Optimization of Freight Truck Driver Scheduling Based on Operation Cost Model for Less-than-Truckload (LTL) Transportation

by

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B.Eng, Dalian Jiaotong University, 1993

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Supervisory Committee

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Abstract

Drivers are essential factors affecting the efficiency and management level of a carrier. In this thesis, the driver assignment problem is investigated and methods for obtaining lower total operational costs are introduced for small and medium-sized truck freight transportation companies. Three interrelated research topics, including the following, have been systematically studied.

Firstly, extending the traditional costing and Activity-Based Costing (ABC) method, the new Time-Driven Activity-Based Costing (TDABC) method, TDABC-FTC, has been introduced for truck freight companies. Detailed implementation process flow has been designed to streamline the easy incorporation of overhead cost.

Fuel costs hold about one-third of the total operational costs of truck freight transportation, and drivers' driving behaviors heavily influence the fuel consumption rate. In this work, the On-Board Diagnostics (OBD) II, GPS tracker and Controller Area Network (CAN) bus are used to retrieve related truck operation data and transfer these data to a central database for later processing to obtain driving behavior parameters. An artificial neural network (ANN) model, built using MATLAB toolbox, is introduced to capture the relations between driving behavior and fuel consumption rate. The fuel consumption indicators for different drivers are then developed to reflect their relative fuel consumption rate quantitatively.

The driver assignment problem is modeled as an optimization problem for minimizing the total operational cost of the truck, and the NP-hard problem is solved as a mixed integer programming problem. Two solution methods, Branch and Bound, and the Hungarian algorithm, are used to solve the formulated driver assignment problem. The Hungarian algorithm has been modified to address two particular situations in the driver assignment problem.

Numerical experiments are conducted to validate the effectiveness of the newly introduced TDABC model, the fuel saving oriented optimal driver assignment method associating driver behavior to truck fuel consumption rate for different transportation tasks, and the solution methods for the special optimization problems formulated in this work. The newly introduced methods were tested using real truck fleet data, showing considerable benefit

of the optimal scheduling techniques, and forming the foundation for further research in this area.

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Nomenclature

ABC	Activity-Based Costing
ADAS	Advanced Driving Assistance Systems
ANNs	Artificial Neural Networks
B&B	Branch and Bound
CAGR	Compound Annual Growth Rate
CAN-bus	Controller Area Network
DTC	Diagnostic Trouble Code
ELD	Electronic Logging Devices
ECU	Engine Control Unit
GAP	Generalized Assignment Problem
GDP	Gross Domestic Product
GPS	Global Positioning System
HOS	Hours-of-Services
HMM	Hidden Markov Method
LTL	Less-than-Truckload or Less-Than-Load.
MSE	Mean Squared Error
NAFTA	North American Free Trade Agreement
OBD	On-Board Diagnostics
OBD II	An improvement over OBD in both capability and standardization
SVM	Support Vector Machine
TDABC	Time-Driven Activity-Based Costing
TDABC-FTC	Time-Driven Activity-Based Costing – Freight Transportation Company
TL	Truck-Loaded
TOC	Theory Of Constraints
VSP	Vehicle Specific Power
3PL	Third-party Logistics

Chapter 1 Introduction

1.1 Research problem and background

1.1.1 Freight transportation industry in North America

The fast-expanding world economy offers incredible opportunities for Canadian entrepreneurs to position themselves for growth and take advantage of the momentum of economic development. In 2017, Canada had substantial economic growth of 3.1%, and goods exports were up 8.7% year over year [1]. Such high growth has come from economic activities of Canada.

With the growth of the gross domestic product (GDP) in recent years, the road freight transportation market is anticipated to increase at a steady rate and will generate a compound annual growth rate (CAGR) of close to 4% during the forecast period in whole North America. The increasing growth in the automotive and auto components industry is the primary driving factor of road freight transportation market in North America until the end of 2021 because road freight transportation mode is the primary method for automotive and components manufacturing companies in North America [2]. The increasing use of alternative fuels is another influence on the road freight transportation market since oil consumption costs occupy about one-third of the total operational costs in road freight transportation.

As the second-largest country geographically in the world, with a population stretched from coast to coast, Canada has unique transportation challenges. Consequently, the transportation industry remains a significant force in the Canadian economy, occupying 4.7% of GDP [3]. In 2010, transportation and warehousing GDP advanced 4.3%, ahead of the 3.3% growth posted by the whole economy. Truck transportation, the largest component of transportation GDP, contributed $17.1 billion and represented 29.3% of the overall transportation and warehousing GDP [4]. Medium and heavy-duty truck transportation industry plays an important role in the Canadian economy, which exists in many fields, such as creating employment, affecting land use and real estate prices, and influencing commercial activities. According to the Canadian Trucking Alliance (2012), trucking is a $65 billion industry. It employs more than 260,000 drivers and nearly 400,000 Canadians overall [5].

The main categories of all modes of transportation include freight movements by truck, rail, vessel, pipeline, and air. The data from the Bureau of Transportation Statistics show that trucks carried 65.6% of U.S.-NAFTA freight, and continued to be the most heavily utilized mode for moving goods to and from both U.S. and NAFTA countries. From 2015 to 2016, trucks carried 60.1% of the value of the freight to and from Canada, which created a 1.3% increase from 2006 [6]. Figure 1 shows the shares of various modes of freight transportation between Canada and USA in 2016 with the largest number from truck transportation at $700 billion.

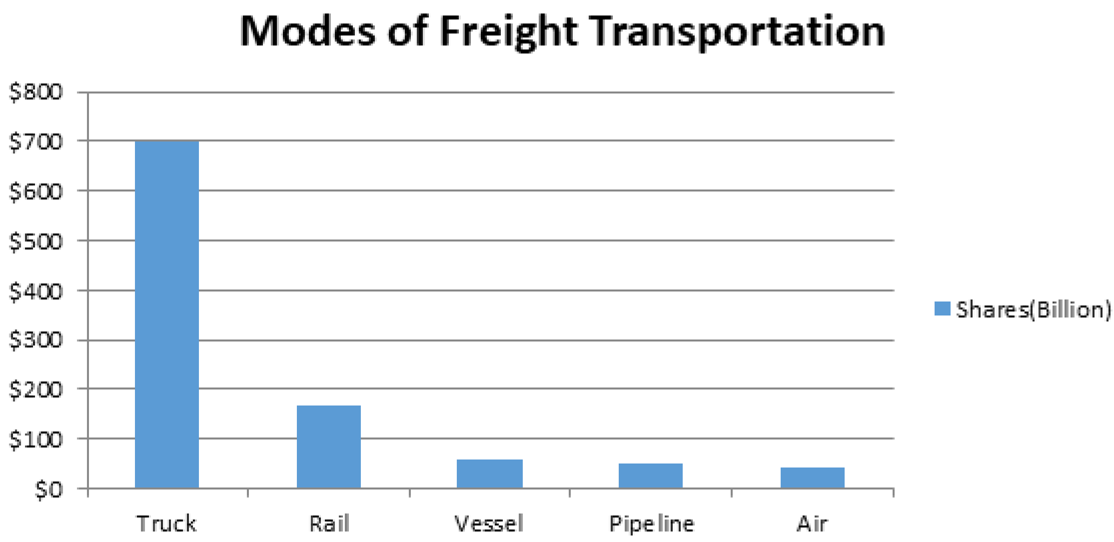


Figure 1: Shares of Freight Transportation Modes between Canada-U.S. in 2016

Thus, truck freight transportation sector plays a critical part in Canada's economy. A series of research topics associated with truck freight transportation became a focus of academic and industrial fields, such as costing method and transportation scheduling in truck freight transportation.

1.1.2 Main challenges faced by truck freight transportation industries

Rapidly the freight transportation industry of today is evolving accompanied by the development of new technologies: big data, pattern recognition, optimization, and Artificial Intelligence, making improvements of freight transportation efficiency more viable.

(1) Fierce competition

With the contraction of the national economy in Canada, the number of freight transportation transactions shows a reduction. However, there are still a large number of carriers in North America competing for a smaller share of the freight transportation market. Such a situation brings out the fierce competition.

(2) Increasing operation costs

In recent years, though the price of fuel shows a rapid change and some time has a significant reduction, fuel cost is still a big challenge for most small and medium-sized truck transportation companies, with 39% of the total operational cost [7]. Apart from fuel cost, workforce cost occupied the second largest share of the total operational cost, about 25% in truck freight transportation industries. Safety issues also increase operational cost in truck transportation. Table 1 presents the average marginal cost per mile from 2008 through 2015 [8]. From Figure 2, it is evident that the total average marginal costs per mile showed an upward trend from 2008 to 2015 though there are significant fluctuations in some years.

Table 1: AVERAGE MARGINAL COST PER MILE FOR U.S. (2008-2015)

Average Marginal Costs per Mile($), 2008-2015									
Motor Carrier Costs		2008	2009	2010	2011	2012	2013	2014	2015
Vehicle-based									
	Fuel & Oil Cost	0.633	0.405	0.486	0.59	0.641	0.645	0.583	0.403
	Truck/Trailer Lease or Purchase Payments	0.213	0.257	0.184	0.189	0.174	0.163	0.215	0.23
	Repair& Maintenance	0.103	0.123	0.124	0.152	0.138	0.148	0.158	0.156
	Truck Insurance Premiums	0.055	0.054	0.059	0.067	0.063	0.064	0.071	0.092
	Permit and Licenses	0.016	0.029	0.04	0.038	0.022	0.026	0.019	0.019
	Tires	0.03	0.029	0.035	0.042	0.044	0.041	0.044	0.043
	Tolls	0.024	0.024	0.012	0.017	0.019	0.019	0.023	0.02
Driver-based									
	Driver Salary	0.435	0.403	0.446	0.46	0.417	0.44	0.462	0.499
	Driver Benefits	0.144	0.128	0.162	0.151	0.116	0.129	0.129	0.131
Total		1.653	1.452	1.548	1.706	1.634	1.675	1.704	1.593

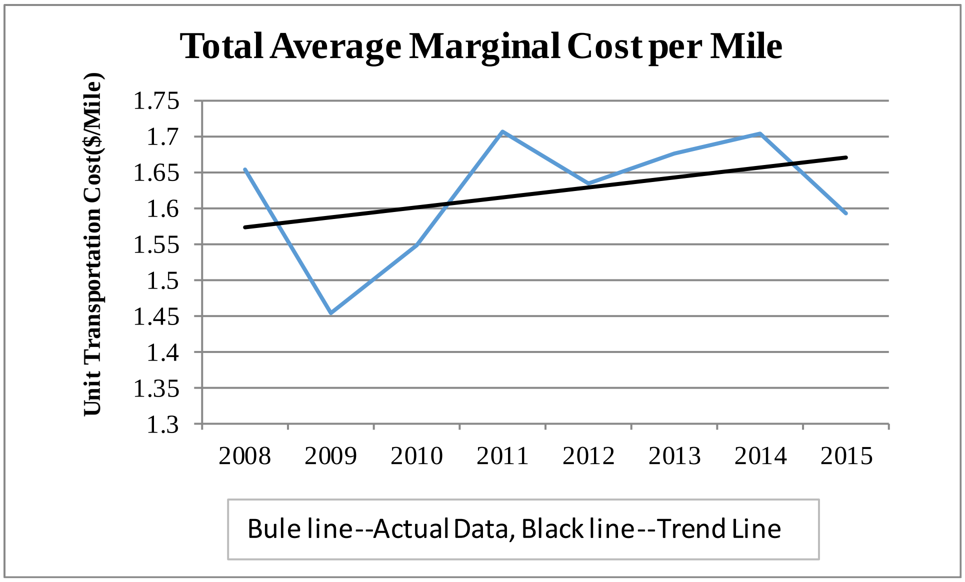


Figure 2: Total Average Marginal Cost per Mile from 2008 Through 2015

(3) Influence of new strict regulations

Safety issues are crucial to truck transportation. To reduce vehicle accidents and improve safety, all carriers have to install electronic logging devices (ELD) in their trucks to collect all operational data in real time and to report to the Transportation Management Authority. Meeting the hours-of-service (HOS) requirements for drivers is another crucial concern among freight transportation companies. In the past, drivers were subject to fewer restrictions on mandatory breaks and time off the road. Now, the newer HOS regulations mean that is difficult for a driver to move shipments as quickly as before. These new strict regulations make fleet management more difficult and increase operational costs.

(4) Low efficiency in transportation management

In truck freight transportation, a backhaul is the return trip of a commercial truck that is transporting freight back over all or part of the same route it took to get to its current location. Due to limited freight information and transportation capacity, small and medium-sized carriers in most cases cannot utilize return trips to serve other customers to offset the expense. Such a situation brings out a large number of empty return trips leading to lower efficiency and higher costs.

(5) A lack of a fleet management system

A lot of small and medium-sized carriers still use manual job dispatching up to now, just because it is suitable for their daily business needs. When volume, job complexity or unpredictability in transportation environment increases, however, manual dispatching process begins to fail [9]. For example, a sudden change in job (e.g., adding a new job or canceling a planned job) during the day is too difficult to change the dispatch by a dispatcher. With the company's growth, many additional resources, such as trucks and drivers, are required. Dispatchers cannot manage the resources and jobs effectively any longer. On average, a single dispatcher can only handle several to a dozen drivers during the day using a manual dispatching system. Generally, the job of a dispatcher in the freight transportation industry is not just to allocate loads to truck and driver. The dispatcher also needs to consider how to allocate drivers at lower costs, which is regarded as the most important job. Because the decisions made by dispatchers are not recorded in any enterprise system, the knowledge sharing only relies on human interactions between the dispatcher and the drivers. Even for a newly-hired dispatcher, it needs to take a longer time to understand the service environment thoroughly and carry out the job adequately and effectively [9].

Due to a lack of scientific dispatching method in transportation management, dispatchers in small and medium-sized carriers perform their jobs based on their experience. Therefore, manual dispatch causes serious space waste and brings higher operational costs.

1.1.3 Truck freight transportation systems

The demand for freight transportation comes from the business transaction between shippers and consignees. Shippers generate an order. Carriers supply transportation services. Considering the type of service they provide, ports, intermodal platforms, and other facilities may be described as carriers as well. The roadway network is the infrastructure for freight trucks [10].

Because there exists a significant amount of transportation transactions and complicated management processes, currently, most medium-sized carriers utilize a fleet management system to manage freight transportation. The primary functions implemented in a typical fleet management system involve resource management, vehicle tracking, job dispatching, repair and maintenance management, and reporting. Though carriers can use the system to improve service efficiency and lower management costs, the most critical process of carriers, job dispatching, depends on dispatcher experience to do manual dispatch, particularly in small and medium-sized carriers. The primary jobs of a dispatcher in small and medium-sized carriers involve assigning loads to trucks; determine transportation routes for driver and related management jobs. When the loads are in transportation, the dispatcher needs to track the truck and loads.

1.1.4 Truck fleet management practice

Many companies operate truck fleet with varying cargo transportation tasks and a group of trucker drivers with different driving skills and habits on different types of routes and cargos. In this work, a privately-held transportation company, established in Vancouver, Canada in 1987, has been selected to acquire truck operation data and for operation scheduling improvements. Since its foundation, the company has experienced steady growth through a holistic approach to the market, and provided various transportation services to meet customers' needs. The company now has 80 trucks/tractors, 100 trailers, 80 drivers and many containers to support services, including local logistics in Canada and line-haul service through Canada and the U.S.A.

In this carrier, there are only two dispatchers. They need to develop dispatch solution and to track the loads and vehicles. Due to the lack of a fleet management system supporting the dispatching position, the dispatchers have to do the job manually depending on their experience. It is very challenging and tough for dispatchers to design optimal dispatch solutions, which has a significant impact on management efficiency and operational costs.

A typical truck transportation process in the company involves several stages: generating orders, picking up loads from a shipper, loading freight, transporting, unloading, delivering to a consignee, and other administrative activities. Though different carriers may have various process flows, the common transportation process flow is summarized and presented in Figure 3 below.

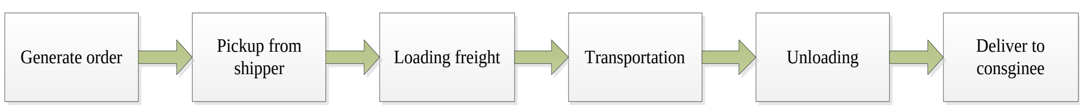


Figure 3: Truck Freight Transportation Process Flow

1.2 Operational cost based driver assignment problem and associated technologies.

1.2.1 Operation of a truck transportation system

The truck freight transportation mode is a critical mode of truck logistics in North America, and truck freight transportation occupied about two-thirds of the total transportation market share [11]. Various classification methods for the truck freight transportation processes have been proposed, according to transportation distance, including local, long-haul, and international transportation. For local transportation, the addresses of the shipper and consignee are in the same region, and transportation time is less than 5 hours. When the addresses of the shipper and consignee are in different areas, and transportation time is more than 5 hours, the transportation is considered as long-haul. When freight is transported to other countries, it is regarded as international transportation.

Another classification method is the loading option: Truck-loaded (TL) and Less-than-Truck loaded (LTL) [10]. TL is the best way to transport freight with a large shipment or a delicate shipment occupying the truck space exclusively. Thus, TL is also a significantly faster way to carry cargo and generally more expensive than LTL transportation. LTL is the most cost-effective way to transport freight. A truck will pick up freight from the shipper and combine it with other customers who are willing to share the costs of transportation. Instead of paying for a whole truck shipment, the customer will only pay for a portion of the cost. The appropriate transportation mode for freight will be based on the size of the load, the category of the shipment, budget, and the expected delivery time.

1.2.2 Cost analysis of truck freight transportation

No matter what the transportation mode is, freight costs are typically comprised of three elements: line-haul, fuel, and accessorial costs. The actual freight cost also includes components for picking-up, cross-docking, line haul transportation and delivery to the customer. Embedded in this expense are administration costs. Fuel cost is usually the second largest component in the overall transportation cost [12].

To improve freight transportation management and competition level of carriers, cost analysis is necessary. In freight transportation companies, freight cost analysis can be conducted for several purposes, including driving cost savings through freight rate negotiations and process improvements, and identifying both opportunities and the causes of potential problem areas with a particular shipping lane, carrier or product line. After cost analysis, the cost components for a specific freight can be identified and obtained.

1.2.3 Relationship between driver and fuel consumption

Among all elements in a truck freight transportation system, the driver is an influential factor. Meanwhile, the driver is also a critical component of whether the freight transportation process can be carried out at low cost and high efficiency. In the entire transportation process, the driver may adopt different driving strategies aiming at different road conditions. It is a complicated decision for the driver.

Many factors affect fuel consumption rate, including type of vehicle, road conditions, weather, drivers, etc. Finding the influence mechanism of each element is difficult. Commonly, these factors are combined to work on fuel consumption. Such topics attracted considerable interests from researchers, and many research literatures have been produced on the influences of driver's driving behaviors on fuel consumption rate [13].

1.2.4 Driver assignment problem

As mentioned in previous sections, a driver's behavior can affect the fuel consumption rate considerably. Therefore, the different assignment of driver to truck may bring different total operational costs. Searching for optimal driver assignment solutions significantly improves cost-effectiveness of carriers. It is well known that the generalized assignment problem is NP-hard [14]. For the small-scale problem, an exact approach is available to obtain an optimal solution. As for medium and large-scale problems, it is harder, even impossible.

1.3 Research object and scope

1.3.1 Scope of the research

This research covers three topics, to examine the current literatures regarding cost estimation models to develop an objective, reasonable cost estimation model for the truck transportation industry; to build a truck driver behaviour model from transportation data in order to develop the relationship between fuel consumption rate and driver behaviour features; and, to develop a linear integer programming model for driver assignment problem based on lower total operational costs.

(1) Modeling of operational cost

Some typical costing methods are regularly used in the financial sector: traditional costing method, Activity-Based Costing method (ABC), Time-Driven Activity-Based Costing (TDABC), and Lean costing method. There are differences among them and each has a particular application field. After conducting research on the characteristics of different costing methods and truck freight transportation processes, a new costing method based on TDABC is proposed and implemented focusing on small to medium-sized carriers.

(2) Modeling the relationship between driver behavior and fuel consumption

Fuel cost has the most substantial part in all operating cost components. There are many factors impacting fuel consumption in a truck transportation system, such as vehicle parameters, environmental elements, and drivers. The relationships between these factors and fuel consumption are too complicated to deal with efficiently. In this research, after analyzing some factors affecting operation costs, a driver is chosen as the primary factor to study the relationship between driving behavior and fuel consumption rate by Artificial Neural Networks (ANNs).

(3) Modeling and solving driver assignment problem

Based on the effects of different driver behavior on fuel consumption and operational cost, driver assignment problem is modeled as a linear integer programming model. The modified Hungarian algorithm is developed to solve the problem. The dispatch solution is compared with another algorithm's results.

1.3.2 Objectives of the research

(1) Build operation cost estimation model. TDABC-FTC is developed to model the operation cost for truck freight transportation companies. This method can estimate and allocate overhead to cost objects quickly and accurately compared to other costing methods.

(2) Quantitative driver performance. A relationship between driving behavior and fuel consumption rate is developed, and an ANNs model is realized by MATLAB box. The fuel consumption indicator is defined to quantitatively describe the driver’s fuel consumption performance to increase management efficiency.

(3) Build optimal driver assignment model. The operational costs based driver assignment problem incurred in truck freight transportation is modeled as a mathematical model and two kinds of solutions are developed to solve the assignment problem.

1.4 Organization and framework of the thesis

1.4.1 Organization of the thesis

The thesis is organized as follows. Chapter 1 introduces the background and development of truck freight transportation, outlining the motivations and focus of this research. Chapter 2 reviews related work on costing methods and application in logistics, the relationship between driver behavior and fuel consumption rate, and the driver scheduling problem in truck freight transportation. Chapter 3 develops a new costing method that is appropriate for small and-medium-sized truck transportation companies - TFBABC-FTC. In this method, indirect cost is allocated to transportation job to estimate total operational cost. Chapter 4 analyzes the primary factors impacting operational costs in truck freight transportation and builds the relationship between driver behavior and fuel consumption rate. Comprehensive performance indicators for drivers are developed. ANN is used to build the relationship between driver behavior and fuel consumption rate. The fuel consumption indicator of a driver is derived from related driving behavior parameters. In Chapter 5, a linear integer programming model is developed for driver dispatching problem in truck freight transportation. The objective of this optimization model is to minimize the total operational cost. Several solution methods for solving this kind of problems are summarized and the modified Hungarian algorithm is developed. Real transportation data are used to validate the model and scheduling solutions. Chapter 6 summaries the research contributions of this thesis and proposes future research works.

1.4.2 Frameworks of the thesis

The framework of this thesis is illustrated in Figure 4, comprising of four modules: truck freight transportation system, operational cost estimation, fuel consumption estimation, and driver assignment. The latter three form the main parts of this thesis. The truck freight transportation system describes main components in truck transportation, including truck, trailer, driver and loads, which provide the research backgrounds and input data for the cost estimation module and the fuel consumption estimation module. The output from the above two modules is transferred into the driver assignment module to achieve an optimal driver assignment solution based on lower operational costs.

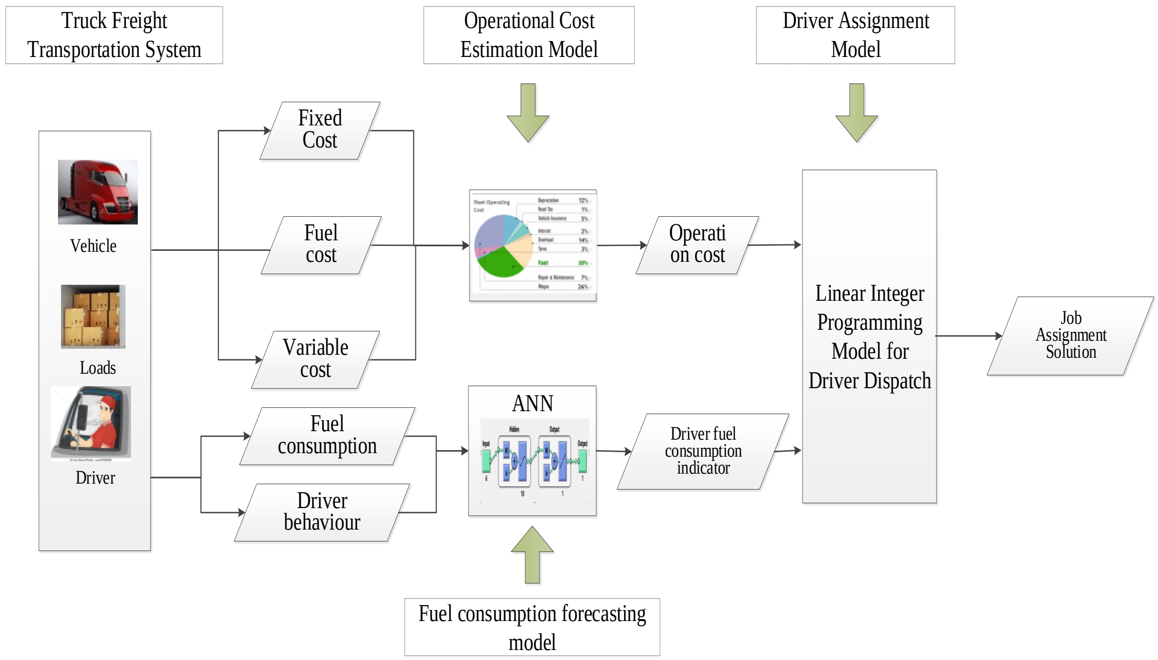


Figure 4: Framework of Thesis

Chapter 2 Literature Review

2.1 Truck freight transportation

Freight transport is the physical process of transporting commodities and merchandise goods and cargo from one place to another place. Modes of shipment can be classified into ground, ship, air, and intermodal according to mainly used transportation medium [15]. The ground shipping can be performed by train or by truck. Even in air and sea shipments, the ground transport is also required to take the cargo from its original place to the airport or seaport and then transport to its destination. The ground transport is more affordable than the air but more expensive than the sea transport. This research focuses on cost issues and dispatch problems existing in truck freight transportation depending on roads. This chapter will review the associated documents on three inter-related research topics: modeling methods of operational cost, modeling relationship between driver behavior and fuel consumption rate, and driver assignment problems in truck freight transportation companies.

2.2 Operational costs for truck transportation

The cost issue is a critical factor for truck transportation companies. Though there are various ways to calculate the operational costs of freight transportation by different modes, the data used in these cost computation methods may be difficult to obtain. Thus, it is challenging to estimate truck transportation operational costs. Statistical methods are commonly used in costs estimation research. For example, Levinson et al., utilized four different mathematical models, including a linear regression model, a Cobb-Douglas model, a Trans-log model, and the Box-Cox model, to compare the modeled results to "observed" costs data. Statistical model depends on data availability. When rate data are unavailable, unreliable or lacking exact meaning, engineering cost model becomes another good choice. Engineering cost model is another method in which the total shipping costs can be computed. The accuracy of the engineering cost model relies mainly on the chosen variables and the weights associated with each variable. Building cost function is another method [16]. The cost functions in this literature vary from the expected usage, such as engineering purposes, planning purposes, or policy purposes.

Due to the noticeable drawbacks of traditional costing method, activity-based costing and their varieties become common in modern society.

2.2.1 Activity-based costing methodology

The ABC method focuses on what was done regarding activities instead of what was spent. In ABC, several cost pools and a variety of cost drivers are needed [17]. The activity cost pool means the overall costs incurred in an activity, and the cost driver represents a feature affecting the cost and the performance of the activity over time [18].

There are many applications of ABC in logistics companies. For example, Carles analyzed the main costs in a third-party logistics (3PL) company and developed an application of activity-based costing method. The research investigated the most important activities of distributing the product to the final receiver [19]. Xiong and Li addressed the cost calculation problems happening in third-party logistics enterprises through ABC. They imported the ABC to analyze the activities of the 3PL enterprises to calculate costs, which proved the effectiveness of ABC [20].

As for small companies, due to high application costs and complicated processes of implementation of ABC, Narcyz et al. developed a procedure allowing small businesses to switch quickly from a traditional costing system to an ABC system. The method is called a two-stage activity-based model. Firstly, it is to determine cost information by professional estimation, systematic appraisal or actual data collection. Then the overhead expenses are allocated to product cost information using newly developed metrics. Such proposed procedures could help small manufacturing companies efficiently implement ABC [21].

To reduce logistics costs and improve customer service level, it is essential to know the resources used in every activity through an efficient logistics cost analysis system. Thus, Francesca Bartolacci studied the costs consumed in logistics activities and collaborated with the inter-company processes to decrease operating costs [22]. To keep high competitiveness in today's demanding and turbulent business environments, logistics enterprises should have the ability to control everything related to business. As a result of the dynamic attribute and complexity of characteristics of logistics practices, the overhead portion is very high. An integrated costing model was proposed in the document [23], which combines ABC, target costing and kaizen costing in a process-modeling framework. The model made it possible to estimate cost and improve cost-effectiveness in logistics enterprises. Popesko and Novak implemented an application of ABC in an urban mass transport company operating land public transport via buses and trolleys within the city. The case study was done to calculate real costs of individual operation, and to measure the profitability of transport lines [24].

Apart from application in logistics enterprises, the ABC method is also adopted in cost analysis processes of supply chains and manufacturing companies. Kim compared reusable packaging systems with expendable packaging systems based on total cost analysis. Firstly, three costs in packaging systems were developed by the ABC method, and activity drivers, activity costs, and total packaging costs were also calculated. A static simulation was used to explore relationships between packaging system costs and supply chain costs in eleven scenarios. The author built a dynamic simulation model to compare the company-provided data with the result of the ABC model by ARENA software in seven examining scenarios. The research results verified the effectiveness and applicability of the ABC method [25]. Document [26] created an ABC model on logistics costs in a production company, and assessed its efficiency in the exposure of logistics cost compared with traditional cost accounting, and the result showed that ABC method has better cost reduction.

Overall, the above documents proved the effectiveness of the application of ABC to various kinds of sectors. However, the drawbacks of ABC are significant when it will be used in small and medium-sized carriers, liking large amount of labors and funds required and a lack of adequate financial information.

2.2.2 Time Driven Activity-based Costing methodology

The main idea of TDABC is to identify the capacity of each department or resource and to allocate the cost of each department or resource to the cost object regarding the time required to perform an activity [27]. A TDABC can build time equations considering the difference in activity characteristics. The time equation will allocate the time and the cost of an activity to the cost object. Therefore, two critical parameters are required, the unit cost and time, to implement the TDABC method in manufacturing and service enterprises. Some applications below have demonstrated the implementation process of TDABC in various sectors.

In document [28], the method of TDABC was explored, and a mathematical model of TDABC was built to describe the time equations with different complexities in logistics.

The results of a case study at a distribution company were also presented. After considering the costing model for different tasks and processes, Afonso and Santana explored the logistics process in a distribution center of wood and carpentry-related materials, and developed a TDABC model for the logistics function [29]. Meanwhile, the cost model presented the costs and profitability of different cost objects, i.e., products, clients, distribution channels, processes, and activities.

Though ABC and TDABC have been investigated for several decades, the relevance and applicability of the TDABC method is still an open question. Santana, et al. developed an integrated TDABC-ABC model from the relationship between ABC and TDABC methods and proposed the methodology [30]. In the practical logistics process, the activities are connected with each other, but the traditional ABC only deals with the cost of each activity. Thus, the document [31] built an analysis model based on TDABC and TOC to help managers accurately recognize logistics cost and improve logistics processes and logistics cost structure. From some difficulties in implementation of TDABC, which include unavailability of accurate time drivers, a variety of time drivers, difficulties of collecting data, and huge volume of data, Seyed et al. developed a novel mechanism for the TDABC system integrated with fuzzy theory. Here, fuzzy logic was utilized to estimate inputs to realize TDABC by highlighting deviations caused by deterministic estimates in TDABC [32].

2.3 Relationship between driver behavior and fuel consumption

2.3.1 Modeling method

With the increasing energy requirement, there have been a great number of discussions on how to reduce fuel consumption in a vehicle from the 1980's. For example, Evans performed research on how a change in driver behaviour will affect fuel consumption in urban driving. The results showed that expert drivers could save fuel without increasing trip time by only adjusting their speed to avoid stops at traffic signals [33]. Driver characteristics have been the research points in automotive control in some research. Through discussing the driver features based on driving behavior and characteristics, some key technologies of the driving symptom were reviewed, which include classification and identification methods of driver behavior. Some typical applications were studied finally [34]. To model driving behavior among different drivers, a hierarchical fuzzy system for human was developed, involving the precision, age and driving individuality, to model the behavior [35]. With the continuous improvement in vehicle technologies, the drivers become one of the last major factors affecting fuel economy. Moreover, driver aggressiveness was proven to have a substantial impact on the fuel consumption rate in many studies. Many fuel economy tests have been developed to measure the fuel efficiency of today's vehicles and their related technologies. Research results showed that the driver variability could impose up to 10% fuel economy even on shorter distance routes [36].

It is well-known that, with the development of automotive industry, the transport vehicle emissions including carbon dioxide are the primary source influencing our environment. How to decrease emission from vehicles interests scientists and industries. By using a back-propagation neural network, Wu and Liu proposed a predictive system for car fuel consumption, which consists of three parts: information acquisition system, fuel consumption forecasting algorithm and performance evaluation. Five impact factors, the make of a car, the engine style, the weight of a car, vehicle type and transmission system type, were drawn as input information of the neural network. The prediction results demonstrated the effectiveness of the proposed predictive system and satisfactory performance [37]. With the development of mobile technology, a solution that advised the driver paths or driving behavior to reduce fuel consumption was developed based on a fuel consumption estimating model through its real time data. Smartphones were used to collect data with embedded GPS and OBD. A regression model was developed to determine the instantaneous fuel consumption. The experiment results proved the model's reliability and robust to different types of vehicles and urban routes [38].To find what will influence fuel consumption in a truck transportation, Walnum and Simonsen adopted multivariate regression analysis and mean elasticity analysis to a set of driving indicators. They found that road situations, variables associated with infrastructure and vehicle properties have more significant influence than driver-influenced variables do. No matter what the infrastructure condition is, driver behavior is an essential factor. Such research results could help transportation companies to manage fleet efficiently [39]. Driving styles are also considered to have a significant relationship with fuel consumption, so Beusen and Denys developed a method to measure long-term effects on fuel consumption of eco-driving education. Most of the experiment results demonstrated long-term fuel consumption existing after eco-driving training [40].

Driving behavior can not only affect fuel consumption but also have a significant effect on driving safety. There are lots of documents on the relationship between driver behavior and driving safety. For example, Lin et al. modeled the driver handling behavior in a driver-vehicle-environment system to design vehicle systems and transport systems from the viewpoint of safety and efficiency of human mobility. This model was developed by artificial neural networks by document [41]. In some situations, driver behavior has been considered a major cause of road accidents. Therefore, Kumar and Prasad developed a driver behavior analysis and prediction model, which was separated into a driver behavior analysis model and a driver behavior prediction model. The driver behavior analysis model adopts various methods to recognize driver behavior and obtain driver driving information, and the driver behavior prediction model predicts the drivers' driving nature in safety issues [42]. Evaluating fuel efficiency is an important process during vehicle design and operation. Thus, Ben-Chaim et al. developed an analytical method of evaluating fuel consumption, in which fuel consumption was separated into two different operating modes: cruising and acceleration. In each of the two modes, fuel consumption was calculated from the instantaneous engine efficiency and an analytical function was used to approximate fuel consumption. Experimental calculation results demonstrated the adequacy and accuracy of the model finally [43].

The driving behavior and the driving cycle type may affect the range of an electric vehicle. A new strategy was developed to classify driver behavior into aggressive or defensive and driving cycles into highway or urban. A neural network was used to simulate aggressive and defensive driving behavior for electric and hybrid vehicles [44].

Providing guidance and information to drivers to help them make fuel-efficient route choices is an important strategy to reduce fuel consumption in the transportation industry. A fuel consumption estimation model is a vital point in implementing the strategy. A mesoscopic fuel consumption estimation model was developed to be integrated into an eco-routing system. Statistical analysis processes were conducted to ensure the validity of the model and the results [45].

2.3.2 Building relations between driver behavior and fuel consumption

Though there is much research about the relationship between driver behavior and fuel consumption, emission and safety issues, some other technologies are still required to transfer the research results to practice.

In document [46], Galit et al. built a framework to measure and collect data from DVRs, then evaluated the effectiveness of feedback based on In-Vehicle Data Recorders to improve driving behavior, increase driving safety, and reduce fuel consumption. After conducting tests on actual vehicles, it showed that feedback could bring a reduction of 3-10% in fuel consumption, and 8% in safety incidents. With higher development of automobile technology, it is easy to obtain driving parameters from the ECU and results of CAN bus. An integrated solution combining VSP and CAN bus was developed to estimate the fuel consumption. The results showed that the relationship between VSP and the fuel consumption rate is consistent with the result derived from the fuel consumption meter [47].

To support intelligent transportation system development by DrivingStyles architecture, Javier et al. designed a mobile platform to develop driving styles classification and generate fuel consumption based on driver characteristics. An algorithm was implemented to describe the degree of aggressiveness of each driver. Authors also demonstrated the impact of the driving system on fuel consumption [48]. Hoping to keep the vehicle running the environmentally friendly driving zone and reduce harmful exhaust gases, Gennaro et al. developed a real-time microscopic fuel consumption linear model that was integrated into simulation platforms to design and test for an Advanced Driving Assistance Systems (ADAS). A large-scale experiment with more than 100 drivers and over 8000km of driving distance was performed to verify the model [49]. Eco-driving techniques can significantly improve fuel consumption. Thus, a retro-fittable driver behavior improvement device was developed to provide real-time audio and visual feedback to the driver to improve driving style [50].

Since the 1990's, the On-Board Diagnosis (OBD-II) standard makes people have access to the vehicles' Electronic Control Unit (ECU) smoothly through a Bluetooth OBD-II connector. A DrivingStyles architecture was developed to help drivers correct their bad driving habits, where data mining techniques and neural networks were adopted to analyze and generate a classification of driving styles by examining the characteristics of the driver along the route followed. A study with more than 180 users was conducted to verify the effectiveness of the DrivingStyles proposed [51]. Similarly, a novel driving behavior analysis method based on OBD and AdaBoost algorithm was proposed. The method can collect vehicle operation information via the OBD interface and then build a driving behavior classification model by the AdaBoost algorithm to determine whether the current driving behavior belongs to safe driving or not. Experimental results showed that the proposed method can achieve a higher accuracy rate in various simulations [52].

Big data information and pattern analysis have deep applications in many industrial sectors. Using big data on commercial vehicles can assist traffic safety and improve eco-driving. Cho and Choi calculated fuel consumption rate by processing and analyzing big data with the MapReduce mechanism. This research provided a possibility to estimate fuel consumption only through analyzing driving patterns obtained from digital tachographs big data [53]. In document [54], Lee et al. developed an estimation method of fuel consumption from vehicle information through OBD-II. A quadric function and a surface function were modeled with OBD-II data and fuel consumption data. A 5 km road test was implemented to demonstrate the effectiveness of the proposed method, and the results showed that the proposed method could estimate the fuel consumption precisely. To estimate the fuel consumption only from driver behavior, three devices, gravity sensors, accelerometers, and OBD, were used to collect the data of azimuth, acceleration, movement records, and fuel quantities. Some intelligent methods, such as genetic algorithm and neural network, were performed to analyze fuel consumption and finally divide driver behaviors into multiple kinds. Based on the high cost and measurement errors of sensors, a lower-cost solution was proposed and implemented to estimate the fuel consumption for the logistics sectors. The practical experimental results showed that the accuracy of the proposed fuel consumption estimation method was about 95.87% [55].

2.4 Driver dispatching problem

Scheduling problems exist in all aspects of industry. In the logistics sector, there are various scheduling problems associated with different resources such as vehicles and drivers. The drivers affect fuel consumption in truck freight transportation. Therefore, many researchers and logistics companies are concerned about the driver dispatch problem. Some typical solutions are summarized as follows.

2.4.1 Exact solution

An exact solution can obtain an optimal solution. As for the NP-hard problem, when it is a small-scale problem, an exact solution will find optimal results in an acceptable time; when it is a large-scale problem, an exact solution may produce feasible results. The Branch and Bound method, the Cut plane method, and the Dynamic Programming method are common exact solutions.

The generalized assignment problem (GAP) is the problem of assigning *n* jobs to *m* agents to realize the minimal total costs and each job is assigned to exactly one agent and subject to the agent's capacity. Due to its NP-hard, a transportation branch and bound algorithm was developed to solve such kind of problem, where the sub-problems were solved by transportation techniques rather than the usual simplex methods and a selecting branching variables techniques was presented to minimize the number of sub-problems [56].

Similar to driver scheduling in the truck transportation sector, Katsoulas and Sadowski developed a resource allocation technique by a branch and bound algorithm which can optimize the allocation at a specific point in time. The algorithm allocated individual performance ratings to each resource and weighting factors to each activity. A small example was implemented to illustrate the effectiveness of the algorithm [57].

The assignment problem is a special type of the transportation problems. The target of the assignment problem is to assign the resource to a task to obtain an optimal objective. In document [58], two methods including Hungarian method and Alternate method of an assignment were used to solve the assignment problem. Comparison experiments were performed, and the results illustrated that both methods can produce same optimal solutions while the Alternate method has higher efficiency. A Modified Assignment Approach was developed to solve assignment problem in document [59], in which the algorithm was presented and a numerical instance was explained to show its efficiency, and comparison results with Hungarian Algorithm were also shown.

In addressing the assignment problem, the Hungarian method was used in the parallel environment to assign a job to a processor. A traditional Hungarian method may be used to assign each processor one job at a lower cost when the number of processors and the number of jobs are the same. In most cases, the number of jobs is larger than the number of processors, and then this method does not work. Thus, an alternate approach similar to Hungarian method was developed to assign more jobs to lesser processors [60].

2.4.2 Heuristics solution

The heuristics solution is another popular method which can obtain a near-optimal solution or an optimal solution based on a certain possibility employing intuitive judgment or a heuristic method. There are two kinds of heuristics solutions: traditional heuristics and meta-heuristics.

The staff assignment problem exists widely in industry operational processes. To obtain the optimal staff assignment solution with minimal total operational costs, Dong et al. developed a novel discrete state transition algorithm which can implement the second transition by the first transition. The algorithm was used to expand the range of candidate solutions and improve the diversity of the candidates. Simulation results proved the effectiveness of the improved method and stability for this problem [61]. In addition to the exact solution and the heuristic solution, intelligent approaches were used to deal with the assignment problem. An evolutionary heuristic algorithm, which is a specially modified variant of a cultural algorithm, was implemented to solve assignment problems. Numerical experiments showed that this algorithm is more efficient than the existing methods, including the Hungarian method and genetic algorithm [62].

Chapter 3 Modeling of Operation Costs based on Time-Driven Activities-Based Costing Method

3.1 Introduction

Operation cost is critical to the transportation industry, leading to more research interests and efforts. Some of these studies calculated costs using highly subjective “value of time” calculations that may extend beyond direct costs [63]. For example, from 2008, the American Transportation Research Institute (ATRI) began to investigate the cost issue on motor carrier operations. The goal was to accurately distinguish current operational costs based on real-life data provided directly by motor carriers, which is helpful to verify the operational costs exactly. However, obtaining the cost of products or services is difficult in highly competitive environments. Costing systems can help companies determine the costs of a product or service. Direct costs such as direct labor and materials are relatively easy to measure and can be directly allocated to specific products or services. However, indirect costs such as depreciation, marketing, overhead and tax cannot be attributed to a cost object directly. Approximation method is usually used to estimate the indirect cost allocation on cost objects. Cost analysis is the first step to do cost estimation.

Cost analysis is associated with logistics management because resources are required to operate all significant activities of a logistics system. The activities may range from procurement to warehousing, transport and information systems, and they involve human, capital, and material inputs [64]. Small and medium-sized carriers in Canada hold a significant amount of the truck freight transportation market. Due to a lack of efficient costing technology and enough financial input, the Approximation method based on subjective "value of time" calculations is broadly utilized in these carriers.

In earlier research, it has been concluded that the control of logistics costs will become increasingly important for firms seeking a competitive advantage. Managers require more accurate and focused costing information to ensure a company's profitability. However, successful efforts depend on whether the firm's cost accounting system can track costs to specific logistics activities correctly.

In this chapter, some essential content on operational costs will be discussed, and an operational cost estimation model will be developed based on a Time-Driven Activity-based-Costing (TDABC) methodology.

3.2 Cost modeling for truck freight transportation companies

3.2.1 Cost structure

With the growing use of advanced technological equipment in many organizations, the indirect costs of manufacturing companies and service companies have gradually increased over the last two decades.

The cost structure presents the types and relative proportions of fixed and variable costs that a business incurs. The concept can be defined in smaller units, such as a by product, service, product line, customer, division, or geographic region. To establish a cost structure, every cost incurred concerning a cost object needs to be defined. In financial and accounting fields, there are many ways to classify costs according to the specific need, such as direct costs versus indirect costs, fixed costs versus variable costs, and obvious costs versus hidden costs. The section below describes the meaning of some common cost terms.

(1) Direct costs versus. Indirect costs:

- Direct costs: Direct costs refer to costs that can be easily traced to a particular product or service, such as the labor cost associated with the work to produce the product.

- Indirect costs: Indirect costs are costs which affect the entire company, not just one product or service. Thus, these costs are difficult to allocate to a particular product or service. The indirect costs are often called *overhead*.

The significant difference between direct costs and indirect costs is whether a cost can be traced to specific cost objects. A cost object is an accountable object to which a cost is associated, such as a product, a service, a project, or an activity.

(2) Fixed costs versus Variable costs:

- Fixed costs: Fixed costs are costs that do not vary with quantity or volume of output provided in the short run.
- Variable costs: Variable costs are costs that vary with changes in quantity or output volume. In logistics, for example, fuel costs required to operate the delivery process would be considered a variable cost.

From the above description of cost terms, we know that some costs can be thought as fixed costs and indirect costs simultaneously, and some costs can be thought as variable costs and direct costs simultaneously.

3.2.2 Costing estimation methods

From the viewpoint of the cost-output relationship, the total costs vary directly with output. In a manufacturing environment, the total cost first sharply increases, then plateaus at a constant rate and eventually slightly increase. This knowledge is useful for decision-making. In logistics companies, such experience is still effective. The cost-output relationship can be estimated through the following three methods [65-66].

(1) Accounting method:

In the accounting method, the cost-output relationship is estimated by separating the total costs into fixed costs, variable costs and semi-variable costs. These components are calculated based on their attributes. Usually, the number of fixed costs is determined based on inspection and experience. The average variable costs and semi-variable costs are set from the total output and total variable costs. This approach seems quite simple. However, to obtain a reasonable estimation of cost-output relationship, it is necessary to maintain a detailed breakdown of accounts over an extended period of years [67].

(2) Engineering method:

The engineering method estimates cost based upon various input factors, i.e., plant-size, man-hours, and other inputs, for a given output. This is done based on the rated capacity of plant and equipment, and input-output norms. When the physical units of an output level are determined, the cost estimate of the output level is produced by multiplied rated capacity of resources by physical units.

(3) Econometric method:

The econometric method requires good experience of input-outputs norms and constancy of factor prices. This method may be preferred to the accounting method when the account records do not provide a systematic historical basis for estimating cost behavior and when it is required to project cost behaviors beyond the range of past output, and when significant technological changes happened.

However, the three methods above are often integrated comprehensively to deal with costing issue in practical costing application.

3.2.3 Traditional costing method

Traditional costing method is the allocation of organization overhead to products based on the volume of resources consumed. Under this method, overhead is usually applied based on either the number of direct labor hours consumed or machine hours used. The drawbacks of traditional costing is that organization overhead may be much higher than the basis of allocation so that a small change in the volume of resources consumed triggers a massive difference in the amount of overhead applied. This is a particularly common issue in highly automated production environments, where factory overhead is quite significant and direct labor is close to nonexistent [68].

The fundamental principle of the traditional costing method is that the fixed costs and the variable costs are assigned to products or services as a measure of the products produced or services provided. This costing method may ignore the cause-effect relationships between costs and objects, and use ad-hoc cost allocation factors for overhead especially. Therefore, this method can be effective only when the relevance of overhead or indirect costs are low. Universal traditional costing method process flow is shown in Figure 5 below.

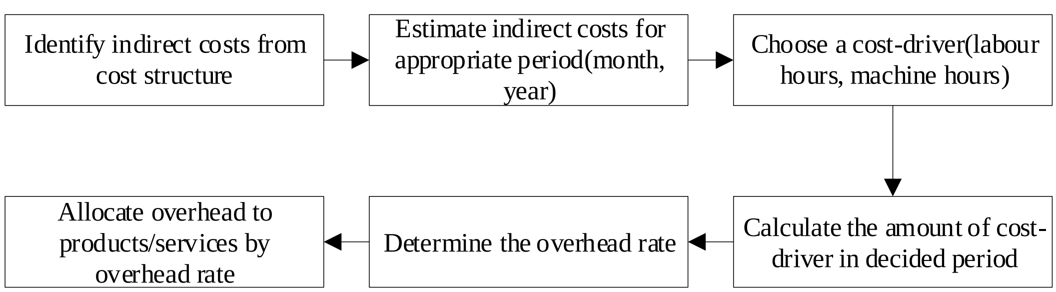


Figure 5: Traditional Costing Method

Step 1: to identify indirect costs from cost structure;

Step 2: to estimate indirect costs for the appropriate period, i.e., week, month, year;

Step 3: to choose a cost-driver, i.e., labor hours, machine hours;

Step 4: to calculate the amount of cost-driver in a decided period;

Step 5: to determine the overhead rate;

Step 6: to allocate overhead to products or services by using an overhead rate;

Thus, six steps are required to conduct the traditional costing method. A critical step, step 5, is to determine the overhead rate. The following equation is used to estimate the overhead rate.

Overhead rate = Estimated overhead costs / Estimated cost-driver amount

For example, the estimated overhead cost is $30,000 monthly, and the number of estimated cost-drivers, product, is 3,000. Thus, the overhead rate for each product is $10.

3.2.4 Activity Base Costing method

Activity-based costing (ABC) method is a costing methodology that determines activities in an organization and can allocate the cost of each activity with resources to all products and services according to the actual consumption number by each product or service. This method assigns more indirect costs, especially overhead, to cost-drivers compared to the traditional costing method. Since the 1980's, the ABC method has become very popular among manufacturing companies and other types of service organizations including financial services, utilities, telecommunications, healthcare and logistics [69].

The fundamental idea of the ABC is to allocate a cost to a product or service according to the actually required resources, both material, and service. Figure 6 presents the logic process of the ABC method.

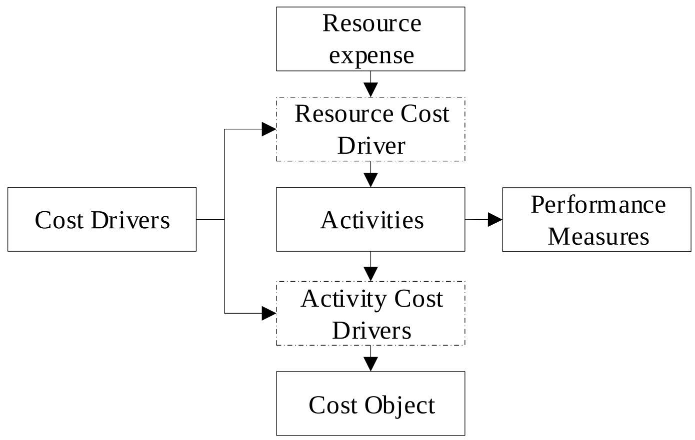


Figure 6: Activity-based Costing Method

The ABC method concentrates on recognizing activities or manufacturing processes, which are conducted to finish a job. These individual activities or processes are grouped with similar operation units into a cost pool that is related to a single activity cost-driver. The cost pools are analyzed and assigned a predetermined overhead rate that will eventually be allocated to individual jobs and products. Compared to the traditional costing method, the ABC is the more accurate method to assign indirect costs. However, many efforts are required to implement the ABC in a logistics company.

There are some applications of the ABC in logistics companies. For example, Griful-Miquela analyzed the initial costs in the third-party logistics companies and developed an application of the ABC method. This research checked the most critical activities of distributing the product to the final receiver [70]. Xiong and Li addressed the cost calculation problems happening in the third-party logistics enterprises by using the ABC method. They imported the ABC to analyze the activity process of the 3PL enterprises to calculate the cost, which proved the effectiveness of the ABC [71]. However, remarkable disadvantages of the ABC application in small to medium-sized freight transportation companies can be summarized.

(1) A lack of sufficient information. The corporate accounting department finds it is hard to provide enough information required for strategic planning and decision-making [72], resulting in a lack of necessary information on the cost-drivers to support the modeling of the time equations.

(2) A lack of required resource. Inadequate resources such as technical, financial and human resources might prevent the corporation from implementing the costing systems.

(3) Considerable resistance from the employee. Documents described the opposition to change because staff were reluctant to fill in the time sheets and to maintain the databases with a large number of activities.

(4) Dynamic transportation trip. Diverse customers' requirements changed the transportation trips, such as routes, transportation modes, and directions, which increased the difficulty of the ABC application.

3.2.5 Indirect cost allocation between traditional and the ABC costing method

Although these two costing techniques, the traditional costing scheme and the ABC method, are commonly used to evaluate costs, there exist remarkably distinctions between these two methods. Figures 7 and 8 show the main differences of these costing method used in logistics industries.

Firstly, the total costs are separated into direct costs and indirect costs. The direct costs are assigned to cost objects directly according to the expenditures. The difference between them is the assignment method of the indirect costs. In the traditional costing method, the indirect costs are first assigned to organizational units, and then to cost objects, i.e., service/trip (as shown in Figure 7). In ABC, however, the indirect costs are first assigned to activities, and then to cost objects, i.e., service/trip (as shown in Figure 8).

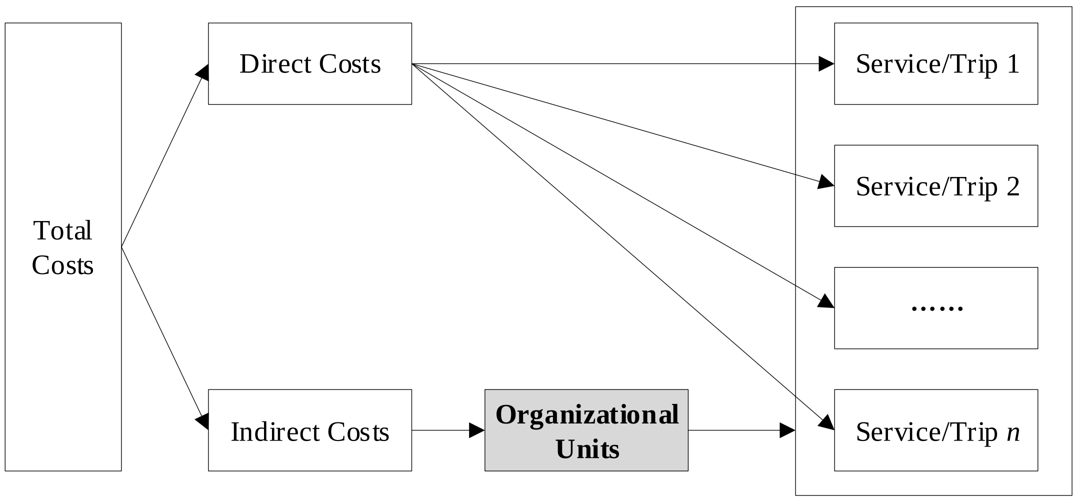


Figure 7: Allocation of Indirect Costs in Traditional Costing Method

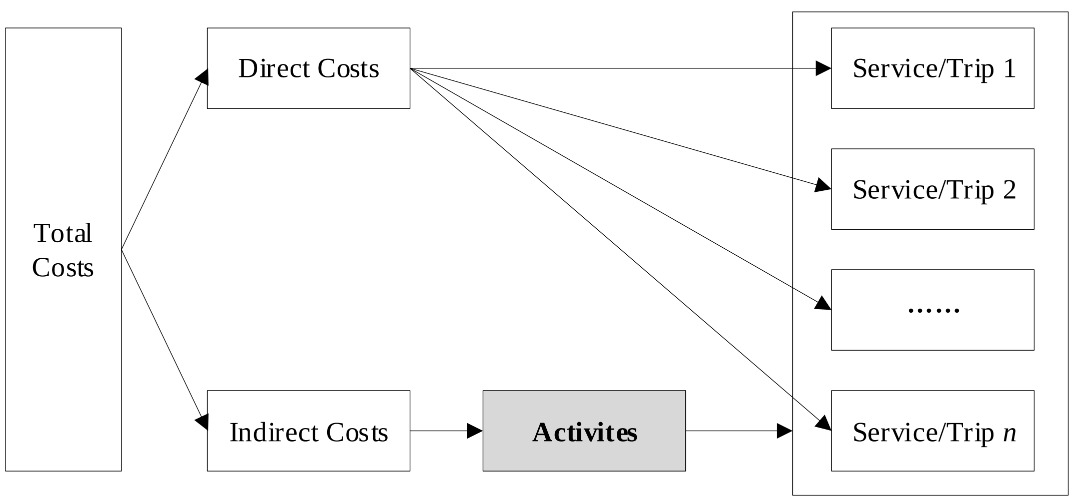


Figure 8: Allocation of Indirect Costs in ABC

3.3 Proposed costing model of freight truck transportation--TDABC-FTC

3.3.1 Trip-Activity-Operation relationship

Some terms associated with costing methods are presented, and the relationship framework among them is shown in Figure 9.

- Cost objects - Cost objects refer to products or services which are accountable for cost consumer. For small and medium-sized truck freight transportation companies, customers and orders usually vary with transportation market fluctuation, so they are not considered as cost objects. Transportation trips are generally thought of as cost objects in the logistics field. A transportation trip consists of many consecutive operation activities from accepting a customer's order inquiry to delivering to a consignee and returning to the home terminal.
- Activities - It means the activities which can be defined explicitly and done by specific staffs. In small and medium-sized truck freight transportation companies, the activities are described as follows.

(1) Asking for price - When a customer needs to transport loads and asks for a price from a suitable carrier.

(2) Returning price - The carrier deals with the order and generates an initial price, then returns the price number to the customer.

(3) Verifying price and generating order - The carrier builds a new order with the confirmed price.

(4) Generating a dispatch solution - The carrier generates the dispatch solution and sends the solution to a driver.

(5) Picking up loads. According to dispatch solution, the driver drives to shipper address to pick up loads with particular service sometimes.

(6) Transporting - The driver drives the truck from the pickup address to the delivery address.

(7) Delivering loads - The driver drives to the consignee address and delivers the loads to consignee with particular services sometimes.

(8) Returning to the home terminal.

- Operations: Operations are defined as some calculable tasks under an activity.

Compared with other cost objects, trips and activities are more manageable to be estimated the costs and hours. Same activities in the different trip, however, may feature different operations. Each operation is considered an independent process unit done by a kind of personnel and/or equipment. Such a definition is helpful to build an activity-cost model.

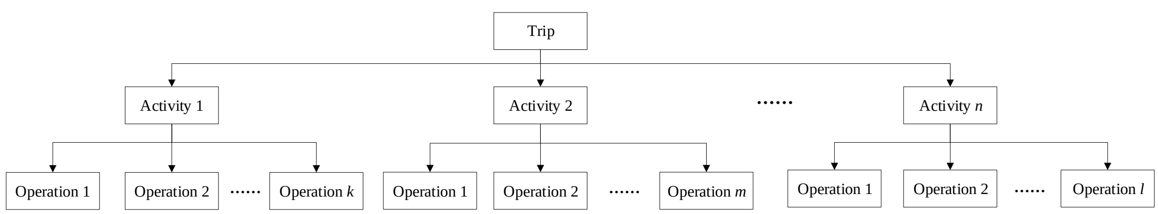


Figure 9: Relationship Framework among Cost Objects, Activities, and Operations

3.3.2 Definition of TDABC and TDABC-FTC

- Time-Driven Activity-Based Costing (TDABC)

The TDABC was created to fix the difficulties faced by the implementation of the ABC models and to use duration drivers instead of transaction drivers because the duration drivers can be quickly modified when conditions change [73]. The idea of the TDABC is to identify the capacity of each department or process and to allocate the cost of this resource group capacity to the cost object based on the time required to perform an activity. First, the characteristics of activities are analyzed, and time equations are generated to describe the time consumed by an activity. Then, the time and the cost of the activity can be assigned to the cost object based on its characteristics.

Two critical parameters of the TDABC are the unit cost of used resources and time required to perform an activity. A conventional process flow of TDABC is shown in Figure 10 below [74].

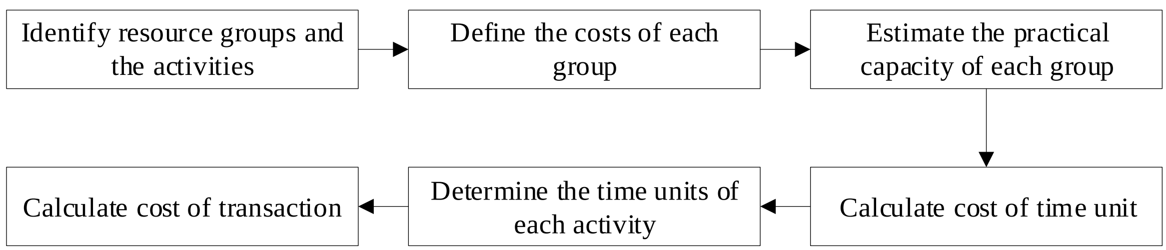


Figure 10: Process Flow of TDABC

- Definition of TDABC-FTC

When a substantial amount of the cost of a company's activities is in a highly repetitive process, the cost assignment can be based on the average time required for each activity. For truck freight transportation companies, when one trip is separated into several activities, and one activity is separated into several operations, the smaller operation units in different trips are the same and have the same cost expenditure. Thus, the TDABC can assign resource costs directly to cost objects using the cost per time unit for supplying the resource, rather than first allocating costs to activities and then from activities to cost objects.

Unlike the ABC which needs many efforts and multiple calculations, the TDABC is implemented based on two important parameters: the cost per time unit of capacity and the time required to complete an operation— the time is usually considered as the measure of the capacity [75]. Generally, implementation procedures of the TDABC are as follows: first, estimate the costs of all resources (equipment, personnel, etc.), and divide the costs by the capacity; second, distribute the resource costs by the capacity cost rate and resource requirement to each cost object. In the IT era, some jobs are done by the software system in most carriers. For example, staff do pricing operations for newly received loads by IT systems. Dispatchers build dispatch solution by using a fleet management system. These changes in tools add difficulty to costing.

Based on the TDABC and the characteristics of truck freight transportation companies, a modified costing method called TDABC-FTC is developed in this research. This costing method is designed to satisfy the requirement of small and medium carriers' costing method. The process flow is shown in Figure 11 below.

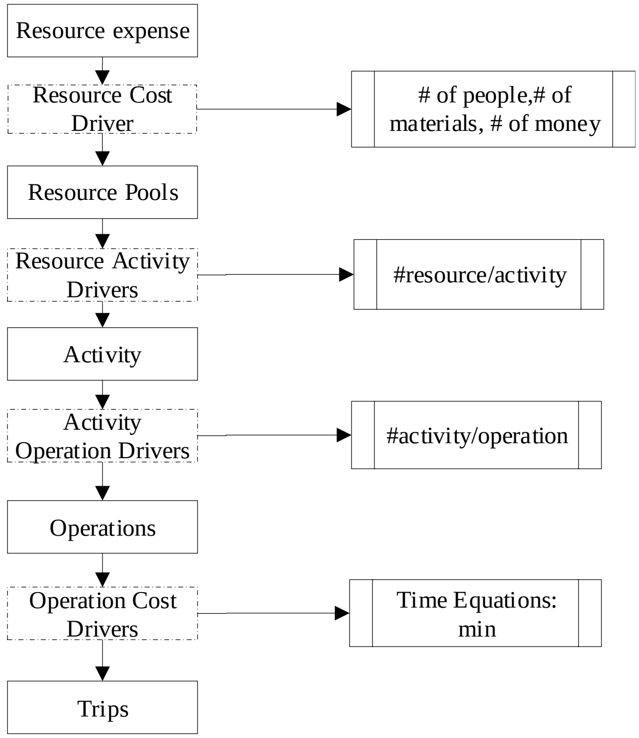


Figure 11: Process Flow of TDABC-FTC

Different from the logic of common TDABC, a new process flow for TDABC-FTC was created. New operations obtained by decomposition of activities were developed, which were useful to analyze complicated and various business flows in logistics companies. Firstly, resource pools were obtained, and resource expenses were allocated to resource pools. After analyzing resource activity drivers, the relationship between resources and activities was established. Then, operations are generalized from components of all activities. Thus, the operation can be considered the basic cost unit.

A cost pool is a group of individual costs, typically incurred by a department or service center. In a service industry, the cost pools are commonly used for the assignment of overhead to units of service. For example, the costs of the operation department are accumulated in a cost pool and then allocated to those departments using its services. The implementation plan of TDABC-FTC in small and medium-sized carriers is shown in Figure 12 below.

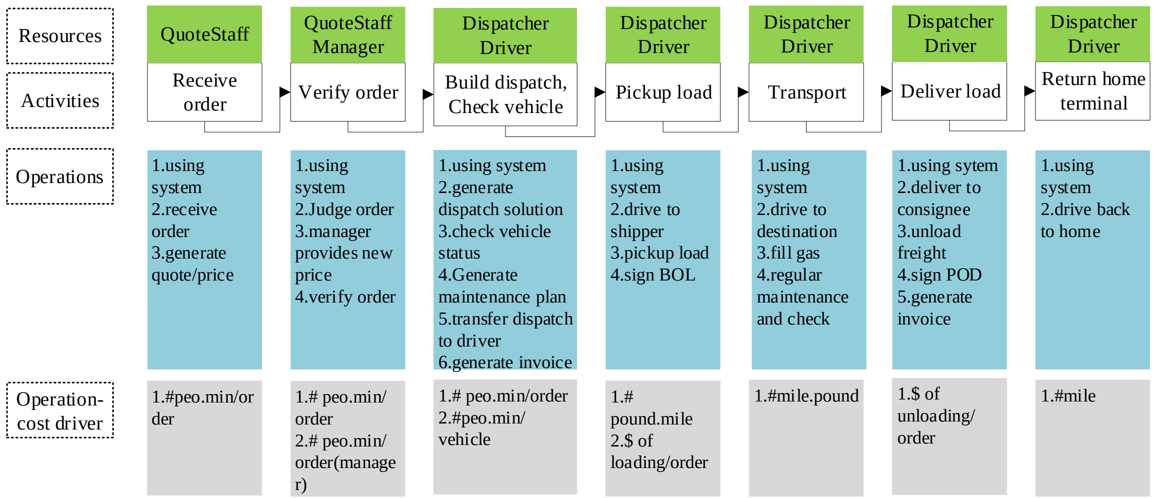


Figure 12: Implementation Plan of TDABC-FTC

The TDABC-FTC needs to generate time equations for individual operations in each equation. To build time equations of each subtask (operation), four steps are implemented.

Step 1. Create resource cost pools and select resource cost pool allocation bases.

Firstly, resource cost pools are generated and the resource cost drivers are selected. Here the most significant resources are chosen as the nucleus for the first resource cost pool, resources with consumption patterns that correlate with the base resource consumption pattern are added, and the nucleus are utilized as the assignment base.

Step 2. Create activity operations pools.

Then, activity is separated into several sequential operations and each operation is defined as an independent action done by independent labor with specific resources in a successive period. Through this step, the relationship between resource and operation are developed.

Step 3. Create operation cost pools and select time drivers.

In this step, operation cost pools are created.

Step 4. Use resource cost pools and time drivers to generate the time equations and calculate the resource cost rates.

Based on the attributes of transportation industry and documents, the linear models will be adopted to build the time equations, because here it assumed that there is a linearly proportional relationship between resource costs and the cost driver consumption. The models consist of three parameters: activity i, operation j and capacity cost rate k. Costs for an individual trip are obtained from the total time consumed by all operations in the activity multiplied by the cost per unit of the relevant functional units [74].

$$TC_p = \sum_{m=1}^{M} \sum_{i=1}^{I} \sum_{j=1}^{J} T_{i,j} C_m \tag{1}$$

where TC_p: Total cost of trip p.

$T_{i,j}$: Total time (minute or hour) of operation j in activity i.

C_m: Cost per time unit (minute or hour) of the functional unit.

J: Number of operations.

I: Number of activities.

M: Number of functional units.

p: Individual trip.

Each time equation presents the total time used in an operation. A time equation for each of the seven activities in the cost center is developed, and the estimated time is to represent the resource demand for each trip variation [74]. The time used to conduct operation (j) of activity (i) can be developed which is shown in the following equation (2).

$$t_{i,j} = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \cdots + \alpha_k x_k \qquad (2)$$

where:

$t_{i,j}$: Time required conducting operation (*j*) of activity (*i*).

α_0: Constant amount of time of operation (*i*) which is independent of the activity (*j*).

α_1: Time of one unit of time driver x_1 when time drivers $x_2,\ldots,x_k$ are assumed constant.

α_2: Time of one unit of time driver x_2 when time drivers x_1, x_3, …, x_k are supposed constant.

k: Number of time drivers determining the time required to perform the activity (*i*).

Then, we can define the cost of an individual operation of activity ($C_{i,j}$) as following equation (3),

$$C_{i,j} = t_{i,j} \cdot c_n \qquad (3)$$

where

c_n: The cost per time unit of the resource pool (*n*).

$C_{i,j}$: The operational cost of the operation (*j*) of activity (*i*).

$t_{i,j}$: The time consumed by the operation (*j*) of activity (*i*).

In order to develop the above time equation models, the time drivers are critical factors because the time drivers can affect the required time in operating a selected activity. Three types of time drivers are summarized in document [74] shown in Table 2 below.

Table 2: TIME DRIVERS

Time drivers	Meanings	Examples
Continuous	The time is related to Continuous variable	Transportation distance, Service time
Discrete	The time is related to Discrete variable	Number of orders, or Number of customers
Boolean	The time is related to Boolean variable	Type of customers-Old or New

3.4 Implementation of TDABC-FTC in transportation operation

3.4.1 Background introduction

The studied company is a small to medium-sized carrier with limited resources where the TDABC-FTC model for the logistics function is designed and applied. The primary resources of the carrier involve vehicles, departments, staff, IT systems, and parking lots. Detailed information of main resources used in this carrier is presented below. The job descriptions for each department are summarized in Table 3.

(1) Vehicles:

a. Trucks and tractors: 80 in total.

b. Trailers and chassis: 100 in total.

(2) Departments:

a. Quote department (3 staff),

b. Financial department (2 staff),

c. Transportation department (2 staff),

d. Management department (2 staff).

(3) Main trips:

a. Local logistics,

b. Long haul.

Table 3: JOB DESCRIPTION FOR EACH DEPARTMENT

Department	Number of Staff	Job description
Quote Department	3	Receiving order, dealing with order
Financial Department	2	Generating pricing, Invoice, Settlement
Transportation Department	2	Generating dispatch solution, tracking vehicles, send dispatch solution to drivers, create real-time dispatch solution
Management Department	2	Generating repricing, other emergent things

3.4.2 Implementation of TDABC-FTC

In this research project, seven activities were built to conduct a trip, and each activity has various operations. There are different time drivers in each operation to calculate time consumed. The features of time drivers are summarized. All these terms are presented in Table 4. From this table, it is easy to build time equations and cost equations for all operations. Here, the operation "Receive order" was took as an example to show how to make a time equation. The same methods can address other operations of all other activities.

In the activity "Receive order", resource "quote staff" is responsible for doing operation "Receive order". Three time drivers include customer types x_1—New/old, order method x_2—Phone call/Email/App/On site, and the number of orders x_3. "App" means customer can make the order by App managed by carrier. "On site" represents that the customer will go to carrier office to make an order. Thus, the time required to do operation "Receive order" was obtained by the time equation and cost was obtained by cost equation,

$$t_{1,1} = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 \tag{4}$$

$$C_{1,1} = t_{1,1} \cdot c_1 \tag{5}$$

where

x_1: customer types—New/Old. The default value is Old. It means the default customer is old customer and the customer's information is in carrier's system.

x_2: order method—Phone Call/Email/App/On site. The default value is App

x_3: number of orders—1, 2, 3, …The default value is 1.

α_0: Constant amount of time of operation when all time drivers are kept constant. Let $\alpha_0 = 7\ min$.

α_1: Time of one unit of time driver x_1 when time drivers x_2, x_3 are assumed constant. Let $\alpha_1 = 2\ min$.

α_2: Time of one unit of time driver x_2 when time drivers x_1, x_3 are assumed constant. Let $\alpha_2 = 3\ min$.

α_3: Time of one unit of time driver x_2 when time drivers x_1, x_2 are assumed constant. Let $\alpha_3 = 1\ min$.

c_1: The cost per time unit of resource –Quote staff. Let $c_1 = \frac{\$0.5}{min}$.

All the constants used in research are obtained by interviewing the carriers. Here, five carriers are surveyed by site investigation to obtain the data, average results are used to implement the TDABF-FTC. Though the survey data is less, result is rationale. Normally, in the implementation of the TDABC, researchers often obtain parameters of the time equation by interviewing the manager and surveying labourers [74]. In this section, the setting table (shown in Table 5) of the parameters of the time equation was developed. Then the time used to implement operation "Receive order" can be calculated. For example, an "Old" customer will have "two orders" with "Phone call”, then the time required to deal with this order is:

$$t_{1,1} = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 = 7 + 2 * 1 + 3 * 1 + 1 * 2 = 14\ min$$

The cost of operation “receive order” is:

$$C_{1,1} = t_{1,1} \cdot c_1 = 0.5 * 14 = \$7$$

Table 4: TIME DRIVERS FOR TDABC-FTC

Activity(j)	Resource pool(n)	Operation(i)	Time Drivers(x)	Features of time drivers
Receive order	Quote staff	Receive order	(1)Customer types	Boolean
			(2)Number of order	Discrete
			(3)Order method	Discrete
	Quote staff	Generate price	(1)Customer characteristics	Boolean
			(2)Number of order	Discrete
Verify order	Quote staff	Verify order	(1) Customer characteristics	Boolean
			(2) Order attributes	Discrete
	Manager	Do repricing	(1) Customer characteristics	Boolean
			(2) Order attributes	Discrete
Build dispatch	Dispatcher	Generate dispatch	(1)Number of order	Discrete
		Transfer dispatch to driver	(1)Number of order	Discrete
		Check dispatch solution	(1)Number of order	Discrete
		Generate invoice	(1)Number of order	Discrete
Pickup load	Dispatcher	Transport to shipper	(1)Number of order	Discrete
			(2)Transportation distance	Continuous
	Driver	Pickup load	(1)Weight of load	Continuous
			(2)Number of order	Discrete
Transportation	Driver	Transport to consignee	(1)Transportation distance	Continuous
Deliver load	Driver	Unload load	(1) Weight of load	Continuous
			(2)Number of order	Discrete
Return to home terminal	Driver	Transport to home terminal	(1)Transportation distance	Continuous

Table 5: SETTING TABLE OF PARAMETERS OF TIME EQUATIONS

Unit(min)		Customer types(x_1)		Order method(x_2)				Order number(x_3)		
		Old	New	PhoneCall	Email	App	Onsite	1	2	3
α_0	7	1	0	1	0	0	0	1	0	0
α_1	2	1	0	1	0	0	0	1	0	0
α_1	2	0	3	1	0	0	0	1	0	0
α_2	3	1	0	1	0	0	0	1	0	0
α_2	3	1	0	0	0.8	0	0	1	0	0
α_2	3	1	0	0	0	0.5	0	1	0	0
α_2	3	1	0	0	0	0	1.2	1	0	0
α_3	1	1	0	1	0	0	0	1	0	0
α_3	1	1	0	1	0	0	0	0	2	0
α_3	1	1	0	1	0	0	0	0	0	3

From the above example of building a time equations, the time equations for all other activities can be developed, and then the indirect costs can be allocated to the trip by using the time equations.

During the implementation of the TDABC-FTC, the problems faced by carriers are a lack of essential quantitative data to support to build time equations and the time estimate rates for Discrete and Boolean activities. A formal time-tracking system and book-keeping can be performed to enhance the ability to solve these problems.

Chapter 4 Modeling relations between driving behavior and fuel consumption

4.1 Introduction

This chapter focuses on the identification of driver characteristics based on driver's operation behavior, namely, the identification of driving behavior characteristics, and development of a relationship between driving behavior and fuel consumption. From the driver's performance measures on fuel consumption, a fuel consumption indicator is developed to quantify drivers in order to obtain better drivers dispatching solution.

4.2 Driver behavior and impacts

As stated in Chapter 2, the driver is a crucial factor in the truck freight transportation system because the driver has a significant effect on the whole performance of a trip. The driver's driving behavior is an energetic element. The driving behavior is a comprehensive term used to describe different concepts associated with a driver's driving actions and driving mannerisms. Among the concepts, the driving style can be defined as the way a driver uses to drive or the driving habits that have become established over a period. The habits involve speed, a threshold for overtaking, headway, and the inclination to commit traffic violations, etc.

Many factors affect vehicle gas emissions and fuel consumption, involving the features of the vehicles, the operation of drivers and the traffic management. Document [76] showed that a vehicle's speed and acceleration have a substantial effect on a vehicle's fuel consumption and gas emissions. Among the factors, engine technology is undoubtedly one of the most crucial reasons from micro-level modeling. Regarding engine types, diesel engines are more fuel-efficient than gasoline engines due to the thermal efficiency of diesel engines being about 30% higher than that of gasoline engines [77]. For example, the most widely used diesel engine technology in the light passenger market today is the supercharged common rail diesel engine with the best fuel economy performance, of which the most representative of the standard rail technology is used by Ford Motor Company. Its working principle is through high-pressure common rail and turbocharger intercooler technology to achieve the purpose of reducing fuel consumption, thus, fuel combustion is more complete.

Generally speaking, the influence factors of vehicle fuel consumption involve three aspects: wind resistance coefficient of a vehicle; engine technologies; and driver's driving habits. At the middle level between micro- and macro-level, the relationship between fuel consumption and driving behavior is very complicated. There have multiple elements impacting the fuel consumption in one trip. The amount of fuel consumption is not only associated with average speed but also influenced by fluctuations of the driving behaviors [77]. Usually, during a trip, a driver is required to operate the vehicle by some actions: start, accelerate, brake, switchgear, decelerate and stop. These actions will be repeated several times during the trip. Critical points are the timing and duration of every action and time interval between two actions.

Current research methods on driving behavior analysis involve the driving data collection, driving modeling algorithms, and applications. Driving data collection includes automotive video capture, car-mounted sensors, and the on-board diagnostic (OBD). As for modeling algorithms, there are Hidden Markov Model (HMM), support vector machine (SVM), decision trees, and other algorithms [78].

Generally speaking, the drivers in truck transportation are different in driving behaviour from that in small private car [79]. Attributes of the driver driving behavior in truck freight transportation trip are summarized as follows:

(1) Keeping stable in a certain period (i.e., quarters or year). It is hard to change driving behavior in the short term.
(2) Keeping longer stable high speed. In order to deliver to consignee quickly, a driver would like to choose highway and drive the truck with high speed.
(3) Transporting heavy loads leading to big inertia. Drivers prefer to hold heavy loads to reduce operational costs. It is hard to harsh accelerating or harsh braking frequently due to heavy loads and high speed.

Engine speed is one of the most critical parameters in the engine output data. Theoretically, the best driving style has not only high vehicle speed and low engine speed but also can make the truck passing the low-efficiency area of an engine in the shortest time. Vehicle speed may respond to the driver's operation directly, which shows current driving status speeding or normal speed.

4.3 Definition of driving behavior parameters

Though many parameters may be chosen to describe driver behavior, common driving behavior parameters used in an analysis of associated fuel consumption involve speed-related driving behavior, turn-related driving behavior, and other types of driving behavior. Speed-related driving behavior types include average speed, speeding, harsh acceleration, harsh braking, harsh acceleration frequency, and harsh braking frequency. Turn-related driving behavior types involve sharp turn, acceleration before a turn, and over-braking before exiting a turn. Detailed parameters definition can be found in following Table 6 [80].

Table 6: SPEED RELATED DRIVING BEHAVIOR TYPES

Behavior name	Description
Harsh acceleration	Harsh acceleration threshold value in accordance with the speed is internally set. Harsh acceleration is recognized if acceleration data exceeds the threshold value.
Harsh deceleration	Harsh deceleration threshold value in accordance with the speed is internally set. Harsh braking is recognized if the braking data for a trip exceeds the threshold value.
Speeding	Over speed threshold value per road type is set. Speeding is recognized if the speed data for the trip exceeds the threshold value. You can configure the threshold for speeding.
Frequent stopping	A stop is detected when the speed value is zero. Frequent stops are recognized if there are many stop instances within a certain time frame in the trip.
Frequent acceleration	Acceleration threshold value in accordance with the speed is internally set. Frequent acceleration is detected if the driver frequently exceeds the threshold value within a certain time frame during the trip.
Frequent deceleration	Deceleration threshold value in accordance with the speed is internally set. Frequent deceleration is recognized if the driver exceeds the threshold value frequently within a certain time frame during the trip.

Table 6 presents the detailed definition of driving behaviour parameters. These qualitative definitions are difficult to be applied in quantitative judgment of a driver. Mathematical definitions are provided here to describe some driver behavior parameters [80].

(1) Harsh deceleration: speed suddenly drops with high deceleration,

- $V_n < V_{n-1}, and\ V_{n-1} - V_n > d$ (7)

  where V_n is current speed, V_{n-1} is previous speed, d is the threshold value of deceleration.

(2) Harsh acceleration: speed suddenly increases with high acceleration,

- $V_n > V_{n-1}, and\ V_n - V_{n-1} > a$ (8)

  where a is the threshold value of acceleration.

From these two equations, how to set the threshold values of a and d is essential to evaluate the performance of driver behavior. It is hard to obtain exact threshold values for a and d from research documents. Carriers always estimate the threshold values according to their practical situations including road, vehicles, and weather. The following are examples of the definition of driving behavior parameters according to the set threshold values. These values depend on actual transportation environment and vehicles situation.

(1) Hard acceleration: when $a > 2.74\ \mathrm{m/s^2}$ lasting for a certain period (e.g. 5 seconds).

(2) Hard deceleration: when $d < -2.74\mathrm{m/s^2}$ lasting for a certain period (e.g. 5 seconds).

(3) Normal acceleration: when $0.1\ \mathrm{m/s^2} < a < 2.74\mathrm{m/s^2}$ lasting for a certain period (e.g. 5 seconds).

(4) Normal deceleration: when $-2.74\mathrm{m/s^2} < d < -0.1\mathrm{m/s^2}$ lasting for a certain period (e.g. 5 seconds).

(5) Speeding: when present speed exceeds the speed limits of roads. Here, we set speed limits as $\mathrm{v}_l = 90\frac{\mathrm{km}}{\mathrm{h}}$ or $60\frac{\mathrm{km}}{\mathrm{h}}$ for highway or urban, respectively.

(6) Idle time: when an engine is on and speed is zero lasting for a certain period (e.g. 3 seconds).

4.4 Modeling relations between driving behavior and fuel consumption rate

4.4.1 Block diagram of the modeling method

This section provides an approach of fuel consumption rate estimation. The fuel consumption estimation flowchart is shown in Figure 13. Firstly, the collected data, vehicle speed, actual load, and fuel consumption rate, are used to predict the fuel consumption by data acquisition devices equipped in trucks including OBD-II and GPS tracker. Those data are processed to obtain driving behavior parameters including the frequency of harsh acceleration, the frequency of harsh deceleration, the frequency of normal acceleration, and the frequency of normal deceleration, idle time rate, and fuel consumption rate. In the next step with those driving behavior data and fuel consumption data, the neural network toolbox in MATLAB is utilized to train and generate the predictive relationship function of driver behavior components and fuel consumption rate. When a set of new driver behavior components is input into the trained net, a new fuel consumption rate can be produced. Finally, a fuel consumption indicator of drivers is developed to represent the relative fuel consumption rate of drivers with different driving behavior parameters.

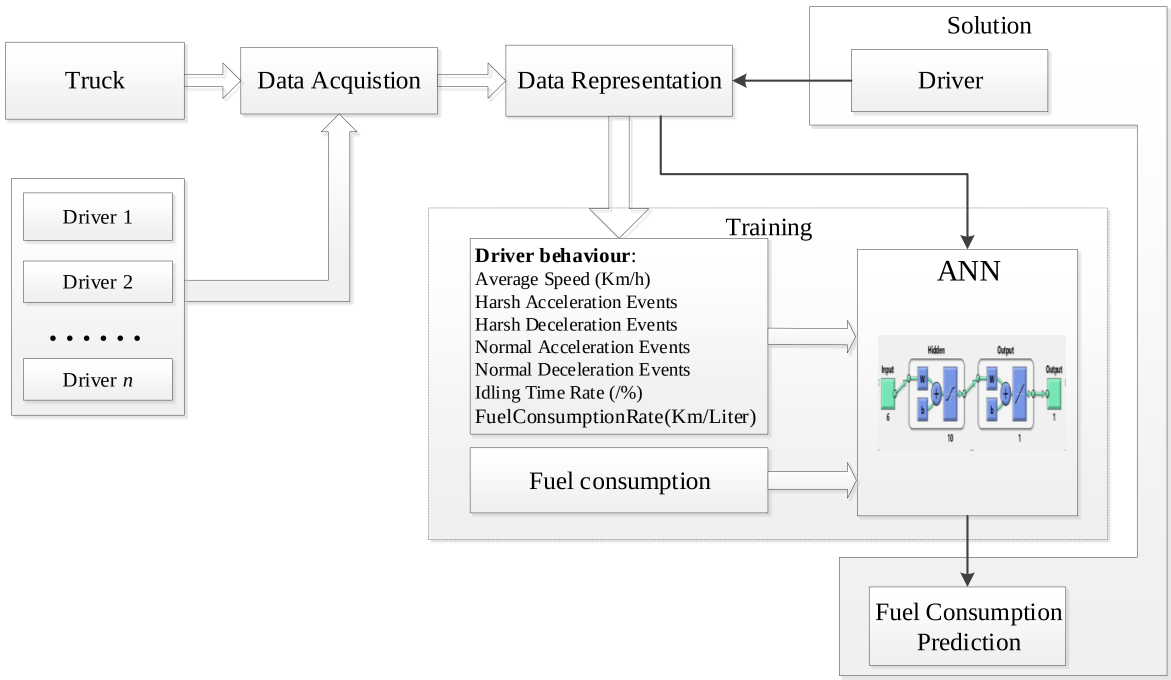


Figure 13: Relation Model for Driving Behaviours and Fuel Consumption

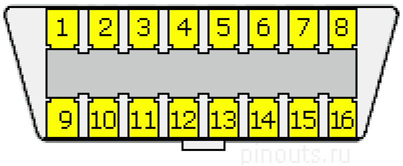
This modeling method provides a simple way to estimate fuel consumption rate only by using driving behavior pattern, and meanwhile to determine driver's fuel consumption index by a set of driving behavior parameters. Through the research result, it is helpful to evaluate driver behavior easily and to obtain optimal driver dispatching solution.

4.4.2 Data acquisition devices

(1) On-board diagnostic system (OBD II)

On-board diagnostics (OBD) is an automotive term describing a vehicle's self-diagnostic and reporting capacity. OBD systems give the vehicle owner or repair technician access to the status of the various vehicle subsystems. The on-board diagnostic system (OBD II) is a standard which was developed in the USA in 1996 by the Society of Automotive Engineers (SAE) [81]. This specification was developed for all manufactured vehicles to satisfy the requirement of the regulation of vehicle emissions issued by the Environmental Protection Agency (EPA). Thus, since 1996 all vehicles are required to be equipped with OBD II under EPA regulation in the USA. When vehicle exhausts higher level of pollution emission contents, OBD II will generate a Diagnostic Trouble Code (DTC) messages and check engine light will display. Meanwhile, OBD II will store this DTC in the memory of ECU. Then the DTC messages can be retrievable through an OBD II scan tool [82]. In addition to gas emission data, users can obtain other vehicle data through OBD II. Fuel consumption calculations from an OBD-II interface device makes it possible accurate measurement of fuel consumption. If the vehicle does not have a device connecting to an OBD-II interface, it is hard to estimate fuel consumption.

Primary attributes of OBD II include: (1) unified J1962 16-pin socket and data link connector (shown in Figure 14(a)). Among these 16 pins, nine of them have fixed functions, and the rest of them are left to the discretion of the vehicle manufacturer; (2) unified DTC and meanings (shown in Figure 14(b)); (3) storage and display of DTC; (4) containing vehicle record capacity; (5) auto-clear and reset function for the DTC. Therefore, under such a standard definition OBD II scan tool can perform the diagnosis and scan against a variety of vehicles equipped with OBD II system.



PIN	Description	PIN	Description
1	Vendor Option	9	Vendor Option
2	J1850 Bus Plus	10	J1850 Bus Minus
3	Vendor Option	11	Vendor Option
4	Chassis Ground	12	Vendor Option
5	Signal Ground	13	Vendor Option
6	CAN(J-2234)High	14	CAN(J-2234)Low
7	ISO9141-2 K-Line	15	ISO914102L-Line
8	Vendor Option	16	Battery Power

(a) (b)

Figure 14: OBD Pins Layout and Meaning

(2) GPS tracker

A GPS tracker is a device that uses the GPS to determine and track a moving vehicle's precise location (shown in Figure 15). The recorded location data can be stored within the tracking unit, or it may be transmitted to a central location database, or internet-connected computer by a cellular, radio or satellite modem embedded in the unit. In truck freight transportation companies, carriers may install GPS tracker by plugging into the OBD port of a vehicle to track the real-time location of a vehicle [83].

Figure 15: Picture of GPS Tracker

(3) CAN-bus system

The Controller Area Network (CAN, also known as CAN bus) is a vehicle bus standard designed to allow electronic control units and devices to communicate with each other in applications without a host computer. As an alternative to conventional multi-wire looms, CAN bus allows various electronic components (such as electronic control units, microcontrollers, devices, sensors, actuators and other electronic components throughout the vehicle) to communicate on a single or dual-wire network data bus up to 1 Mb/s.

The CAN Bus is not only a message based protocol, designed originally for multiplex electrical wiring within motor vehicles, but also can be used in many other contexts. Figure 16 presents a simplified schematic diagram of the CAN system and shows some of the possible units/devices that can be connected to the CAN bus [84].

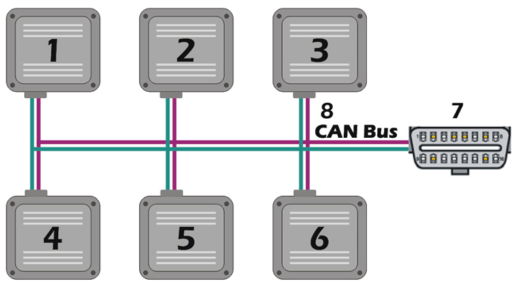


Figure 16: CAN System Schematic Diagram

(1) Engine Management Electronic Control Unit

(2) Transmission Electronic Control Unit

(3) Anti-Lock Braking Electronic Control Unit

(4) Traction Control Electronic Control Unit

(5) Airbag Electronic Control Unit

(6) Power Steering Electronic Control Unit

(7) On-Board Diagnostic (OBD) Connector

(8) Controller Area Network (CAN Bus)

In current work, a tool connecting to the OBD connector has been developed, and the engine parameters can be collected in real time. The tool is based on an automotive pc with

OBD/CAN interface, a GPS tracker, and a Wi-Fi interface to transfer the data to a database located in a central server. The parameters collected with high frequencies (1-10Hz) include rpm, vehicle speed, current location, transporting direction, and time, etc..

4.4.3 Data representation and processing

Though these instruments, OBD and GPS Tracker, are used to obtain the fuel system status, vehicle speed, and engine revolutions per minute (RPM), truck owners need to pay a higher cost to equip these instruments. Moreover, these methods cannot support estimating fuel consumption rate from driver behaviors explicitly. Data processing function will handle the original data from data acquisition devices to satisfy the modeling requirement. That means we need to develop data representation to describe driving behavior.

From section 4.3, we have the definitions of driving behaviors. The critical parts are the thresholds. This study is associated with long-haul truck freight transportation. In North America, trucks in long-haul transportation always travel mainly through a highway with larger gross vehicle weight. Drivers usually keep the similar driving pattern in a specific period (e.g., several months or year).

Table 7 shows part example data of a driver in a trip from Hinton Alberta to Clearwater British Columbia obtained by OBDⅡ and GPS tracker. The total mileage is 391 km and lasts for nearly 4 hours, so the average speed is 98.2km/h.

In this project, ten drivers and trucks were chosen as the research objects. Each truck was installed a set of OBDⅡ and GPS tracker as a tracking tool to record detailed data. After three months, all the data were collected and stored in a central database.

In order to reduce the influence of road conditions, weather and vehicle status on fuel consumption, six driving behaviour parameters for each driver are developed by arithmetic average method that are average speed, average harsh acceleration events, average harsh deceleration events, average normal acceleration events, average normal deceleration events, average idle time rate, and average fuel consumption rate. Normalization is applied to consider different trucks, loads, roads and traffic conditions. Finally, ten drivers' driving behavior parameters are summarized in Table 8.

Table 7: EXAMPLE DATA OBTAINED THROUGH OBDⅡ AND GPS TRACKER

DATE-TIME	SPEED(Km/h)	ADDRESS	LONGITUDE	LATITUTE
2018-03-15 17:00	58.2	HWY-16 W,Hinton,Alberta	53.38901	-117.615647
2018-03-15 17:01	0	HWY-16 W,Hinton,Alberta	53.384572	-117.621083
2018-03-15 17:02	60.3	HWY-16 W,Hinton,Alberta	53.37995	-117.626395
2018-03-15 17:03	93.4	HWY-16 W,Yellowhead County,Alberta	53.370593	-117.637205
2018-03-15 17:04	97.7	50516 HWY-16 W,Yellowhead County,Alberta	53.359323	-117.653172
2018-03-15 17:05	93.4	50418 HWY-16,Yellowhead County,Alberta	53.347448	-117.663868
2018-03-15 17:06	95.4	50330 HWY-16,Yellowhead County,Alberta	53.334135	-117.673602
2018-03-15 17:07	92.9	50312 HWY-16,Yellowhead County,Alberta	53.32391	-117.690323
2018-03-15 17:08	96	50262 HWY-16,Yellowhead County,Alberta	53.312878	-117.705312
2018-03-15 17:09	92	50114 HWY-16,Yellowhead County,Alberta	53.299538	-117.715847
2018-03-15 17:10	99	50014 HWY-16,Yellowhead County,Alberta	53.28739	-117.728308
2018-03-15 17:11	103.3	49776 HWY-16,Yellowhead County,Alberta	53.275675	-117.743247
2018-03-15 17:12	110.1	49570 HWY-16,Yellowhead County,Alberta	53.263342	-117.760478
2018-03-15 17:13	88.5	49424 HWY-16,Yellowhead County,Alberta	53.251242	-117.774997
2018-03-15 17:14	98.1	HWY-16,Yellowhead County,Alberta	53.239715	-117.789622
2018-03-15 17:15	97.9	HWY-16,Yellowhead County,Alberta	53.237707	-117.815592
2018-03-15 17:16	85.2	HWY-16,Yellowhead County,Alberta	53.228297	-117.828553

Table 8: DRIVING BEHAVIOUR PARAMETER OF DRIVERS

DriverID	Average Speed	Harsh Acceleration Events	Harsh Deceleration Events	Normal Acceleration Events	Normal Deceleration Events	Idle Time	Idle Time Rate	Fuel Consumption	Fuel Consumption Rate
	(km/h)					(s)	%	L	Km/L
D001	94	27	18	32	21	122	2.65	15.3	7.84
D002	98	3	9	38	35	203	4.61	13.9	8.63
D003	112	5	28	38	35	165	4.28	9.3	12.9
D004	97	2	7	47	32	191	4.29	19	6.32
D005	91	8	7	50	30	158	3.33	17.1	7.02
D006	91	25	28	47	24	102	2.15	10.6	11.32
D007	100	17	21	31	31	259	6	17.7	6.78
D008	98	6	22	44	29	154	3.49	10.5	11.43
D009	109	17	25	39	47	112	2.83	14.9	8.05
D010	109	21	16	44	34	231	5.83	8.6	13.95

4. 5 Capturing relations of driver behavior and fuel consumption by ANN

Driving style has emerged as an essential determinant of fuel economy [85]. A large number of research results show that driving style can be influenced to improve fuel economy as well as other aspects such as gas emission. However, it is not clear which are the most appropriate and influential factors that have an impact on driver's driving style related to fuel economy. In document [86] acceleration and average speed were found to have the highest influence on fuel economy. However, due to a complicated relationship between driving behavior parameters and fuel consumption and gas emission, it is hard to build a general mathematical model to cover all different transportation situations.

Artificial Neural Networks (ANNs) are computing systems inspired by the biological neural networks which are the main components of animal brains [87]. Such systems can "learn" tasks by considering examples liking human study, generally without task-specific programming. They perform this without a priori knowledge about research objects. An ANN is based on a collection of connected nodes called neurons. Each connection between neurons can transfer a signal from one to another. The neuron that receives the signal can process it. Typically, neurons are organized in layers. Different layers may do different kinds of transformations on their inputs.

From a mathematical standpoint, ANNs can be considered as "black boxes", and serve as an essential analysis and modeling tool for multivariate data sets. ANNs are capable of performing a variety of tasks including prediction, pattern recognition, and other applications [88]. Thus, ANNs is chosen as a modeling tool to analyze the relationship between driver's driving behavior parameters and fuel consumption rate in truck freight transportation trip. Artificial Neural networks have been successfully utilized in classification, identification, and pattern reorganization in various applications such as traffic congestion prediction [89], driver behaviour analysis [90], roadway type detection [91], and performance analysis [92].

4.5.1 Neural Network model

One of the most simple and popular neural networks is the back-propagation learning algorithm. It is a systematic training method for multi-layer perceptrons. Figure 17 is a multilayer BP neural network. In this figure, $x_1, x_2, \dots, x_n$ are input neurons, $y_1, y_2, \dots, y_n$ are output neurons. In this study, the multi-layer feed-forward neural networks were used. The neural networks were trained using the Levenberg-Marquardt back-propagation algorithm.

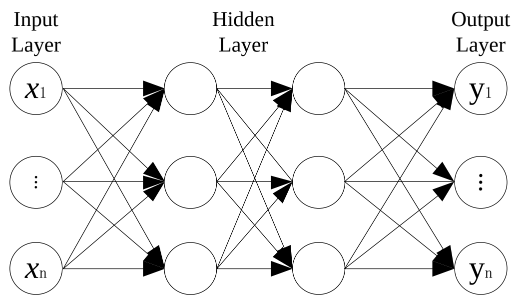


Figure 17: Typical Neural Network Structure Diagram

4.5.2 Network architecture

Building the NN architecture is to determine the number of layers of each type and the number of neurons in each of these layers. The input layer is responsible for receiving data, signals, features, or measurements from the external environment. It is common to set exactly one input layer for neural network. As for the number of neurons in this layer, this parameter is determined when the shape of training data is known. Here, the number of neurons of the input layer is equal to the number of driver behavior parameters. Output layer is responsible for producing and presenting the final network outputs, which result from the processing performed by the neurons in the previous layers. Same as the input layer, every NN has exactly one output layer. The number of neurons is determined by the output value in the relational model. Here the number of neurons in the output layer is one. Hidden layers are used to perform most of the internal processing from a network. In most situations, one hidden layer is sufficient for the large majority of problems. However, the number of neurons in the hidden layer is hard to determine. The number of neurons in the hidden layer is significant to training performance of a neural network. The fitting ability of the network improves with the number of nodes in the hidden layer increasing. Less number of hidden neurons cannot obtain satisfied fitting ability. A larger number of neurons in a hidden layer will increase training time significantly. Extensive research has been done in evaluating the number of neurons in the hidden layer, but still, none was accurate [93]. One empirical formula is used to calculate the range of hidden layer neurons, and the trial and error is performed to determine the actual number. The empirical formula commonly used is as follows [94]:

$$N = \sqrt{n + m} + k \tag{9}$$

where N is the number of hidden layer neurons, n and m is the number of input layers and output layers respectively, and k is a constant which can choose randomly from 1 through 10.

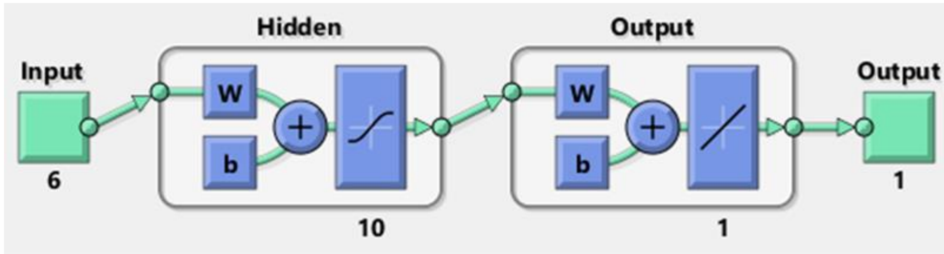


Figure 18: Neural Network Graph by MATLAB

The standard network that is used for function fitting is a two-layer feed-forward network, with a sigmoid transfer function in the hidden layer and a linear transfer function in the output layer. This kind of neural network can fit multi-dimensional mapping problems arbitrarily well. The default number of hidden neurons is set to 10. A neural network is built by MATLAB toolbox with one input layer with six input neurons, one hidden layer with default ten neurons and one output layer with one neuron (shown in Figure 18).

4.5.3 Network training and validation

The network training phase consisted of three steps: training the network, validating the network, and testing the network. The dataset was randomly divided into three different subsets in the following manner: 70% for training, 15% for validation, and 15% for testing. The training dataset was utilized to train the network. The validation dataset was adopted to monitor the network performance and generalization capabilities of the network. The test dataset was to compare the quality of the relationship model when the network is trained and validated.

When the dataset was separated into three subsets as setting values, the random initial weights and bias values were initiated to conduct the network training process. The network was trained using batch learning mode where the weights and biases were updated after each iteration. Mean Squared Error (MSE) is a measurement to evaluate the performance of the network. From MATLAB Neural Network Toolbox, the network training will be terminated when the validation performance failed to decrease in six consecutive iterations. An overview of the ANN training phase for the relationship between driver behavior and fuel consumption rate, along with the network performance results are presented in Table 9.

Table 9: ANN PARAMETERS SETTING AND PERFORMANCE RESULTS

	Items	Value
NN Setting	Network Training	Batch Training
	Learning Algorithm	Levenberg-Marquardt
	Training Dataset	70%
	Validation Dataset	15%
	Testing Dataset	15%
	Performance Criterion	MSE
	Epochs	7
Performance Results	Training Performance	0.95
	Validation Performance	0.46
	Testing Performance	0.31

4.5.4 Network Results and Analysis

After the training phase by MATLAB Neural Network Toolbox, we can obtain the network results and analyze the effectiveness of the network in modeling the relationship between driver behavior dataset and fuel consumption rate data. Figure 19 shows the performance of the network at each epoch during the training phase from training, validation, and testing. The best performance of the network was obtained at epoch 7 when the validation error was at its minimum.

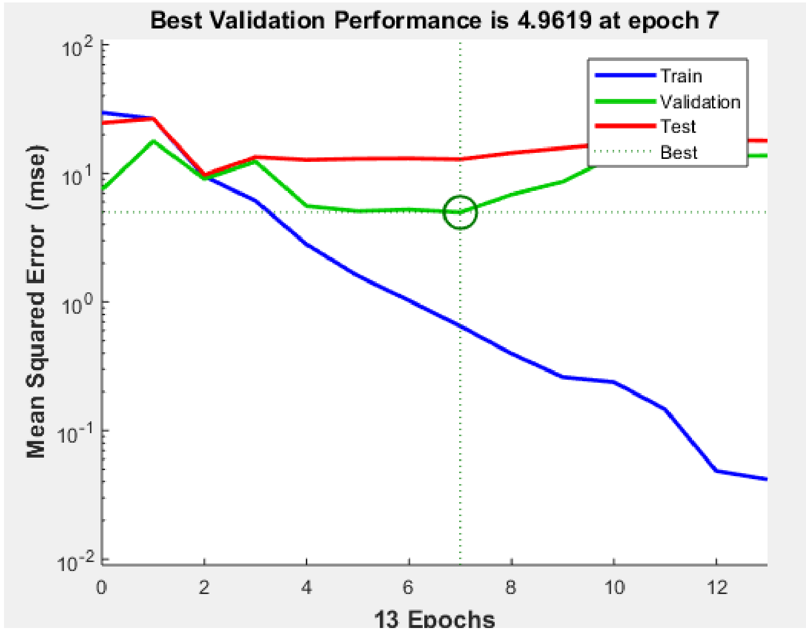


Figure 19: Performance of the Neural Network

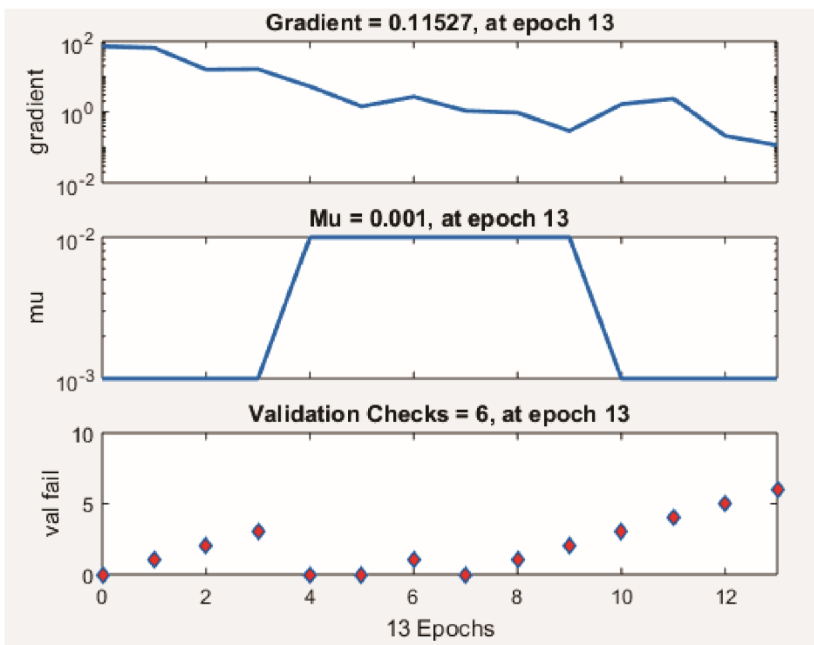


Figure 20: Training State Graph

Figure 20 presents the training state graphs with MSE performance function and transig activation function the Gradient=0.11527 at epoch 13, mu=0.001 at epoch 13 and the validation checks =6 at epoch 13.

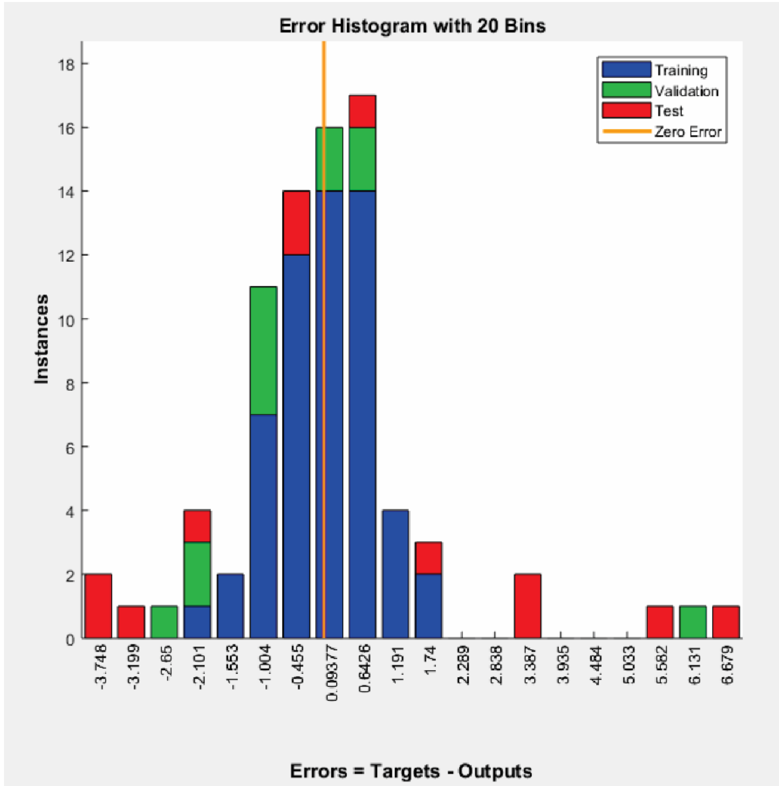


Figure 21: Error Histogram for Designed ANN

To validate the network performance, the error values between the target and the calculated network output can be shown on an error histogram (shown in Figure 21). The error histogram presents a quick visualization of the error distribution generated by the network. In this Figure, the training data is shown in blue, the validation data is presented in green, and the test data is represented in red, respectively. The shape of error histogram looks like an approximate normal distribution curve with the highest errors observed near the zero regions, which means the network is healthy.

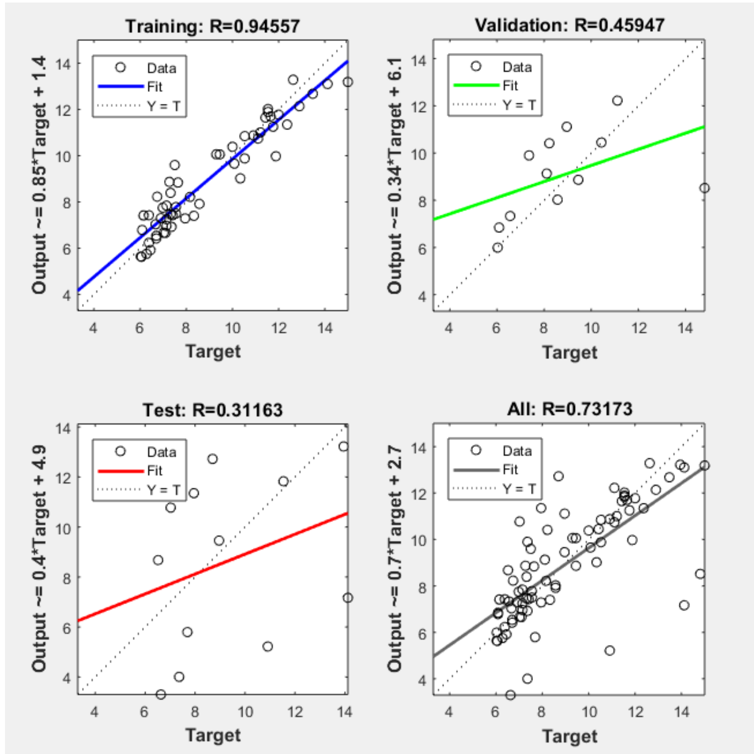


Figure 22: Neural Network Regression in Training, Validation, Testing and All

Figure 22 displays the regression analysis chart for MSE error performance function with logsig activation function. In this graph, the dashed line in each plot represents the perfect result – outputs = targets. The solid line represents the best fit linear regression line between outputs and targets. The R value is an indication of the relationship between the outputs and targets. If R = 1, this indicates that there is an exact linear relationship between outputs and targets. If R is close to zero, then there is no linear relationship between outputs and targets. Within this graph, the training R=0.94557, the test R=0.31163, and the validation R=0.45947. Finally all R=0.73173. In this research, the R values are acceptable because only a few data are used to train the ANNs. With the increasing data, the ANNs will generate more rationale result to predict fuel consumption rate.

In this study, the training data indicates a good fit. The test result also shows a large R value. The validation results show positive R values. The scatter plot is helpful in showing that certain data points have poor fits.

4.6 Fuel consumption indicators of drivers

4.6.1 The significance of evaluating driver's performance

For managers administrating a long-haul fleet, how to improve cost-profit effect is their concern. From chapter three, we know that two main operational cost components in operational cost system are driver's salary and fuel cost. Driver's behavior plays a vital role in affecting fuel consumption and emissions. Therefore, if we consider vehicle, driver, loads, and roads as a system, a driver is core and how to evaluate driver performance in the system may bring a significant amount of effect on fleet management. From the viewpoint of fuel consumption rate, quantitative evaluation refers to difference between the real amount of fuel used and an optimal value assumed the current status of vehicle and environment. Qualitative evaluation means classifying a driver's behavior into various categories, such as aggressive, normal, safe, and abnormal.

Advantages of building fuel consumption indicator:

(1) Realizing quantitative evaluation of driver.

Due to fluctuating truck freight transportation and a shortage of qualified truck drivers in North America, carriers require an evaluation system for truck drivers even though some have qualitative evaluation standard. Building quantitative evaluation indicators are more useful to evaluate drivers quickly.

(2) Easily management of drivers.

Due to the same reasons as above, carriers want to improve drivers' management, for example, job assignment and reasonable salary determination. Carriers can build salary standard according to drivers' fuel consumption indicators.

(3) Optimizing drivers dispatching in truck freight transportation.

Different drivers dispatching solution may produce different fuel consumption values due to drivers' driving behaviour. Further research will be done in the next Chapter.

4.6.2 Fuel consumption indicator of driver

To describe the impacts of driver behaviors on fuel consumption value, an indicator, $\mathrm{I}_i^{\mathrm{fuel}}$, is defined to represent the relative fuel consumption rate of driver *i*. According to the definition of fuel consumption indicator, there are three different meanings of $\mathrm{I}_i^{\mathrm{fuel}}$.

- $\mathrm{I}_i^{\mathrm{fuel}} > 1$: The driver spends more amount of fuel to drive the truck than the normal fuel consumption rate. This kind of behaviour is fuel-wasting behaviour.
- $\mathrm{I}_i^{\mathrm{fuel}} = 1$: The driver spends the same amount of fuel to drive the truck as the normal fuel consumption rate. This kind of behaviour is normal behaviour.
- $0 < \mathrm{I}_i^{\mathrm{fuel}} < 1$: The driver spends the less amount of fuel to drive the truck than the normal fuel consumption rate. This kind of behaviour is fuel-saving behaviour.

Such grouping method will help carrier develop evaluation mechanism for drivers. There are two critical issues need to be addressed: what is the normal fuel consumption rate and how to determine the value of $\mathrm{I}_i^{\mathrm{fuel}}$. In a certain transportation system including a driver, truck, loads, road and weather, etc., fuel consumption rate can be determined by mathematical model [95], or other forecasting models [96]. Due to the complicated relationship between fuel consumption and all elements in the transportation system, there is no general relationship model which can represent all the transportation system. Here I_i^{fuel} is a relative number. It is not necessary to get the exact normal fuel consumption rate. Therefore, a simple estimation method to obtain a fuel consumption rate is described in Figure 23.

(1) To obtain the fuel consumption values with different drivers in the same transportation system;

(2) To get the average of all fuel consumption values;

(3) To get the difference between each fuel consumption value and average;

(4) To divide the difference by the average;

(5) To generate fuel consumption indicator of drivers;

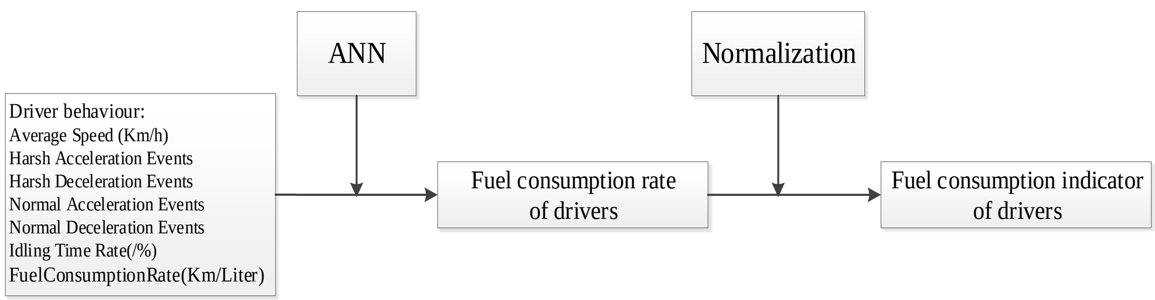


Figure 23: Process Flow of Generating Fuel Consumption Indicator

Considering the complex attribute of the relationship between driver behavior and fuel consumption and fluctuations in driver behavior characteristics, the fuel consumption indicators represent the relative fuel consumption rates of different drivers.

Chapter 5 Driver assignment model with reduced operation cost

5.1 Solution to driver assignment problem with lower total operation cost

A driver is a crucial active element in a truck freight transportation system. Different assignment combination between drivers and transportation jobs may produce different system performance and operational costs. As for carriers in intensive market competition obtaining lower total operational costs is one of the management targets.

This chapter will focus on the modeling method of driver assignment problem and solution. Driver assignment problem is modeled as a linear programming model with minimal total operational costs as an optimization target. Two kinds of solutions, Branch and Bound method and the Hungarian Algorithm, are explored. The scenarios of the assignment problem are presented, and a modified Hungarian Algorithm is developed to solve the different situations. The framework of solution for driver assignment problem is proposed in Figure 24.

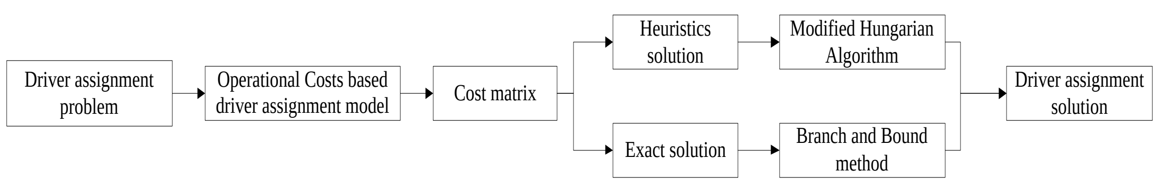


Figure 24: Solution to Driver Assignment Problem

5.2 Integrated operational costs and driver performance model

5.2.1 Operational cost in truck freight transportation

Operational costs are the expenses which are associated with the operation of a business, or with the operation of a device, component, equipment or facility. They are the cost of resources used by an organization to maintain its existence [97]. From this definition, in a truck transportation company, general operational costs fall into three broad categories:

(1) Fixed costs. Fixed costs are costs that are independent of output or trip. These keep constant no matter the vehicle is running or idle. Here, the fixed costs include vehicle cost, insurance fee, license, and permits, etc.

(2) Variable cost. Variable costs are costs that vary with output or trip. These may change with various vehicle running statuses. Here, the variable costs include fuel cost, tire wear, repair, and maintenance fee, and taxes.

(3) Labor cost. Labor costs are costs paid to drivers, including salary and bonus.

5.2.2 Driver performance model

The term *driver performance* is used to refer to the driver's knowledge, skill, and perceptual and cognitive abilities. When a driver is driving, he/she needs to perform complex operations to respond to operating environments. A comprehensive response to the situation can be thought as driver performance index. In this research, we focus on driving behavior and operational costs in truck freight transportation. Thus, the driver's performance issue associated with operational costs is matter. In addition to fuel consumption, there are other operational cost elements affected by driver behavior, such as tire wear and repair and maintenance. A large number of researches have approved that there is a relationship between a driver's behavior and fuel consumption, though the connection is too complicated to build an exact model. As for tire wear and repair and maintenance in truck transportation, it is another complex topic.

In chapter 4, a driver performance indicator, $\mathrm{I}_i^{\mathrm{Fuel}}$, is defined to describe the relationship between driving behaviour parameters of driver *i* and fuel consumption rate. The fuel consumption indicator of a driver can be estimated by this model. Though there are some researches about the effect of driver behavior on tire wear, most studies only can achieve quality results because the relationship between driver behavior and tire wear is too complicated to deal with [98]. Due to the same reason, this research just offers the quality meaning of tire wear caused by driver behavior.

5.2.3 Integrated operational cost model

Based on the definition of fuel consumption indicator of a driver, a newly integrated cost model is developed which considers the effect of driver behaviour on fuel consumption in a transportation trip. The model describes the driver's impact on total operational costs in one trip, shown in following.

$$\mathrm{C}_{i,j} = \left(\mathrm{C}_j, \mathrm{I}_i^{\mathrm{Fuel}}\right),\ i = 1,2,\dots,n, j = 1,2,\dots,m \tag{10}$$

$$\mathrm{C}_{i,j} = \mathrm{C}_j - \mathrm{C}_j^{\mathrm{Fuel}} + \mathrm{I}_i^{\mathrm{Fuel}} * \mathrm{C}_j^{\mathrm{Fuel}} \tag{11}$$

where,

$\mathrm{C}_{i,j}$: the integrated total operational cost with the influence of driver performance including fuel consumption by driver *i* in trip *j*.

C_j : the total operational cost incurred in a standard transportation trip *j* without driver's effect on fuel consumption.

$\mathrm{C}_j^{\mathrm{Fuel}}$: the regular cost of fuel consumed in trip *j*.

$\mathrm{I}_i^{\mathrm{Fuel}}$: the fuel consumption indicator of driver *i*.

i: index of drivers.

j: index of trips.

5.3 Problem description and mathematical model

5.3.1 Problem description and assumptions

In North America, especially Canada, there are a significant amount of small and medium-sized truck transportation companies with less than two hundred trucks and trailers, and a certain number of drivers. Different carriers have different management styles for truck drivers. In ordinary situations, there are two kinds of drivers in carriers: membership drivers and contracted drivers. For the former, the drivers are the members of the carrier, and the vehicles they are driving belong to carriers. The primary jobs of the drivers are to drive the truck to finish tthe ransportation job following dispatch solution from the carriers. In contrast, the contracted drivers are not the member of carriers. They drive their trucks to finish transportation jobs. The driver needs to finish carrier's freight transportation job and pays costs occurred during a trip, such as repair and maintenance, insurance fee, etc.

Firstly, a term, *trip*, is given to illustrate a complete transportation job. To finish a trip, the carrier can choose different truck and trailer to hold loads, driven by various drivers. For small and medium-sized carriers, there are several hundreds of trucks and trailers at most. Considering vehicle’s structures, a truck can hook different trailers, and a trailer can be hooked by any truck. It assumed that a truck could be driven by any driver and a driver can drive any truck. Thus, if there are m trucks, n trailers, s loads and k drivers, it involves $m*n*s*k$ combination of set {truck, trailer, load, driver}. This kind of dispatching problem belongs to NP-hard problem.

The most frequent assignment problems involve task assignment, personnel scheduling, and shift assignment. The assignment process may be allocating workers to jobs, operators to machines, drivers to trucks, trucks to delivery routes, etc. Personnel scheduling, or shift assignment, is the process of establishing work timetables for staff so that a team can satisfy the demand for its goods or services. Traditional assignment problem is a particular type of linear programming problem in which the objective is to assign n jobs to n persons at a minimum cost or maximum profit. It is challenging to obtain the right solutions to these highly constrained and complex problems, and even more difficult to determine optimal solutions that minimize cost, meet staff preference, and satisfy other constraints.

Driver assignment problem in truck freight transportation has the same features as typical personnel scheduling problem but with different requirements. This kind of problem is known as the assignment problem which is a particular case of the transportation problem. The assignment problem is a specific case of the min-cost flow problem, so it can be addressed using some optimization algorithms. Such as, the Hungarian algorithm is often chosen. The driver's assignment problem in a truck freight transportation company can be described as follows.

In a truck freight transportation company, there are some transportation trips which consist of trucks, trailers and loads, and some drivers who can operate the trucks to finish the transportation job. A driver can be assigned to perform any transportation trips, which can incur some costs that may vary with different driver-job assignment. Each trip can be allocated to any driver. The target of the assignment problem is to precisely assign one driver to a trip and one trip to a driver to finish transportation job, meanwhile obtaining minimal total operational costs.

5.3.2 Formulation of the assignment problem

Definition of terms:

Trip: It refers to a combination of a truck, a trailer and loads. Loads are put into the trailer, and the trailer is hooked to a truck. The trip will deliver loads from shipper to consignee.

Operational cost: It means the costs that were incurred during a trip from pickup stage to delivery stage of a job.

Definition of variables:

$c_{i,j}$: Operational cost of trip *j* when driver *i* is assigned to trip *j*.

x_{ij}: Decision variable, $x_{ij} = 1$ if driver *i* is assigned to trip *j*.

z_j: Total operational cost in trip *j*.

C_j^F: Fuel cost of trip *j*.

I_i^F: Fuel consumption indicator of driver *i*.

i: Index of driver, *i*=1, 2, …, *n*.

j: Index of transportation job, *j*=1, 2, …, *m*.

Object function:

$$Minimize\ z = \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} x_{ij} \tag{12}$$

s.t.

$$\sum_{i=1}^{n} x_{ij} = 1 \ \ for\ all\ j \tag{13}$$

$$\sum_{j=1}^{m} x_{ij} = 1 \ \ for\ all\ i \tag{14}$$

$$x_{ij} = \begin{cases} 1, if\ driver\ i\ is\ assigned\ to\ job\ j \\ 0, otherwise \end{cases} \tag{15}$$

$$c_{ij} = z_j + C_j^F * (I_i^F - 1) \tag{16}$$

Here, Equation (12) presents the optimization object which is to minimize the total operational cost when driver *i* is assigned to transportation job *j*. Constraint (13) shows that each trip can be assigned one and only one driver. Constraint (14) shows that each driver can assign one and only one trip. Constraint (15) is 0-1 variable. Equation (16) is total operational cost function with fuel consumption indicator of driver i.

From the above definition, the driver assignment problem in a truck freight transportation trip can be considered as a generalized assignment problem. Normally there are three scenarios need to be investigated separately when:

(1) $m = n$.

It means that the number of trips and that of drivers are equal. In such a situation, the assignment problem can be considered a symmetric assignment problem. There are many approaches to the assignment problem. A typical solution is the Hungarian algorithm [100].

(2) $m > n$.

It shows that the number of trips is bigger than the number of drivers. The Hungarian algorithm can be used to address such a situation when some adjustments required are made. Normally, one method is to add (*m*-*n*) dummy drivers to original drivers. The operational costs for all dummy drivers doing all jobs are set as zero. After the Hungarian algorithm, some trips assigned to dummy drivers have no actual drivers. Thus, these trips need to be assigned in the next dispatching period.

(3) $m < n$.

It presents that the number of the trip is less than the number of drivers. A similar method as the last condition is applied. (*n*-*m*) dummy trips are created to attend assignment. The operational costs between these dummy trips and drivers are set to zero. After the Hungarian algorithm, some drivers being assigned to dummy jobs have no actual transportation jobs.

The latter two conditions belong to asymmetric assignment problems or generalized assignment problems (GAP).

5.3 Cost matrix

The objective of the solution is to obtain an optimal solution with minimal total operational costs. We assumed that every driver could operate every trip with different operational costs and every trip can be operated by every driver. Therefore, an operational cost matrix is developed to represent the cost relationship between drivers and trips. The following defines a cost matrix.

D_i: Driver i, i=1, 2, …, n;

$[D_1 \quad D_2 \quad \cdots \quad D_n]$: Set of drivers.

I_i^F: Fuel consumption indicator of driver i, i=1, 2, …, n;

$\vec{I} = [I_1^F \quad I_2^F \quad \cdots \quad I_n^F]$: Set of fuel consumption indicators.

J_k: Trip k, k=1, 2, …, m;

$[J_1 \quad J_2 \quad \cdots \quad J_m]$: Set of trips.

(K_l, C_l): Operational cost combination incurred in trip l, here C_l is fuel cost, and K_l is the sum of all operational costs but fuel cost. l=1, 2, …, m;

$\vec{K} + \vec{I}\vec{C}$: Cost matrix of assignment problem between trips and drivers.

$$\vec{\mathrm{K}} + \vec{\mathrm{IC}} = \begin{bmatrix} \mathrm{K}_1 + I_1^F \mathrm{C}_1 & \cdots & \mathrm{K}_1 + I_n^F \mathrm{C}_1 \\ \vdots & \ddots & \vdots \\ \mathrm{K}_m + I_1^F \mathrm{C}_m & \cdots & \mathrm{K}_m + I_n^F \mathrm{C}_m \end{bmatrix} \tag{17}$$

Here, K_l and C_l are determined by the trip *l*. I_n^F is determined by the driver *n*.

5.4 Solution method

5.4.1 Branch and Bound algorithm

The branch-and-bound (B&B) algorithmic framework is a fundamental and widely-used methodology for generating exact solutions to NP-hard optimization problems [99]. B&B uses a tree search strategy to implicitly enumerate all possible solution to a given problem, applying pruning rules to eliminate regions of the search space that cannot cause a better solution. Thus, the algorithm can find a better solution through a series of procedures.

The principle of B&B approach is that the whole set of feasible solutions can be partitioned into smaller subsets of solutions. These smaller subsets can then be evaluated systematically until the best solution is found. When the B&B approach is applied to a mixed integer programming problem, it is used in conjunction with the normal non-integer solution approach. Three key issues in B&B are (1) lower bounding, (2) branching rule, and (3) searching rule.

(1) A lower bound scheme

Bounding means to estimate a bound on the solutions in the sub-tree rooted at the active node. In a minimization problem, an upper bound on the optimal solution is provided by any feasible solution, since if y is the cost of a feasible solution, then the optimal solution $y^* \leq y$. The tightest upper bound is provided by the cost of the best solution we have found. A lower bound can sometimes be calculated on the cost obtainable within a given set of solutions. If this lower bound is higher (less good) than the upper bound we already have, then it is not worth enumerating these solutions.

(2) Branching rule

Branching decisions must be made on some points in the search tree. Any nodes when their bounds are less than the minimum bounds of all feasible solutions so far are likely to be the target of branching. Two branching rules are commonly utilized.

- Queue FIFO rule. After calculating the bounds, the boundaries of all the current leaf nodes in the search tree are compared with the bound. The node with the smallest bound is found for the next branch.
- Priority queue rule. The nodes with the smallest lower bound are chosen for the next branch from the newly generated subsets.

(3) Searching rule

- Depth-first searching. This will construct feasible solutions sooner.
- Breadth-first searching. This may prune more of the search tree sooner.
- Best-first searching. This will explore the sets with better bounds firstly.

Standard procedures of the B&B are described as follows:

Step 1: to build root.

Step 2: to select a leaf of the branching tree, i.e., a sub-problem which is not divided into further sub-problems. Estimate the lower bound of leaves of this node.

Step 3: to divide the sub-problem into further sub-problems (branches), define their relaxation.

Step 4: to solve each newly relaxed sub-problem and check if it belongs to one of the cases mentioned above. If so, it is fathomed and no further investigation. If no, store this sub-problem for further branching.

Step 5: if a new feasible solution is found which is better than the current best one, then delete the stored branches having an upper bound less than the value of the latest best feasible solution.

5.4.1.1 Numerical Example and Analysis

A numerical example is processed to illustrate the procedures of B&B. This example is from a driver assignment problem between trips and drivers, and the cost matrix is built as Table 10 below. Each cell in the cost matrix represents the total operational cost when job *j* (column) is assigned to driver *i* (row).

Table 10: COST MATRIX OF A DRIVER ASSIGNMENT EXAMPLE (Unit: $)

	J001	J002	J003	J004
D001	204	281	357	714
D002	210	289	368	735
D003	183	252	320	641
D004	194	266	339	678

Through the Branch and Bound method, the assignment results are presented in Table 11. The total operational cost is $1471. From this table, it is clear that some jobs are not assigned to drivers with the minimal operational cost, though the total assignment solution is for minimal total operational costs. For example, Job ‘J001’ is done by Driver ‘D002’ with cost value ‘210’ that is maximal among all costs for Job ‘J001’.

The full searching procedures of Branch and Bound method and results are displayed in Figure 25.

Table 11: OPTIMAL ASSIGNMENT SOLUTION (Unit: $)

Job	Driver	Cost
J001	D002	210
J002	D001	281
J003	D004	339
J004	D003	641

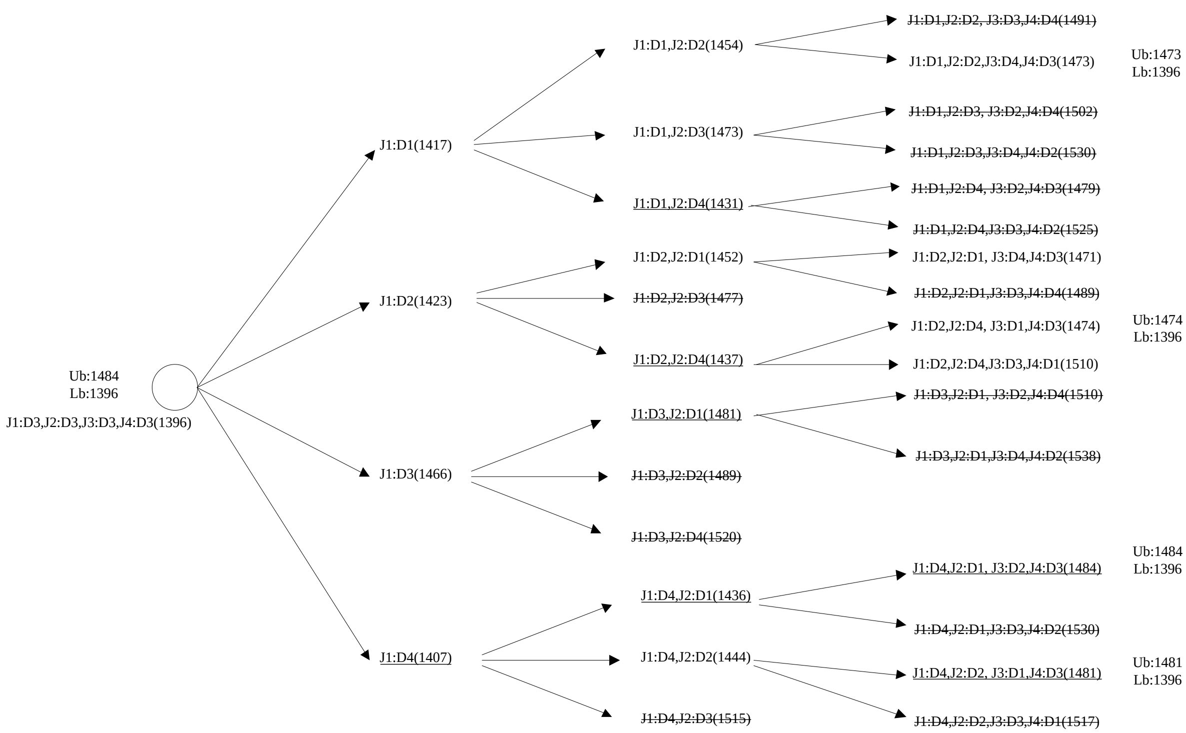


Figure 25: Full Searching Tree of Branch and Bound Method

It is well known that the B&B method can guarantee to obtain an exact solution for this kind of optimization problem. However, the effort required to solve an integer linear program problem increases exponentially with the size of the problem. Although it is not necessary to generate every single possible node by the B&B algorithm, the potential number of nodes required to explore for a significant problem is resource intensive. Another heuristics, the Hungarian algorithm, can be utilized for job assignment problems.

5.4.2 Hungarian algorithm

Theorem 1: If a number is added to or subtracted from all of the entries of any one row or column of a cost matrix, then an optimal assignment for the resulting cost matrix is also an optimal assignment for the original cost matrix.

Assignment problems can be formulated with techniques of linear programming and transportation problems. Due to the particular structure of this kind of problem, it can be solved by a special method called the Hungarian algorithm. The Hungarian algorithm is a combinatorial optimization algorithm that solves the assignment problem in polynomial time, which is developed and published in 1955 by Harold Kuhn [100] from principles of Theorem 1. To use this algorithm, one needs to obtain only the cost of making all the possible assignments. Each assignment problem has a matrix associated with it.

In actual driver assignment problem, there exist some specific scenarios which contribute difficulty in application of Hungarian algorithm. For example, one individual driver cannot be assigned to one particular trip, or one specific driver has to be attached to a particular trip. In some situations, the number of trips does not equal the number of drivers. So assignment problems can be separated into two kinds: balanced assignment problem and unbalanced assignment problem (sometimes called generalized assignment problem) depending on whether the number of trips does equal the number of drivers.

For balanced assignment problem with $n*n$ cost matrix, the ordinary procedures of the Hungarian Algorithm are shown below [101].

Step 1: to generate cost matrix c from the assignment problem.

Step 2: to identify the minimum number in each row and subtract it from every number of that row.

Step 3: to identify the minimum number in each column and subtract if from every number of that column.

Step 4: to make the assignments for the reduced matrix obtained from the above two steps in the following way:

Step 4.1 for each row or column with a single 0 value cell that has not been assigned or eliminated, to box that 0 value as a designated cell.

Step 4.2 for every 0 becomes assigned, to cross out all other 0s in the same row and the same column.

Step 4.3 if for a row and column, there are two or more 0s and one cannot be chosen by inspection, to select the cell arbitrarily for assignment.

Step 4.4 to continue the above process until every 0 cell is either assigned or crossed.

Step 5: an optimal assignment is found when the number of assigned cells equals the number of rows or columns. If no optimal solution is found, go to step 6.

Step 6: to draw the minimum number of vertical and horizontal lines to cover all the 0s in the reduced matrix obtained from step 4 by following procedures:

Step 6.1 to mark all the rows that do not have assignments.

Step 6.2 to mark all the columns (not marked) which have 0s in the marked rows.

Step 6.3 to mark all the rows which have assignments in marked columns.

Step 6.4 to repeat 6.2 and 6.3 until no more rows or columns can be marked.

Step 6.5 to draw straight lines through all unmarked rows and marked columns.

Step 7: To select the smallest number of all the uncovered numbers. To subtract this smallest number from all the uncovered numbers and add it to the numbers which lie at the intersection of two lines. Finally, to obtain another reduced matrix for a new assignment. Go back to Step 4.

Step 8: To obtain minimal operational cost from the assignment solution.

5.4.2.1 Numerical Example and Analysis

A numerical example of assignment problem with cost matrix shown in Table 12 is utilized to illustrate the effectiveness of the Hungarian Algorithm. The solution procedures are presented below.

Table 12: COST MATRIX OF 4*4 DRIVER ASSIGNMENT PROBLEM (Unit:$)

	J001	J002	J003	J004
D001	204	281	357	714
D002	210	289	368	735
D003	183	252	320	641
D004	194	266	339	678

Step 1: to identify the minimal number of each row and subtract the minimal number from all numbers.

Min. value of each row

$$\begin{bmatrix} 204 & 281 & 357 & 714 \\ 210 & 289 & 368 & 735 \\ 183 & 252 & 320 & 641 \\ 194 & 266 & 339 & 678 \end{bmatrix} \begin{bmatrix} 204 \\ 210 \\ 183 \\ 194 \end{bmatrix} \rightarrow \begin{bmatrix} 0 & 77 & 153 & 510 \\ 0 & 79 & 158 & 525 \\ 0 & 69 & 137 & 458 \\ 0 & 72 & 145 & 484 \end{bmatrix}$$

Step 2: to identify the minimal number of each column and subtract the minimal number for all numbers.

$$\begin{bmatrix} 0 & 77 & 153 & 510 \\ 0 & 79 & 158 & 525 \\ 0 & 69 & 137 & 458 \\ 0 & 72 & 145 & 484 \end{bmatrix} \rightarrow \begin{bmatrix} 0 & 8 & 16 & 52 \\ 0 & 10 & 21 & 67 \\ 0 & 0 & 0 & 0 \\ 0 & 3 & 8 & 26 \end{bmatrix}$$

$[\,0 \;\; 69 \;\; 137 \;\; 458\,]$ ⇐ Min. value of each column

Step 3--6: to make the assignment until reaching the optimal assignment solution.

$$\begin{bmatrix} 0 & 8 & 16 & 52 \\ 0 & 10 & 21 & 67 \\ 0 & 0 & 0 & 0 \\ 0 & \boxed{3} & 8 & 26 \end{bmatrix}, \text{ min.=3}$$

Minimal two straight lines cover all the number ‘0’, less than 4, to continue.

$$\begin{bmatrix} 0 & \boxed{5} & 13 & 49 \\ 0 & 7 & 18 & 64 \\ 3 & 0 & 0 & 0 \\ 0 & 0 & 5 & 23 \end{bmatrix}, \text{ min.=5}$$

Minimal three straight lines can cover all the number ‘0’, less than 4, to continue.

$$\begin{bmatrix} 0 & \boxed{5} & 13 & 49 \\ 0 & 7 & 18 & 64 \\ 3 & 0 & 0 & 0 \\ 0 & 0 & 5 & 23 \end{bmatrix}, \text{ min.=5}$$

Minimal three straight lines cover all the number ‘0’, less than 4, to continue.

$$\begin{bmatrix} 0 & 0 & 8 & 44 \\ 0 & 2 & 13 & 59 \\ 8 & 0 & 0 & 0 \\ 5 & 0 & \boxed{5} & 23 \end{bmatrix}, \text{ min.=5}$$

Minimal three straight lines cover all the number ‘0’, less than 4, to continue.

$$\begin{bmatrix} 0 & 0 & 3 & 39 \\ 0 & 2 & 8 & 54 \\ 13 & 5 & 0 & 0 \\ 5 & 0 & 0 & 18 \end{bmatrix}$$

Minimal four straight lines cover all the number ‘0'. The number of lines equals the number of trips. The optimal solution is obtained.

$$\begin{bmatrix} 0 & \mathbf{0} & 3 & 39 \\ \mathbf{0} & 2 & 8 & 54 \\ 13 & 5 & 0 & \mathbf{0} \\ 5 & 0 & \mathbf{0} & 18 \end{bmatrix} \Longrightarrow \begin{bmatrix} 204 & \mathbf{281} & 357 & 714 \\ \mathbf{210} & 289 & 368 & 735 \\ 183 & 252 & 320 & \mathbf{641} \\ 194 & 266 & \mathbf{339} & 678 \end{bmatrix}$$

After several iterations, the final assignment solution is obtained. The assignment solution is presented in Table 13, and the minimal total operational cost is $1471.

Table 13: OPTIMAL ASSIGNMENT SOLUTION (Unit: $)

Job	Driver	Cost
J001	D002	210
J002	D001	281
J003	D004	339
J004	D003	641

5.4.3 Two special scenarios

Some specific cases usually occur in actual driver assignment environment. For instance, a particular trip cannot be assigned to a specific driver, or an individual trip has to be attached to a specific driver. These two instances increase the difficulty of implementation of Hungarian Algorithm.

(1) Assigned strictly.

This method refers to a transportation job has to be assigned to a particular driver no matter what the operational cost is. Such assignment may happen when only a particular driver is very familiar with the transportation line or there is a special requirement for the driver. In this situation, a simple assignment method is to assign the job to the individual driver and cancel the assignment combination from the original cost matrix. Another way is to first change the number of cost to zero for this assignment of transportation job and driver, after assignment the cost number is returned to original value to calculate the total operational cost.

For instance, job 'J002' has to be assigned to driver 'D002' with cost '289' shown in Table 12. After direct assignment process, the cost matrix of the numerical example is reduced to a 3*3 cost matrix (shown in Table 14).

Table 14: REDUCED 3*3 COST MATRIX (Unit: $)

	J001	J003	J004
D001	204	357	714
D003	183	320	641
D004	194	339	678

After the Hungarian algorithm, the assignment solution is as following Table 15 and the total operational cost is 1473.

Table 15: OPTIMAL ASSIGNMENT SOLUTION (Unit: $)

Job	Driver	Cost
J001	D001	204
J002	**D002**	**289**
J003	D004	339
J004	D003	641

From another way, firstly we set the virtual cost value to zero for the assigned solution strictly, and the new cost matrix is as the following Table 16.

Table 16: NEW COST MATRIX (Unit: $)

	J001	J002	J003	J004
D001	204	281	357	714
D002	210	**0**	368	735
D003	183	252	320	641
D004	194	266	339	678

Through the above Hungarian algorithm, we obtained the same assignment solution as Table 15 and total operational cost as the last situation.

(2) No-assignment strictly;

In practical driver assignment problem, some jobs cannot be assigned to particular drivers due to individual requirements. It may bring out new issues. Here, a new solution for such situation is developed, which is to set the cost value to "Infinity" because we want to obtain a minimal total operational cost solution. If the optimal problem is to obtain a maximal value, just set the number of cost to zero. For example, the job 'J002' cannot be assigned to the driver 'D001'. The cost value of the cell of 'J002' and 'D001' is set to "Infinity". The new cost matrix is as Table 17 below.

Table 17: NEW COST MATRIX WITH NO-ASSIGNMENT STRICTLY (Unit: $)

	J001	J002	J003	J004
D001	204	***Infinity***	357	714
D002	210	289	368	735
D003	183	252	320	641
D004	194	266	339	678

Through the Hungarian algorithm, the assignment solution obtained is same as Table 15, and the total operational cost is the same as the last answer, which is 1473.

5.5 Comparison of the Hungarian algorithm to Branch and Bound method

Having considered the two means of solving the driver assignment problem, numerical examples were sourced and solved using the two methods. The results obtained showed that the Hungarian Algorithm has the same assignment results with that in Branch and Bound method for small-scale assignment problem, and the former can achieve the solution in less number of iteration when problem scale increases. Table 18 shows the comparison results between Branch and Bound method and Hungarian Algorithm.

Table 18: COMPARISON RESULTS BETWEEN TWO SOLUTIONS

Algorithms	Complexity/ Estimating Time	Assignment Problem Scale			
		10	10^2	10^3	10^5
Hungarian algorithm	O(n^3)	0.0025s	0.122s	17 min	32 years
Branch and Bound	O(n^3*ln^2(n))	0.54s	15 min	---	---

Due to different attributes of two methods, Branch and Bound method can deal with any kinds of job assignment problem, even for asymmetrical assignment problem; however, the Hungarian Algorithm is better to address symmetrical assignment problem. In some situation, dummy elements can be utilized to change asymmetrical assignment problem to symmetrical assignment problem.

Chapter 6 Conclusions and Future Works

6.1 Conclusions

6.1.1 TDABC-FTC for small and medium-sized freight truck carriers

The cost issue is crucial to truck freight carriers, especially to small and medium-sized carriers. Intensive competition in the freight transportation market increases carrier's operational costs. Carriers have to adopt multiple measurements to improve their profit rate. Appropriate costing method is helpful to estimate costs accurately and enhance management level.

Compared to traditional costing method and the ABC, the TDABC methodology is a better method to do costing. Due to a lack of enough resource and capital, traditional costing method and the ABC are challenging to be utilized effectively in the carriers' accounting department. The TDABC becomes a widely used costing method in logistics companies. Based on attributes of truck freight companies and implementation procedures of the TDBAC, an improved costing method, TDABC-FTC, and implantation process are developed. Hierarchy relationship of trip-activity-operation is proposed to implement the TDABC-FTC, and two parameters are estimated to create time equations and cost equations. Through TDABC-FTC it is convenient to create a costing model for small and medium-sized carriers and helpful to increase cost management level. Actual data from a carrier is chosen to validate the TDABC-FTC.

6.1.2 Modeling the relations between driver behavior and fuel consumption

Among the many elements in a transportation system, the driver is the most energetic factor. The driver’s driving behavior plays a significant effect on truck fuel consumption and fleet operational costs. However, the relations between driving behavior and fuel consumption is too complicated to present mathematically clearly though there are a large number of researches on it.

A comprehensive model framework is developed to study the relationship between driving behavior and fuel consumption rate. The OBD Ⅱ and GPS tracker are used to install objected trucks to collect data about vehicle status, including speed, location, and engine power, etc. These data are processed to describe the drier's driving behavior.

An Artificial Neural Network model is designed to build the relationship through a MATLAB toolbox. Through this model, the fuel consumption rate for a particular driver can be estimated by driver's driving behavior parameters. A fuel consumption indicator of a driver is proposed to present the relative fuel consumption rate of drivers.

6.1.3 Driver assignment problem and solutions

Minimal total operational costs based a linear integer programming model is developed to model the driver assignment problem which considers the effect of driver behavior on fuel consumption. Driver assignment problem belongs to NP-hard optimization problem. An exact solution is only available for the small-scale assignment problem. In this thesis, the B&B method is applied to solve the driver assignment problem with small scale. Modified Hungarian Algorithm is developed to solve medium and large-scale driver assignment problem, which brings out a better solution with high efficiency compared with the B&B method.

6.2 Research Contributions

Driver assignment problem is fundamentally more complex and different from conventional production scheduling and planning problem. The explicit equation based cost summary methods are no longer valid. The thesis presents a systematic study on TDABC methodology and application in small and medium-sized truck carriers, a relationship between driving behavior and fuel consumption rate, and modeling and optimization of driver assignment problem in truck freight transportation companies. The specific research contributions of this research include the following:

(1) Implemented and tested the TDABC for small and medium-sized truck freight carriers. Focusing on truck freight transportation carriers, the new TDABC-FTC method has been introduced. With this new method, the carriers can estimate and assign the indirect costs to cost objects with less effort.

(2) Modeled the relationship between driving behavior and fuel consumption by neural networks. The driving behavior parameters are built from driving cycle data. The new model made easily estimating fuel consumption rate from driving behavior parameters. A fuel consumption indicator of a driver is developed to provide a quantitative evaluation measure in terms of fuel economy. It is helpful to manage drivers scientifically. The research result can be applied in other related fields.

(3) Different from traditional, efficiency-focused optimization formulations for a scheduling problem, this research introduced a driver assignment problem with minimal total operational costs as the objective of the optimization, to improve the economic compatibility of carriers. A linear integer programming model of driver assignment problem has been developed, and B&B and modified Hungarian Algorithm have been utilized to solve the driver assignment problem to obtain minimal total operational cost.

6.3 Future works

In this thesis, only the relationship between driving behavior and fuel consumption is studied. In a practical situation, however, drivers' driving behavior will affect other elements in a truck transportation system. For example, tire wear and brake wear are other two factors. Meanwhile, in addition to driving behavior, there are other elements affecting fuel consumption, such as vehicle engine, road, and environment condition. From a different view to consider the relationship between driver behavior and fuel consumption rate, tire wear and brake wear will be next research focus.

A fuel consumption indicator for a driver is designed in this research by the arithmetical average method to measure relative drivers' performance concerning fuel economy. A new evaluation method considering multiple components should be explored in the future work.

Drivers' assignment problem is a complex combinational optimization problem. Only operation cost based drivers assignment problem is studied in this thesis. However, a different route which the driver chooses to travel also produces different fuel consumption rate. Therefore, a new driver assignment problem together with vehicle routing planning is worthy to investigate.

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