is 55 mph and it will be the reference speed in our working paper. Table B2 shows % differences in MPG for different speeds.

TABLE B2 % Difference in MPG For Different Speeds (55 mph is the reference speed)

speed	% Difference
35	18
40	16
45	13
50	8
55	0

We know from equation 1 for an empty truck (33,000 lb) the MPG is 7.17, the estimated MPGs for different speeds as in table B3.

TABLE B3 Estimated MPG For Different Speeds

Speed	% Difference	Estimated MPG
35	18	5.88
40	16	6.02
45	13	6.24
50	8	6.60
55	0	7.17

By using equation 3 the MPG for the speeds from 35-50 has been found as in table B4.

TABLE B4 Estimated MPG By Using Equation 3

Speed	MPG (Equation 3)
35	4.18
40	4.33
45	4.46
50	4.57

A correction factor had been calculated to update equation 3, this correction factor found by calculating the difference in MPG for different speeds as shown on table 3 and 4. Table B5 shows the correction factor.

TABLE B5 Correction Factors

Speed	MPG (Equation3)	MPG (Good Year)	Diff	Correction Factor
35	4.18	5.88	0.41	1.41
40	4.33	6.02	0.39	
45	4.46	6.24	0.40	
50	4.57	6.60	0.44	

To update equation 3 for speed ≤ 54mph, we could multiply that equation by the correction factor which is 1.41. But to make the relation more practical and smoother we multiply the equation by 1.536. The Milwaukee approximation for heavy truck fuel consumption is as follows:

$$TFC_{mpg} = \begin{cases} \sum_{i=5}^{15} Wsli55 \left(\frac{33{,}000}{M}\right)\left[\frac{1.536}{0.17 + \left(\frac{2.43}{V}\right)}\right] & (\text{speed} < 55\text{mph}) \\ + & \\ \sum_{i=0}^{4} Wsmi55 \left[\frac{1}{[(1.53 * 10^{-6} * M) + (2.94 * 10^{-5} + 1.94 * 10^{-13} * M) * V^2]}\right] & (\text{speed} \geq 55 \text{ mph}) \end{cases}$$

TFC$_{mpg}$: Truck fuel consumption (mileage per gallon)
The total truck fuel consumption (mpg) for a shipping trip is as below:

$$TFC = \begin{cases} \sum_{i=5}^{15} Wsli55 * \text{Dist}(\text{Xis} - \text{Xif}) / \left[\left(\frac{33{,}000}{M}\right) \left[\frac{1.536}{0.17 + \left(\frac{2.43}{V}\right)}\right] \right] & (\text{speed} < 55\text{mph}) \\ + & \\ \sum_{i=0}^{4} Wsmi55 * \text{Dist}(\text{Xis} - \text{Xif}) / \left[\frac{1}{[(1.53 * 10^{-6} * M) + (2.94 * 10^{-5} + 1.94 * 10^{-13} * M) * V^2]} \right] & (\text{speed} \geq 55 \text{ mph}) \end{cases}$$

Where,

TFC: Truck fuel consumption (gallon).

M: Total truck and trailer Mass (lb)

V: Driving speed (mi/hr)

$W_{sli55:}$ The probability of driving at speed class i, while i more than 4 (less than 55 mph).

W_{smi55}: The probability of driving at speed class i, while i less than or equal 4 (more 55 mph).

Dist (X_{is}-X_{if}): The distance traveled by speed class i, which starts by speed more than X_{is} and end by speed equal or less X_{ie}

According to the available data of the relation between speed and distance traveled from heavy truck duty cycle project, W_{sl55} = 0.124, and W_{sm55} = 0.876.The relation between speed (mph) and distance traveled follows Poisson distribution with mean = 2.61.

The relation between speed (mph) and travelled distance (mile) published in Transportation Energy Data Book, edition 28-2009 as a part of vehicle Duty Cycle Project, are used to find the probability of each driving speed class more, less, and equal 55 mph. Vehicle Duty Cycle Project data are summarized in table B6, the four main columns of this table are organized by the type of tires that were mounted on the tractor and trailers, speed classes are divided into 5-mile intervals, going from0 + mph (i.e., speed > 0.00 mph) to 80 mph.

TABLE B6 Fuel Economy for Class 8 Trucks as Function of Speed and Tractor-Trailer Tire Combination

	Dual Tire Tractor -			**Dual Tire Tractor -**			**Single (Wide) Tire Tractor -**			**Single (Wide) Tire Tractor -**			**Average Distance Traveled (miles)**
	Dual Tire Trailer			Single (Wide) Tire Trailer			Dual Tire Trailer			Single (Wide) Tire Trailer			
Speed (mph)	Distance Traveled (miles)	Fuel Cons. (gal)	Fuel Econ. (MPG)	Distance Traveled (miles)	(miles) Cons. (gal)	Fuel Econ. (MPG)	Distance Traveled (miles)	Fuel Cons. (gal)	Fuel Econ. (MPG)	Distance Traveled (miles)	Fuel Cons. (gal)	Fuel Econ. (MPG)	
Idling	N/A	1,858.5	N/A	N/A	967.9	N/A	N/A	1,676.4	N/A	N/A	706.0	N/A	N/A
0+ to 5	281	101.8	2.76	148	50.4	2.93	368.0	124.2	3.0	156	52.8	2.96	238.25
5+ to 10	674	198.8	3.39	368	103.2	3.56	808.0	245.4	3.3	331	98.8	3.35	545.25
10+ to 15	723	192.0	3.77	396	98.3	4.03	848.0	216.5	3.9	343	87.0	3.95	577.5
15+ to 20	744	199.1	3.73	404	100.9	4.00	882.0	221.6	4.0	361	90.5	3.98	597.75
20+ to 25	938	228.4	4.11	489	113.6	4.31	1,111.0	244.2	4.6	462	101.1	4.57	750
25+ to 30	1,178	266.9	4.41	609	131.5	4.63	1,420.0	286.9	5.0	580	117.6	4.93	946.75
30+ to 35	1,481	336.8	4.40	753	154.2	4.88	1,774.0	341.1	5.2	708	141.1	5.02	1179
35+ to 40	1,917	403.5	4.75	1,000	193.6	5.17	2,284.0	433.6	5.3	941	184.3	5.10	1535.5
40+ to 45	2,955	584.1	5.06	1,543	285.9	5.40	3,380.0	603.6	5.6	1,350	254.4	5.31	2307
45+ to 50	4,935	907.9	5.43	2,573	447.7	5.75	5,410.0	872.8	6.2	2,177	360.4	6.04	3773.75
50+ to 55	9,397	1,629.8	5.77	4,962	811.5	6.11	10,046.0	1,622.7	6.2	3,877	625.5	6.20	7070.5
55+ to 60	20,656	3,297.2	6.26	11,707	1,721.9	6.80	22,373.0	3,257.8	6.9	8,710	1,246.9	6.99	15861.5
60+ to 65	38,964	5,879.6	6.63	21,472	2,980.8	7.20	34,517.0	4,840.0	7.1	14,944	2,049.4	7.29	27474.25
65+ to 70	58,304	8,313.2	7.01	27,931	3,652.2	7.65	65,063.0	9,256.4	7.0	27,144	3,880.1	7.00	44610.5
70+ to 75	56,378	7,483.2	7.53	21,751	2,745.5	7.92	66,882.0	8,435.6	7.9	32,887	4,056.1	8.11	44474.5
75+ to 80	7,849	808.2	9.71	3,610	403.2	8.95	11,513.0	911.1	12.6	6,817	512.2	13.31	7447.25
Total[a]	207,374	30,831.0	6.73	99,714	13,994.0	7.13	228,680.0	31,913.0	7.2	101,790	13,858.0	7.35	159389.5

The relation between speed classes and each truck distance traveled, and average distance for all truck types are shown in figure B 1 and B 2. Where DD : Dual tire tractor - Dual tire trailer, DS: Dual tire tractor – Single tire trailer, SD: Single tire tractor – Dual tire trailer, and SS: Single tire tractor – Single tire trailer.

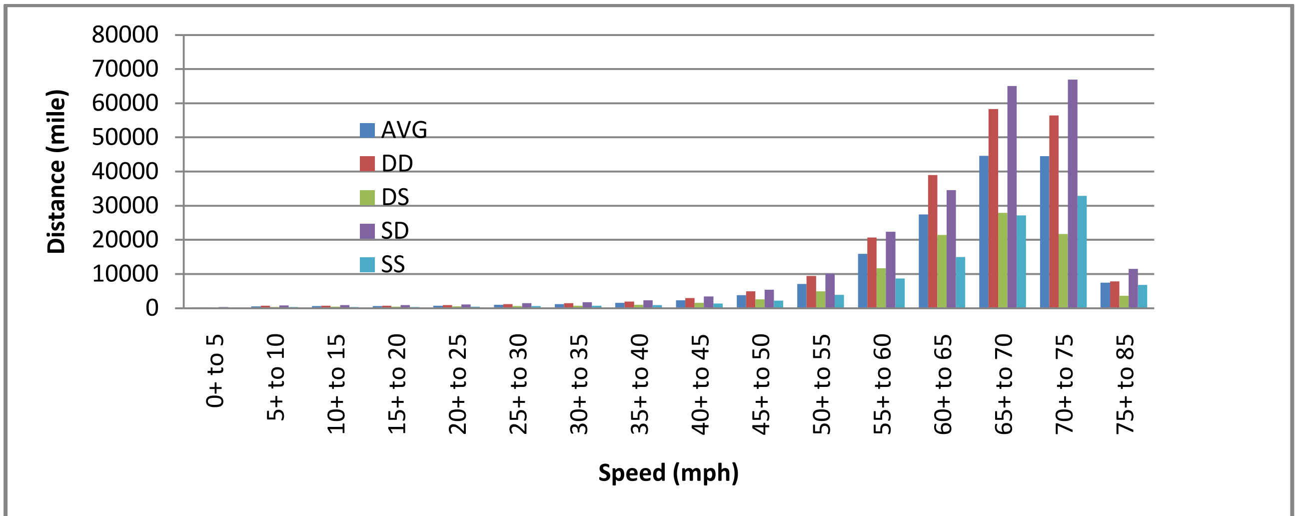

FIGURE B1 The relation between traveled distance (miles) and speed (mph), for all trucks types, as in table B6.

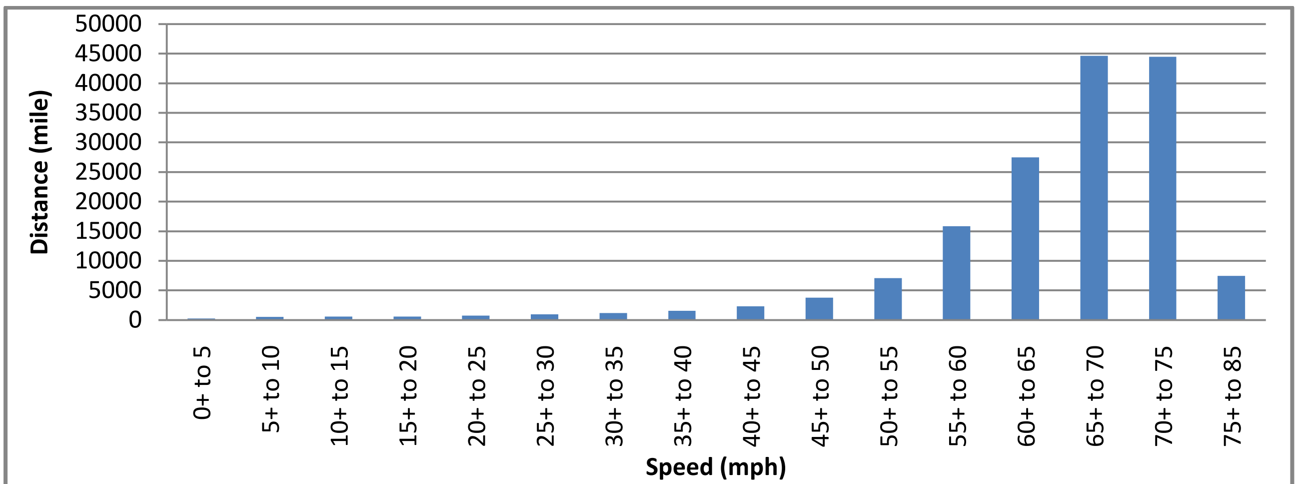

FIGURE B2 The relation between average traveled distance (miles) for all trucks types and speed (mph), as in table B6.

The figure B1 and B2, show that the relation between traveled distance and speed has the same behavior of reverse Poisson distribution and reverse gamma distribution. Gamma and Poisson distributions are candidates to represent the available data of speed and traveled distance. Testing for goodness of fit is used to find out the appropriate distribution that represents the available data. Using a small number of data points leads to no candidates may be rejected, while all candidates may not be rejected for a large number of data points.

Each mile in these data represents one observation for statistic test purposes, from data in table B6, it is obvious that these tables have a large number of data points which causes the rejection of all the distribution candidates. Comparing the histogram of the data points with the shape of the candidate distributions' density functions are valid for large sample sizes. (Reverse) gamma and Poisson distribution have the same shape as in the data we have. The Poisson distribution has been selected to represent the data of traveled distance and speed. This distribution was selected because the available data for truck driving speeds in term of travelled distances can be represented as a discrete distribution, and the gamma distribution can be defined as a cumulative Poisson distribution.

Table B7 shows Poisson calculations for the available data, the classes are arranged in descending order to avoid the difficulties in calculating reverse Poisson distribution, each speed class had given a Poisson number from 0-15, speed class 75+-80 has a (0) Poisson number value. Column 6 includes the observations, which is a truncated traveled distance to two digits. The mean speed of this data is 64.33 mph with Poisson number equal 2.61. This model fuel consumption formula is divided into two parts, less than 55 mph and more than and equal to 55 mph. 55 mph has Poisson No. equal 4.5. Figures B3 shows the Poisson distribution for all truck types. Figure B4 shows the Poisson distribution for the average data of all trucks.

TABLE B7 Poisson Distribution For Table B6 Data.

Class Order	Poisson No. (Class No.)	Speed Class	mid-class	Traveled Dist (mile)	Trun. Obs.	Avg. Speed	Prob	Cum Prob	1- Cum Prob
16	0	75+ to 80	77.5	7447.3	**74**	**5735**	0.074	0.074	0.926
15	1	70+ to 75	72.5	44474.5	**445**	**32262.5**	0.192	0.265	0.735
14	2	65+ to 70	67.5	44610.5	**446**	**30105**	0.250	0.516	0.484
13	3	60+ to 65	62.5	27474.3	**275**	**17187.5**	0.218	0.734	0.266
12	4	55+ to 60	57.5	15861.5	**159**	**9142.5**	0.142	0.876	0.124
11	5	50+ to 55	52.5	7070.5	**71**	**3727.5**	0.074	0.950	0.050
10	6	5+ to 10	47.5	3773.8	**38**	**1805**	0.032	0.983	0.017
9	7	45+ to 50	42.5	2307	**23**	**977.5**	0.012	0.995	0.005
8	8	40+ to 45	37.5	1535.5	**15**	**562.5**	0.004	0.998	0.002
7	9	35+ to 40	32.5	1179	**12**	**390**	0.001	1.000	0.000
6	10	30+ to 35	27.5	946.8	**9**	**247.5**	0.000	1.000	0.000
5	11	25+ to 30	22.5	750	**8**	**180**	0.000	1.000	0.000
4	12	20+ to 25	17.5	597.8	**6**	**105**	0.000	1.000	0.000
3	13	15+ to 20	12.5	577.5	**6**	**75**	0.000	1.000	0.000
2	14	10+ to 15	7.5	545.3	**5**	**37.5**	0.000	1.000	0.000
1	15	0+ to 5	2.5	238.3	**2**	**5**	0.000	1.000	0.000
			Total	159389.6	**1594**	**102545**	1		
					Average	**64.33**			

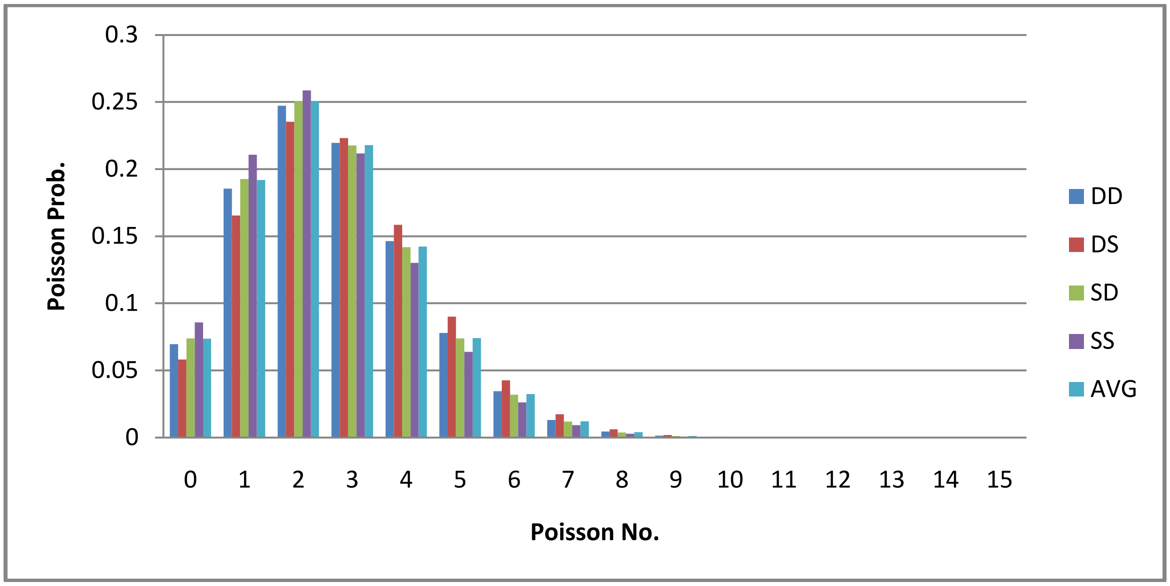

FIGURE B3 Poisson distribution for the data in table B6.

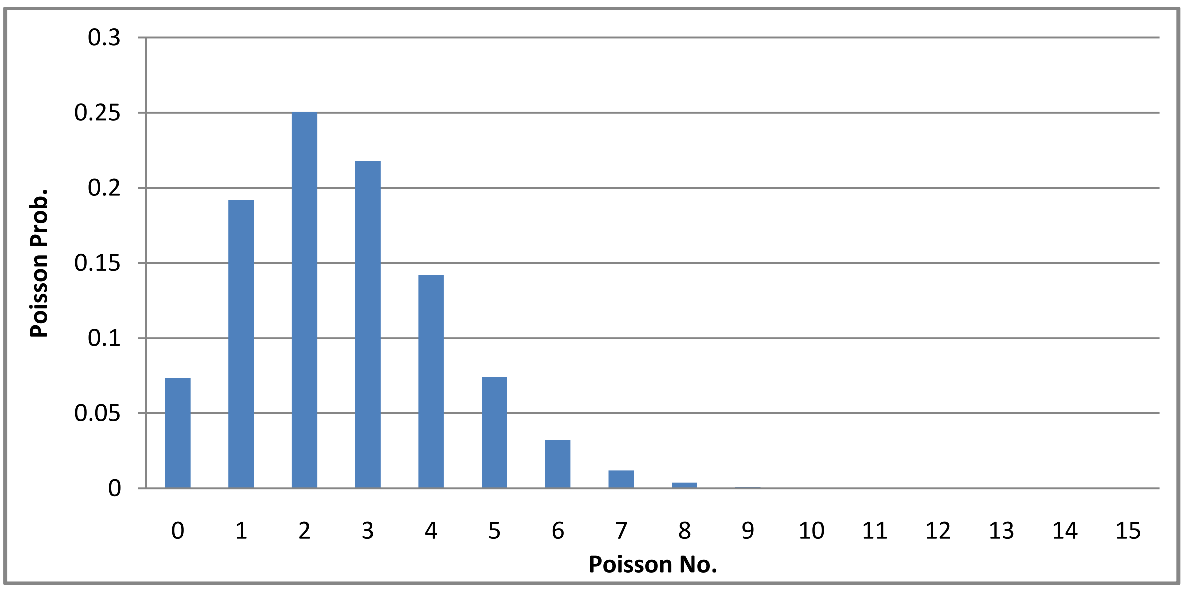

FIGURE B4 Poisson distribution for average traveled distance for all trucks in table B6, while average speed is 64.33 mph and 2.61 Poisson No.

The flow chart in figure B5 shows the required data, calculation, and procedure of total shipping trip fuel consumption.

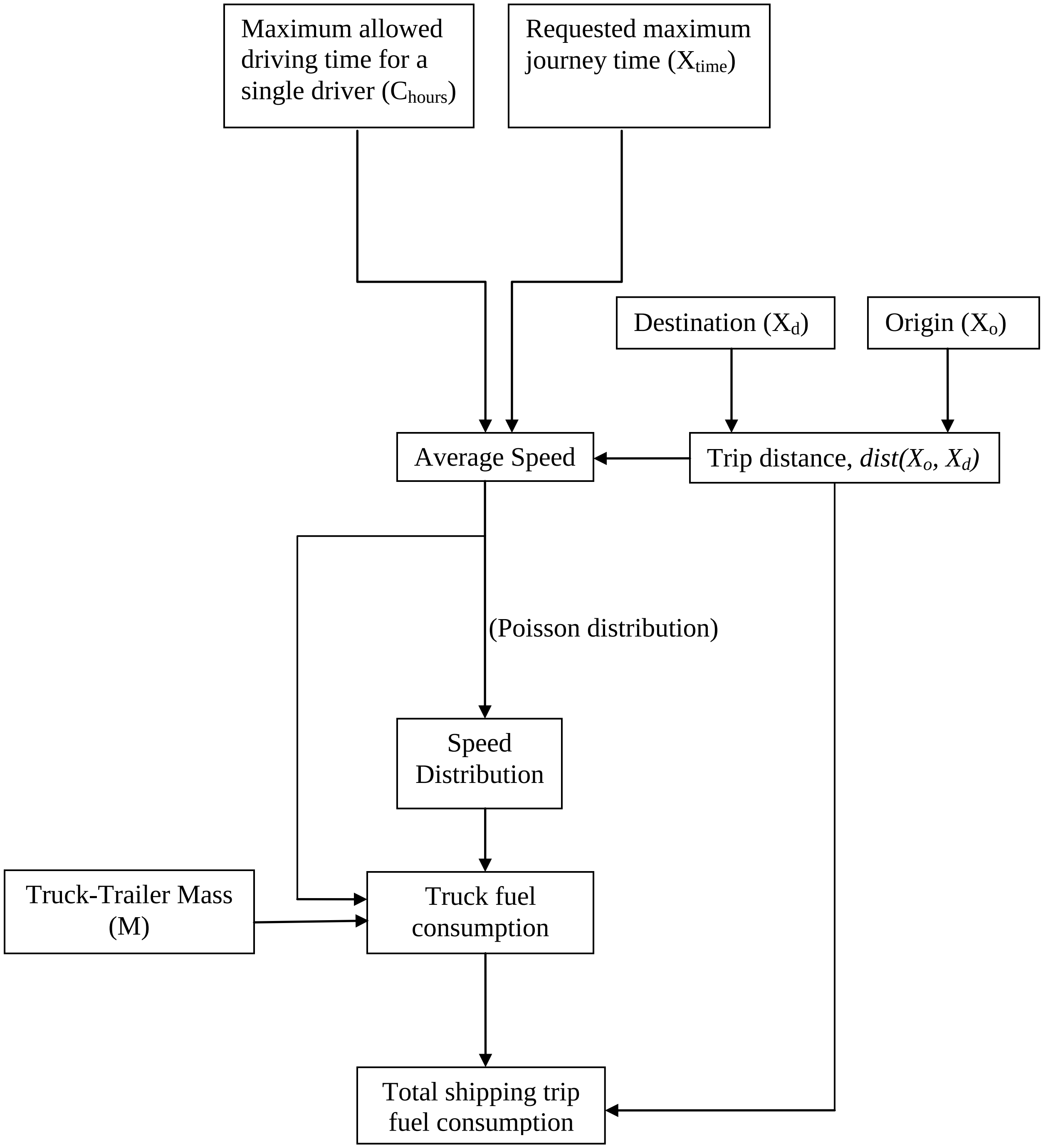

FIGURE B5 Flow chart of required data and procedure for calculating total trip fuel consumption (for traveling purposes only).

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