ESTIMATION OF ROAD FREIGHT TRANSPORTATION EMISSIONS IN TURKEY

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ABSTRACT

ESTIMATION OF ROAD FREIGHT TRANSPORTATION EMISSIONS IN TURKEY

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To obtain a more sustainable transportation system, it is also important to decrease both fuel consumption and carbon emissions in road freight sector, as well. The first step towards this goal is to determine the current level of road freight demand and related emissions. This is rather challenging in Turkey, because disaggregate commodity flow data does not exist. However, annual roadside axle survey, performed by the Turkish General Directorate of Highways, is a valuable source of circulation information, which are used jointly with aggregate level national freight flow statistics to develop a hybrid model in this study. Using this model, annual road freight emissions for the period of 2000 to 2009 are calculated with COPERT 4 software. The results show that CO_2 level remained almost constant during this period. Secondly, a decrease of 25% is observed in the share of rigid truck emissions, while emissions from articulated trucks are tripled. Sensitivity of the model to the available level of disaggregate data is tested via scenario analysis. Assuming 2009 emissions as the base case, emission reduction potentials are evaluated for three interventions: While emissions could be reduced up to 11% by penalizing empty movements just only in the long haul, another scenario focusing on elimination of only inefficiently loaded movements did not provide significant emission reduction capacity. A scenario of replacing Conventional trucks with Euro IV ones showed significant potential, especially for regulated emissions, and it may be the most promising option from application perspective.

Keywords: Road Freight Transportation, Roadside Axle Survey, Truck Emissions, COPERT 4

ÖZ

TÜRKIYE'DE KARAYOLU YÜK ULAŞIMI EMİSYONLARININ TAHMİNİ

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Daha sürdürülebilinir bir ulaşım sistemi elde etmek için yakıt tüketimini ve karbon emisyonlarını azaltmakta önemlidir. Bu amaca ulaşmak için ilk aşama mevcut karayolu yük talebini ve bunun yarattığı emisyonları belirlemektir. Türkiye gibi yük akış verisinin olmadığı ülkelerde bu kolay bir iş değildir. Diğer taraftan, Karayolları Genel Müdürlüğü tarafından yıllık olarak gerçekleştirilen yol kenarı dingil ağırlığı etütleri değerli bir hareketlilik verisi kaynağıdır. Bu çalışmada, bu veri ile yıllık yük akış istatistikleri bir arada kullanılarak karma bir model geliştirilmiştir. Bu model kullanılarak 2000 ile 2009 yılları arasındaki emisyonlar COPERT 4 programı ile tahmin edilmiştir. Elde edilen sonuçlara göre CO_2 emisyonları bu sürede neredeyse sabit kalmıştır. Ayrıca, standart kamyonların emisyon paylarında %25 azalma görülür iken, büyük kamyonların emisyon payları üç katına çıkmıştır. Modelin kullanılan verinin detay derecesine olan hassisiyeti duyarlılık analizleri ile test edilmiştir. 2009 yılı için hesaplanan emisyonlar temel alınarak üç farklı senaryo için emisyon azaltım potansiyelleri hesaplanmıştır: Emisyonlar, kamyonların sadece uzun mesafede boş gitmelerinin engellenmesi durumunda, %11 oranına kadar azaltılabilirken, sadece az dolu giden kamyonların ortadan kaldırıldığı senaryoda kayda değer bir emisyon azaltımı sağlanmamıştır. Geleneksel kamyonları Euro IV kamyonları ile değiştirmeyi öngören senorya ise, özellikle kontrol altında tutulan emisyonlarda, ciddi bir azaltım potansiyeli göstermiştir; ve bu senaryo sektör açısından bakıldığında en ümit vadedendir.

Anahtar Kelimeler: Karayolu yük taşımacılığı, Yol kenarı dingil ağırlığı etütleri, Kamyon emısyonları, COPERT 4

To Habip Özen

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Last but not the least; I would like to dedicate this thesis to my family. Special mention should go to my father Habip Özen who not only dedicated himself for my education, but also he gave me the backbone to be in the place, I am now.

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CHAPTER 1

INTRODUCTION

In Turkey, total transportation sector emissions almost doubled and increased to 51.8 million tons of CO_2 equivalents between 1990 and 2007. 84.2% of these emissions are from road transportation. As recent signatory of Kyoto Protocol, Turkey should develop some policies to control greenhouse gas emissions, including those from transportation sector. Freight transportation is one of the application areas, which is mainly dominated by truck transportation by 90% market share, 216,123 million ton-km and 21,223 million vehicle-km in 2012. Truck transportation ton-km increased by 6.4% in 2012 as compared to 2011 values, and this trend is expected to continue in the near future in the developing Turkey. While distances between main economic centers within Turkey are in the long haul range, for various reasons long haul domestic transport still is performed by trucks not leaving much market share for intermodal transportation in Turkey, yet. Development of some operational and technological strategies is necessary to decrease this dependency and increase efficiency of road freight movements.

Recently, Climate Change Action Plan (CCPA) prepared by the Ministry and Environment and Urbanization has some targets to achieve more sustainable transportation system. It aims to increase share of intermodal transportation to achieve balanced utilization of freight transportation modes. Specifically, the CCPA set target to increase the share of railways in freight transportation to 15% and the share of domestic maritime transportation to 10% as of 2023. Furthermore, it aims to increase the utilization of energy efficient vehicle in freight transportation.

1.1 Research Objectives

To develop better policies, road freight demand forecasting and greenhouse gas emissions have to be determined, first. Such evaluations are very challenging in the absence of disaggregate commodity flow data, which is the case in Turkey. So far, the only data source of truck freight transportation is the roadside axle load surveys performed by Turkish General Directorate of Highways. This data includes truck, trip and commodity information for approximately 10,000 truck surveyed each year. This data can enable estimation of intercity truck emissions if combined with the aggregate level national freight statistics in a hybrid manner, which is the main focus of this study. As these surveys are performed on intercity roads, the proposed model can only provide emission estimations for intercity trucking. In the calculation of emissions, COPERT 4 emission model is selected due to its moderate level data requirements which can be compiled using axle survey data, and its wide use in Europe. It is also the preferred method in the European Environment Agency's Emission Inventory Guidebook. While achieving the primary objective of estimating emissions from truck freight transportation in Turkey, it is possible to estimate emission reduction potential based on the available level of truck freight data details.

1.2 Thesis Structure

Chapter 2 mainly presents the required background necessary to study truck freight emissions, developed in two parts: The first part reviews briefly the literature on truck travel demand forecasting and related models. The second part gives the detailed review of the road freight emission studies and emission estimation models. In addition, it also focuses on truck transportation emission reduction studies in the literature.

Chapter 3 presents national freight transportation statistics of Turkey. Furthermore, it describes the nature of road side axle surveys in detail, with detailed analysis of the data between 2007 and 2009 based on truck type, commodity type, loading condition and trip distance.

Chapter 4 presents proposed methodology to calculation of road freight transportation emissions in Turkey. Challenges of the road freight transportation emission calculation in

Turkey are discussed separately. As one of the major challenges, Chapter 5 discusses the need and the current state of the truck travel demand forecasting in Turkey. Secondly, a missing piece of the truck demand modeling, the network assignment principle, is evaluated and discussed in detail, emphasizing on the mismatching of the trip distribution and assignment levels in Turkey.

Chapter 6 concludes the thesis summarizing the main findings of the research, and discussing the further research needs in the area of truck freight emissions.

CHAPTER 2

LITERATURE REVIEW

In the first part of the literature review, the history of truck traffic forecasting and network assignment models are provided. In the second part, literature on models of truck emissions are presented. Furthermore, COPERT model used in this study is presented thoroughly. Finally, studies on truck emission reduction strategies are provided.

2.1 Freight Transportation Modeling

Travel demand modeling is an essential part of transportation planning to provide reliable estimates of long term transportation flows and evaluate alternative policies accommodating future needs (Chatterjee and Venigalla, 2004). The theory of travel demand modeling is largely derived from economic theory of consumer choice (Morlok, 1978). Initial travel demand models were developed in the mid-1950s and took a standard form at the end of the 1960s. These early models mainly developed to estimate effects of capacity increments in transportation network (Ben-Akiva, 2007). Later, freight demand models have captured the interest of researchers since the 1960s (Souleyrette et al., 1960; Allen, 1977, Fries and Patterson, 2008).

Major improvements in freight demand modeling were achieved in the early 1980s (USDOT-FHWA, 1999). However, most of researches in the following few decades have focused on the passenger transportation. After many years of regret, there has been a growing interest of freight modeling due to its critical role in regional economic growth and development as well as improvements of freight transportation infrastructure, policies and regulations (Pendyala, 2002). But, it is believed that freight modeling is still less comprehensive than passenger transportation in spite of recent progresses (Pendyala et al., 2002; Tavazzy, 2006). One reason behind this issue is the limited data availability for freight transportation (Celik, 2004). Another reason is the existence of a number of different decision makers and factors in the freight transportation supply chain (Ortuzar and Willumsen, 2001; Victoria and Walton, 2004). Decision makers include producers, consumer, shippers, carriers and government (Harker, 1986; Pendyala, 2002; Horowitz and Farmer, 2009). Factors include economy, industrial location patterns, land use, globalization of business, energy availability and prices, industrial location patterns, logistic sources and practices, trade and trade agreements, packaging materials, user charges and other taxes, and the role of the country in the global economy (Cambridge Systematics, Inc. et al., 1995; Bruggeman et al., 2006). Therefore, a freight demand model is expected to be responsive to all these factors affecting freight transportation. But, due to the availability of limited data sources on some of these factors, generally simple statistical methods are used to extrapolate past trends. These factors can directly or indirectly affect truck demand (see Figure 2.1).

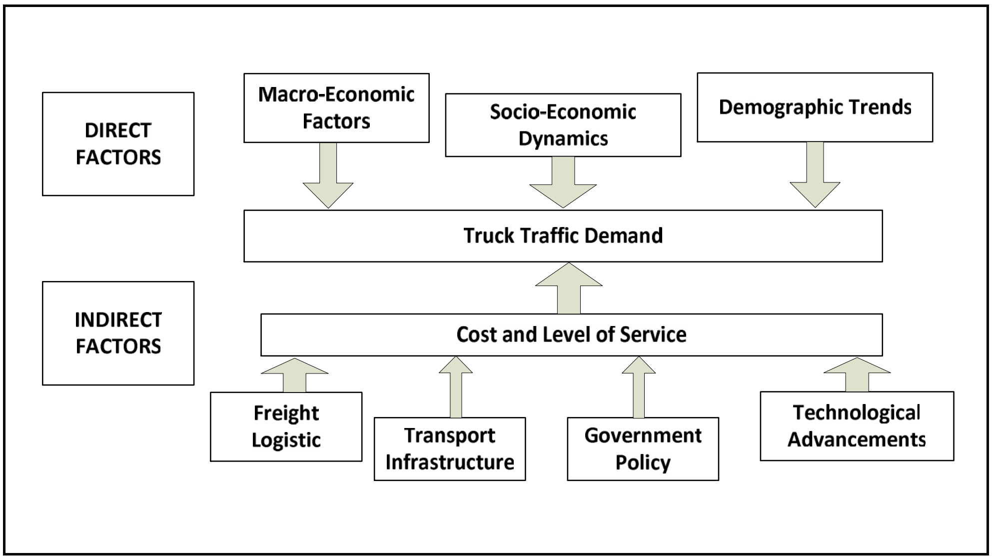


Figure 2.1 Factors affecting freight transportation demand (Source: Stone et al., 2006)

Direct factors influence the demand for truck movements. Direct factors can be grouped as follows (Stone et al., 2006):

- **Macroeconomic factors:** The level of economic activity, intermodal trade and other economic phenomena.
- **Socio-economic dynamic factors:** Changes in the habits, values, perceptions, and employment.
- **Demographic factors:** Changes in overall population, age distribution and spatial location.

It is easy to find data sources of direct factors for cities or towns, but it is difficult to integrate them into truck demand models due to variations of the trucks volumes on the highway segments, even in the same city or county. On the other hand, indirect factors influence truck demand by affecting cost and the level of service of truck transportation. It is difficult to find data for indirect factors and incorporate them into basic demand forecasting methods. These factors might be classified as follows (Stone et al., 2006):

- **Technological advances:** Intelligent transportation systems and logistics communications.
- **Government policy:** User charges and taxes, environmental and safety regulations and other public sector institutional issues.
- **Freight logistics:** Just-in-time delivery centralized warehousing facilities, industry alliances, and demand-responsive scheduling.
- **Transportation infrastructure:** The design, operation, and level-of-service of multimodal and intermodal transportation facilities.

2.1.1 Freight Demand Modeling Literature

Freight demand models can be classified as aggregate or disaggregate (Harker, 1986). The primary distinction of these two models is the level of the data used. Aggregate models use the data of total flows at regional or national level and describe behavioral characteristics of a large group of shippers. Disaggregate models focus on characteristics of the individual decision makers and shipments (Small and Winston, 1998; Zlatoper and Austrian, 1989). Actually, both aggregate and disaggregate models should eventually be derivable from individual firm behavior (Winston, 1983). On the other hand, from aggregate to disaggregate, all models have been increasingly focusing on representing individual shipments and their choices to capture the heterogeneities in movements (Ben-Akiva, 2007). Winston (1983) implied the difficulties of collecting huge amount of data to represents aspects of individual decision makers in disaggregate models. Generally, convention demand models uses aggregate level data in the presence of steady state network conditions (Harker, 1986; Ben-Akiva et al., 2007).

In the literature, a number of truck traffic estimation models have been developed and implemented to emphasize specific aspect of freight transportation (Wigan, 2005). The simplest of these approaches are the statistical models that use past traffic counts, direct and indirect variables as indicators of freight activity. These models are the least data intensive, but they do not allow evaluation of network effects such as congestion, network improvements, and changes in land use and economy (FHWA, 1999). Growth factor methods are one of these approaches that can be used to forecast the future freight demand. It can be applied based on historical traffic trends or forecasts of the economic activity. The first one involves the direct application of growth factor, calculated based on the historical traffic data to the baseline traffic data. The latter forecasts the changes in freight traffic based on the corresponding changes in economic variables, such as employment, population, income, etc. are employed to predict changes in freight traffic (Cambridge Systematics, Inc. et al., 1995).

More complicated network models use traditional planning procedures including trip generation, trip distribution, mode choice and network assignment steps (Paladugu, 2007). Truck network models can be geographically grouped as urban, regional, national and international truck models. Specifically, urban models deal with urban traffic congestion of truck movements, whereas regional, national and international models focus on economic competitiveness and efficiencies between regions and countries (Paladugu, 2007). de Jong et al. (2004) claimed that national and international level models are much more developed than urban and regional. Two different approaches are used in truck network models: a) vehicle based approach and b) commodity based approach (Boile et al., 2004; Raothanachonkun et al., 2007). Vehicle based approach focuses on the truck trip flows. It estimates trucks trips based on land use characteristics, socioeconomic, employment and travel survey data. It can be fully integrated traditional four step traffic demand forecasting process (i.e. trip generation, trip distribution, mode choice, network assignment). On the other hand, commodity approach focuses on the amount of commodity being transported.

Economic factors can be better adopted into commodity based models as compared to vehicle based models. First, commodity based approach generates and distributes the total amount of commodities. Then, it allocates the commodities to the different freight modes (e.g., road, rail, water). Finally, commodity based approach converts the total amount of commodities into an equivalent number of trips and assigns them to the corresponding networks (Paladugu, 2007).

The commodity based technique was used in the Indiana Freight Model (Bernardin, Lochmueller&Associates and Cambridge Systematics, Inc., 2004), Wisconsin Multimodal Freight Model (Wilbur Smith Associates, 2004) and Kentucky Freight Model (Wilbur Smith Associates, 2005). In the Indiana freight model, specific trip generation equations were developed for 21 commodity groups based on a regression of 1993 Commodity Flow Survey (CFS) data. Then, the gravity model was used to distribute truck flows. Finally, these flows were converted into equivalent number of trips using payloads factors determined separately for each commodity group. In the last step, the truck traffic was assigned to the highway network (Paladugu, 2007).

The Wisconsin multimodal freight model is another commodity based model to estimate freight flows of 39 commodity groups between 140 county level Traffic Analysis Zones (TAZs) considering truck, air, water and rail transportation modes. The main data source of this model was TRANSEARCH database, which provides traffic statistics between BEA (Bureau of Economic Analysis) regions by mode (water, rail, air and truck) and by commodity. Unlike the Indiana Freight model, the Wisconsin model did not have a conventional trip generation step; therefore, trip generation and attraction equations were not developed. Instead, base year TRANSEARCH flows were directly distributed between county level TAZs. The future freight volumes were estimated using econometric models that incorporated employment and productivity forecasts. Total amount of freight flows were converted into an equivalent number of truck trips. This conversion was performed separately for each commodity type using average payload values obtained previously. Finally, these flows were assigned to appropriate networks. For truck assignment, all-or-nothing principle was used. “Most likely carrier” option was selected for rail flows. On the other hand, air and water traffic were not assigned (FHWA, 1999).

2.1.2 Freight Demand Modeling in Turkey

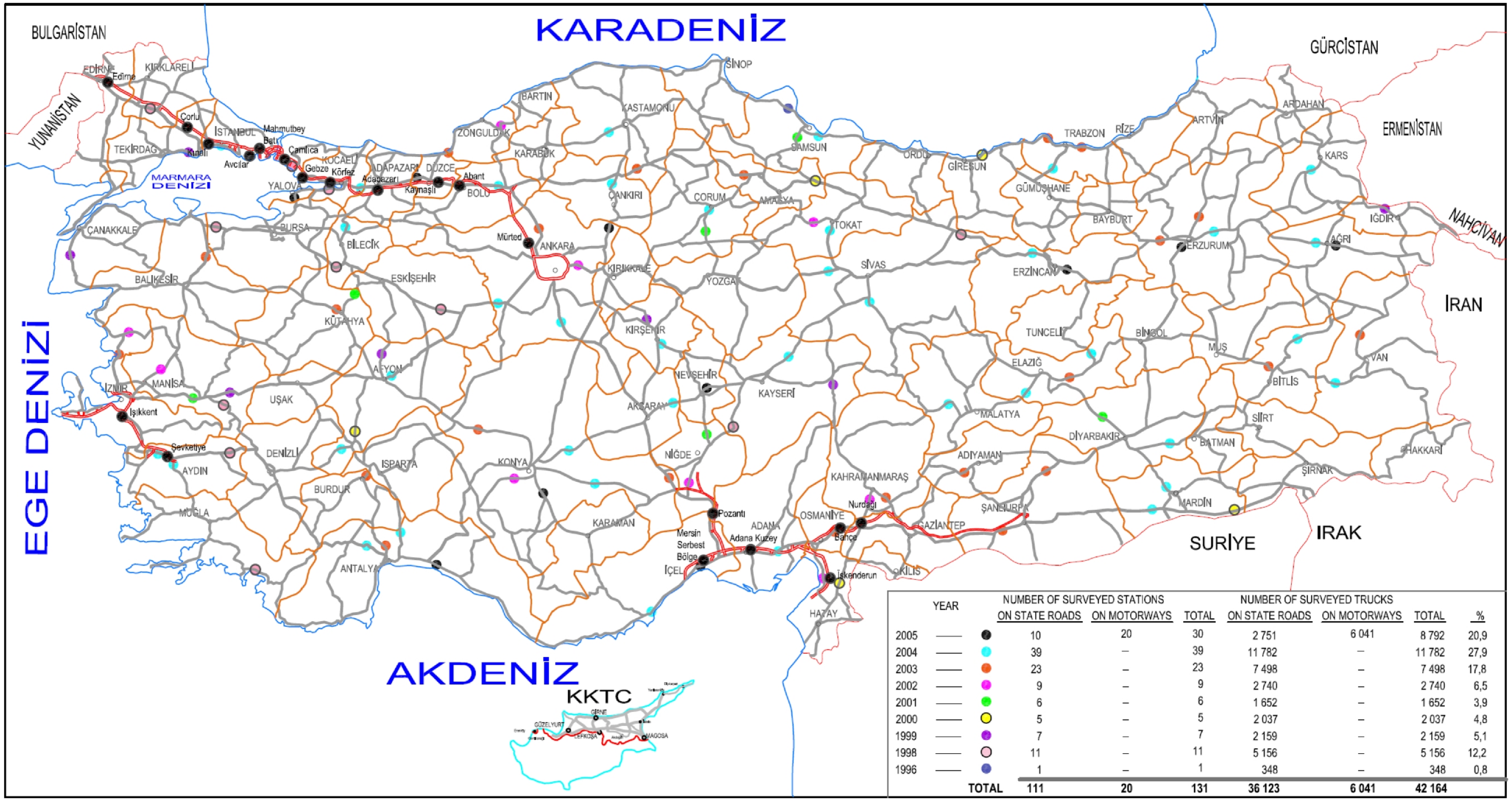
In Turkey, Unal (2009) performed trip generation and trip distribution steps of intercity road freight transportation modeling. In the absence of any commodity flow data for Turkey, Unal (2009) aggregated the data collected through roadside axle surveys between 1996 and 2005. A total number of 42,164 trucks were surveyed during this period. Locations of these surveys are presented in Figure 2.2. The details of roadside axle surveys will be discussed in Chapter 3. Using aggregated 42,164 surveyed trucks data, Unal (2009) produced province level 81x81 Origin-Destination (O-D) base matrices in three dimensions: a) number of trucks, b) ton-km and c) total tonnage of transported commodities. However, these matrices were not produced for each commodity type due to limited data availability. Instead, a single commodity matrix was produced for each dimension based on aggregation of all commodity types. Then, regression analysis were performed to obtain province level freight trip generation and attraction equations. A set of demographic and socioeconomic variables were tested in regression analysis to find the most significant and uncorrelated ones. Based on the regression analysis, the following province level equations were found:

Freight Trip Production:

$$\begin{aligned}\text{Number of Produced Trips} &= \text{f(Number of Employees)} \\ &\quad + \text{Dummy (International Port Existence)} \qquad (2.1) \\ &= 70{,}498.06 + 0.981^{*}\text{(Number of Employees)} \\ &\quad + 302{,}163.4 \text{ (if International Port Exist)}\end{aligned}$$

Freight Trip Attraction:

$$\begin{aligned}\text{Number of Attracted Trips} &= \text{f(Population, Passenger Car Ownership per 1000 Households)} \qquad (2.2) \\ &= -25{,}454 + 0.287^{*}\text{Population} \\ &\quad + 672.976\ ^{*}\text{Passenger Car per 1000 Household}\end{aligned}$$



YEAR			NUMBER OF SURVEYED STATIONS ON STATE ROADS	ON MOTORWAYS	TOTAL	NUMBER OF SURVEYED TRUCKS ON STATE ROADS	ON MOTORWAYS	TOTAL	%
2005	——	●	10	20	30	2 751	6 041	8 792	20,9
2004	——	●	39	–	39	11 782	–	11 782	27,9
2003	——	●	23	–	23	7 498	–	7 498	17,8
2002	——	●	9	–	9	2 740	–	2 740	6,5
2001	——	●	6	–	6	1 652	–	1 652	3,9
2000	——	●	5	–	5	2 037	–	2 037	4,8
1999	——	●	7	–	7	2 159	–	2 159	5,1
1998	——	○	11	–	11	5 156	–	5 156	12,2
1996	——	●	1	–	1	348	–	348	0,8
		TOTAL	**111**	**20**	**131**	**36 123**	**6 041**	**42 164**	

Figure 2.2 Roadside axle survey locations, 1996-2005 (Source: Unal, 2009)

Freight Commodity Production:

Tons of Produced Commodity = f(Number of Employees) +
Dummy (International Port Existence) (2.3)
= 1,542,173 + 1.294*(GDP in Million TL)
+ 302,163.4 (if International Port Exist)

Freight Commodity Attraction:

Tons of Attracted Commodity = f(Population, Passenger Car Ownership per 1000 Household) (2.4)
= -333,701 + 3.556 Population
+ 6317.94 Passenger Car per 1000 Household

"International Ports" include Trabzon Port, Samsun Port, Haydarpasa Port in Istanbul, Izmir Port, Antalya Port, Mersin Port, and Iskenderun Port in Hatay (see Figure 5.8). It should be noted here that Unal (2009) used 2004 values of the aforementioned variables. Turkish Statistical Institute published province level "Number of Passenger Car" and "Population" variables for 2004. However, "Gross Domestic Product (GDP)", "Number of Employees", "Number of Households" were not available for 2004. Therefore, unavailable province level variables were estimated by using trend extrapolations for 2004 by Unal (2009). After prediction of province level trip productions and attractions, Unal (2009) used TRANPLAN travel demand software to distribute these trips between province level 81x81 O-D pairs. TRANPLAN uses the following form of gravity model:

$$T_{ij} = k\frac{O_i^{\lambda} D_j^{\alpha}}{d_{ij}^{\beta}} \qquad (2.5a)$$

where,

T_{ij} flow from zone i to zone j

k a proportionality constant

O_i flow originating from zone i

D_j flow terminating from zone j

d_{ij} distance between zone i and zone j

β a parameter for friction of flow between two zones

λ potential to generate movements (emissiveness)

α potential to attract movements (attractiveness)

Finally, using initially aggregated 42,164 surveyed truck information, regression results produced the following trip distribution equation:

$$T_{ij} = 0.498 \frac{O_i^{0.641} D_j^{0.628}}{d_{ij}^{0.894}} \tag{2.5b}$$

As mentioned by Unal (2009), β, λ and α may change in time as a result of econmic development and technological improvements. Improvements in transportation efficiency tends to decrease β value. Similarly, developments in the economy are likely to influs λ and α (Rodrigue et al., 2006).

2.2 Road Freight Emissions

CO_2 emissions from urban transport system have been widely investigated in the literature, mostly focusing on the role of personal transport systems and strategies to reduce emissions from movements of the people around cities. Recently, the environmental impacts of the freight transportation caught the attention of researchers in different regions due to the robust growth in freight transportation activity (Zanni and Bristow, 2010). Principally, road freight transportation emissions are the function of two variables: a) the nature of the vehicle and b) operating conditions (see Figure 2.3). Both sets of factors can be considered to evaluate environmental impacts of road freight transportation (Piecyk, 2010a).

Two different categories are used to evaluate environmental impacts of transportation. “Source” category refers to only direct emissions from the sector. “End user” category include both sources emissions and emissions from upstream sources. This classification shows that freight transportation tailpipe emissions equal to source emissions. “Source” emissions can be divided into the following categories (EPA, 1994 and Krzyzanowski et al., 2005):

- **Exhaust (tailpipe) emissions:** These emissions include cold-start and hot emissions. “Cold start emissions” refers to the emissions during transient thermal engine operation.

On the other hand, the term “hot emission” is used for the emissions after the vehicle is warmed up (i.e. under stabilized engine operation).

- **Evaporative emissions:** Evaporative emissions are important for the petrol and gas fuelled vehicle due to volatility of these fuels. As the “diesel fuel” is heavier and oiler than petroleum, evaporative emissions are primarily arise from passenger traffic. They are an important source of non-methane hydrocarbon emissions from road transportation.
- **Fugitive emissions from tire and break wear:** These emissions are non-exhaust particulate matter emissions produced by wear on vehicle components (tires, brakes and clutch) and road abrasion.

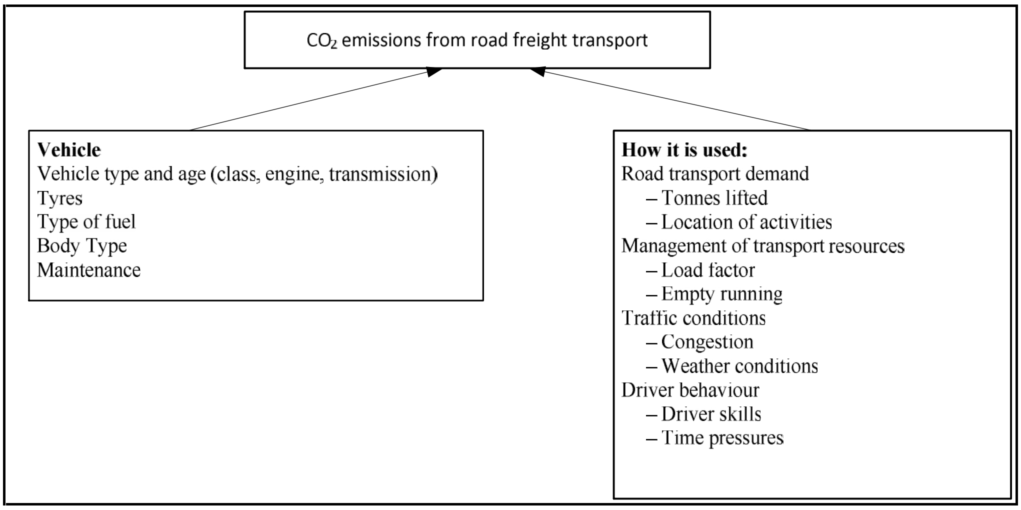


Figure 2.3 Factors affecting CO_2 emissions from road freight transport (Source: Piecyk, 2010a)

Life Cycle Assessment (LCA) also known as life cycle analysis, goes further in the evaluation of environmental impacts of road freight transportation. It considers all environmental impacts associated with all the stages of a product's life, from cradle to grave (i.e. from raw material extraction, manufacture, distribution, use, repair, disposal or recycling) (Baumgartner and Rubik, 1993). A full LCA should “*include a detailed description of raw materials and energy inputs used at all points in the life of the product. It will also include detailed analysis of a range of emissions (such as pollutants and noise), effluent and solid waste outputs, and material and energy resource depletion*” (Browne et al., 2005a). Road freight transportation LCA analysis goes beyond tailpipe emissions and includes emissions from the manufacturing, use, maintenance, and end-of-life (EOL) of vehicles, the construction, operation, and EOL of transportation infrastructure, as well as oil exploration, fuel refining, and fuel distribution (Facanha and Horvath, 2006).

Basic concepts of emissions were presented in this section. Emission types, and their environmental and health effects will be presented in Appendix A. Furthermore, history of the heavy vehicle emission regulations and trends in road freight transportation emission will be discussed in Appendix A.

2.2.1 Road Freight Emission Goals

Global warming and climate change has become a worldwide concern since 1990s. In the December 1997, the Kyoto Protocol was adopted in response to international threat of global warming. The most commonly tracked six gas emissions are CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), HFC's (hydrofluorocarbons), PFCs (perfluorocarbons) and SF_6 (sulphur hexafluoride). Among these six greenhouse gases CO_2 (carbon dioxide) is the most important one, as it comprises almost 80% of the worldwide greenhouse gas emissions (Baumert et al., 2005). The European Union (EU)-15 committed to reduce these gas emissions in overall by 8% compared to 1990 levels, between 2008 and 2012. Furthermore, EU set a target for reducing the CO_2 emissions by 20% and increasing the share of renewable energy sources to 20% of total EU energy consumption by 2020 (EC, 2008). Recently, European Commission (EC, 2010) reported that EU-27 total greenhouse gas emissions decreased from 5,564 million tons of CO_2 equivalents (1990 level) to 5,045 million tons by 2007, corresponding to a drop of approximately 9.3%. In the same period, CO_2 emissions per capita decreased from 9,305 kg to 9,106 kg. However, transportation sector emissions increased to 982.5 million tons of CO_2 equivalents (2007 level) from 779.7 million tons since 1990. The increase in transportation sector emissions was observed in every member state of the EU-27 during this period (EC, 2010).

Currently, HDVs (Heavy Duty Vehicles) are responsible for 6% of total EU emissions. HDV emissions still continue to increase despite improvements in vehicle technology, due to increasing share of road freight traffic (EC, 2013a). Furthermore, freight transport is projected to increase by around 40% in 2030 and by over 80% by 2050 with respect to 2005, which is slightly higher than the expected increase in passenger traffic. Therefore, European

Commission (EC) pointed out some CO_2 strategies to reduced HDV emissions in its 2010 Strategy on Clean and Energy Efficient Vehicles. White Paper on Transport 2011 by EC proposed some goals to achieve a more efficient and sustainable European freight transportation transport system (EC, 2013b). By 2050, key goals in White Paper 2001 include a 50% shift of medium distance intercity freight trips from road to rail and waterborne transport (EC, 2013c). EU's future strategies on HDV fuel consumption and CO_2 emissions aims to:

- Improve vehicle efficiency through new engines, materials and design.
- Achieve cleaner energy use through new fuels and propulsion systems.
- Provide efficient use of networks and vehicle fleets with the support of information and communication systems (EC, 2013b).

As a developing country and an EU candidate state, Turkey signed Kyoto Protocol in 2009. As a recent signatory to Kyoto Protocol, Turkey is not bound by any of the pre-2012 Kyoto targets, because it was not a member of the United Nations Framework Convention on Climate Change (UNFCC) when the protocol was first adopted. However, if the EU targets are considered, total greenhouse gas emissions in Turkey increased from 170.1 million tons of CO_2 equivalents (1990 level) to 372.6 million tons in 2007. Similarly, CO_2 emissions per capita increased from 3,012 kg to 5,279 kg during the same period. Furthermore, transportation sector emissions in Turkey almost doubled and reached to 51.8 million tons of CO_2 equivalents in 2007. 84.2% of these CO_2 emissions are attributable to road transport (EC, 2010). Parallel to the emission reduction targets of EU states, some policies are being developed to control road transport greenhouse gas emissions in Turkey.

Climate Change Action Plan (CCPA) prepared by the Ministry of Environment and Urbanization has some targets in transportation sector to achieve more sustainable transportation system. It aims to develop better intermodal transport system to ensure balanced utilization of freight transport modes (MEU, 2012). In order to establish such a system in Turkey, Turkish State Railways has started to establish 11 logistics villages to generalize combined transportation. These high freight demand locations are namely Halkali (Istanbul), Ispartakule (Istanbul), Kosekoy (Kocaeli), Kaklik (Denizli), Eskisehir, Bogazkopru (Kayseri), Balikesir, Yenice (Adana), Palandoken (Erzurum), Konya and Usak (OECD/ITF, 2009). Specifically, the CCPA aimed to increase the share of railroads in freight transportation to 15%, and the share of domestic maritime freight transportation to 10% as of 2023.

CCPA also defined flowing targets to increase efficiency and decrease energy consumption of freight sector:

- Increasing use of energy efficient vehicles in land, sea, air transportation.
- Collecting data and statistics on emission data of all vehicles used in passenger and freight transportation, and developing strategies to limit emissions.
- Conducting research and creating statistical data on use of alternative fuels in passenger and freight transportation.
- Collecting, computerizing, monitoring and evaluating real and reliable transport data in passenger and freight transportation in all sectors by building the necessary infrastructure.
- Examining all transport lines in terms of GHG emissions and ensuring the data is recorded as measurable, reportable and verifiable.
- Setting up a platform where all sector stakeholders can work together on limitation of GHG emission increase in the transportation sector and adaptation of the transport infrastructure to the impacts of climate change (MEU, 2012).

2.2.2 Freight Emission Estimations

Schipper et al. (1997) studied the trends in carbon emissions from freight transportation in industrialized countries from 1973 to 1992. These countries include Japan, France, West Germany, Italy, Norway, Sweden, Denmark, Finland and the US and the UK. The authors concluded that a) trucking dominated the freight transportation in almost every studied country, b) freight transportation energy use and associated emissions increased more noticeably than those associated with passenger transportation in the study period, and c) energy use and carbon footprint for freight transportation would continue to grow unless improvements in the energy efficiency of the truck sector took place. Consequently, the pattern of CO_2 emission from freight reflected the domination of trucking. As there is a close interaction between demand of goods and GDP, it is important to understand the relationship between GDP and freight transportation emissions. Figure 2.4 presents ratio of CO_2

emissions per Purchasing Power Parity (PPP) for 18 members of International Energy Agency (IEA) countries, split into truck and other modes (OECD/IEA, 2008). There are considerable variations among countries, because of emission intensities and modal share as well as the total amount of freight activity. Canada has the highest emissions per GDP, largely due to long transportation distances. Switzerland, Austria and Sweden have much lower emission intensities due to a significantly shorter transportation distances. Norway, Greece, Canada and the USA had significant CO_2 share from rail and ship modes.

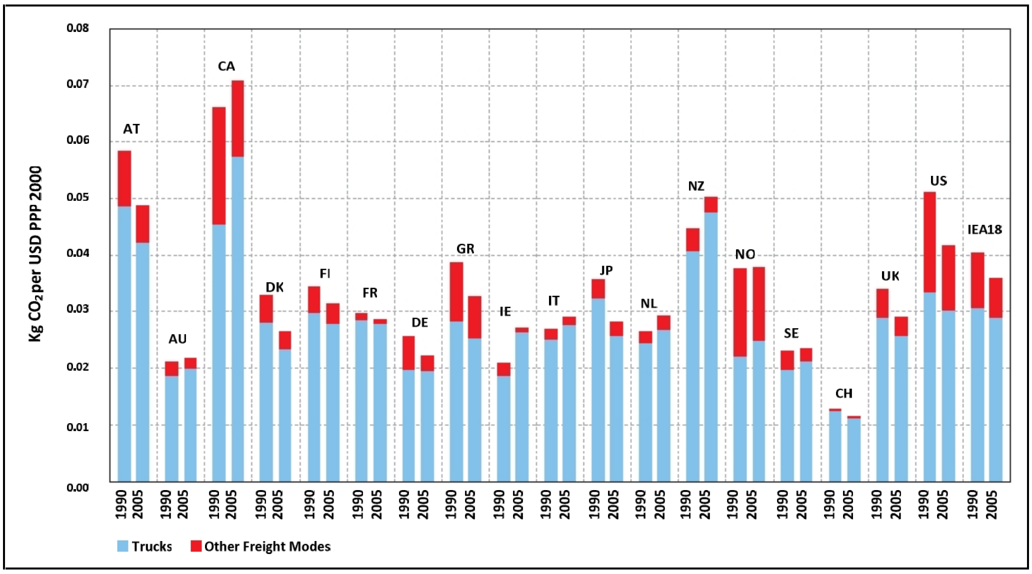


Figure 2.4 Freight CO_2 emissions per unit of GDP (Source: OECD/IEA, 2008)

Kamakate and Schipper (2009) compared the trends in road freight transportation energy use and carbon footprint in Australia, France, Japan, the UK and the US between 1973 and 2005. The authors found that road energy consumption and emissions dominate total consumption in freight sector, even in countries with relatively even modal shares. Besides, trucking energy and carbon emission intensity is decreasing especially in Australia, Japan and the US due to improvements in truck vehicle efficiency. It was also concluded that, trucking movements were still not optimized and future energy and emission savings could be achieved from improvements in truck and engine technologies, as well as better management of freight transportation and improvements in traffic conditions. Lakshmanan and Han (1997) explored the factors affecting the growth of the CO_2 emissions from freight transportation sector in the US during 1970-1991 period. Growth of the gross domestic product was found as the most important factor in increasing freight transportation energy use and carbon emissions. The shift towards truck and air transportations was the other factor as they were the more energy intensive modes compared to the others.

Ang-Olson et al. (2005) studied the contribution of freight transportation modes to regional emissions in urban areas of the US. The study clearly showed the dominant role of trucking in urban freight movements and emissions in all study regions. Steenhof et al. (2006) investigated GHG emission profile of surface freight transportation modes in Canada. This study included decomposition analysis to evaluate historical trends and scenario analysis to predict potential emission changes in the future. Decomposition analysis is one of the most commonly applied tools to quantify the contributions of several pre-defined factors to changes in energy consumption and its environmental side effects (Ang and Zhang, 2000). The results of the decomposition analysis revealed that the increasing freight transportation greenhouse gas emissions was primarily influenced by increasing freight transportation activity in ton-km and modal shifts towards heavy trucks. It was also found that, surface freight transportation emissions were increased to 140% of 1990 level in 2003.

Perez-Martínez (2010) studied the trends in freight transportation energy use and emissions in Spain from 1990 to 2007. It was found that freight transportation emissions increased faster than the other sectors in Spain during this period. Freight transportation emissions increased by 68% between 1990 and 2007, and road freight experienced most of this increase. The researchers stated that road freight energy use and emission would continue to increase unless there was a shift towards less energy intensive freight modes and technologic improvements to improve efficiency of diesel engines. CO_2 emissions were expected to continue to increase by 53% from 2007 to 2025 under business-as-usual scenario. On the other hand, emissions could be reduced 3.3% by 2025 compared to the 2007 level, if efficiency of the diesel engines would be increased by 55% (Perez-Martínez, 2010).

Zanni and Bristow (2010) presented historical trends in CO_2 emissions from road freight transportation in London using vehicle-km based emission factors without considering the loading conditions of the freight vehicles (see Table 2.1). Significant upward trend in truck transportation (16.8%) and CO_2 emissions (18.2%) had been observed in London during the period of 1996-2005. Léonardi and Baumgartner (2004) studied CO_2 emission efficiency and the influencing factors of road freight sector in Germany (see Table 2.2), highlighting mainly the influence of vehicle class and load weight factors. CO_2 efficiency showed a large variation from 38 g to 1.25 kg per ton-km, where mean efficiency was 96 g of CO_2 per ton-km. Department for Transport (DfT, 2007a) in the UK suggested an average CO_2 efficiency of 82 g per ton-km for articulated trucks over 33 tons. CO_2 emission efficiency values presented by the Departments of Transportation in Germany and France were around 100 g per ton-km (MTETM/SESP, 2006 and KBA, 2006). Van Wee et al. (2005) presented a range of 45 g to 100 g per ton-km for road freight vehicles. Perez-Martínez (2009) estimated a range of 91.1 g to 127.5 g for per ton-km of road freight transport in Spain, which were noticeably higher than the range presented by Wan Wee et al. (2005).

Table 2.1 Emission factors (Source: Zanni and Bristow, 2010)

Euro Standard Technology	Emission factor (kg CO_2/km)	
	Rigid Trucks	Articulated Trucks
Pre-1988 models [a]	0.581	1.273
1988-1993 models [a]	0.571	1.263
Euro I [a]	0.684	1.801
Euro II [a]	0.672	1.569
Euro III [b]	0.672	1.569
Euro IV [b]	0.652	1.522
Euro V [b]	0.652	1.522

Source: [a] AEA, 2007; [b] Adopted from NERA, 1999

Table 2.2 Correlation analysis of selected variables (Source: Léonardi and Baumgartner, 2004)

Variables	Correlation Coefficient
Correlation of CO_2 efficiency in (tkm/kg CO_2) with	
Efficiency of vehicle usage (in tkm/mkm)*	0.96
Vehicle load class (in t)	0.70
Vehicle empty weigh (in t)	0.61
Degree of utilization by volume (in %)	0.42
Fuel consumption	0.42
Load factor (in 5 of maximum load capacity)	0.41
Correlation of efficiency of vehicle usage (tkm/mkm)* with	
Fuel consumption	0.39

* The weight of the empty vehicle plus load of the freight results in total weight (m) of a vehicle

Wang et al. (2010) estimated the potential to reduce fuel consumption and mitigate CO_2 emissions from urban freight transportation modes (highway, railway, civil aviation and pipeline) in Beijing based on "system dynamics model". The model was set in terms of specific parameters which strongly influence the freight CO_2 emissions. These main parameters include overall level of freight transportation activity, the share of the freight activity and energy consumption parameters for each mode. The results showed that there exists a 13% to 30% emissions reduction potential in the freight transportation system of Beijing. Another study by Hao et al. (2012) employed a bottom-up life cycle model to evaluate the future trends of fuel consumption and life cycle greenhouse gas emissions by road trucks in China. The researchers found that life cycle emissions would increase with an annual rate of 4.2% until 2050 under the base case scenario.

McKinnon and Piecyk (2009) adopted different approaches to estimate road freight CO_2 emissions in the UK (see Figure 2.5). The main idea of each approach was to estimate fuel consumption of the road freight transportation, which was then converted to CO_2 estimations using standard conversion ratio, e.g. 2.63 kg of CO_2 per liter of diesel fuel consumption suggested by DEFRA (2005). The results showed that depending on the method of calculation and data sourced used, road freight transportation vehicles emitted between 18.6 and 25.8 million tons of CO_2 in 2006. The following data sources were used to calculate emissions:

- **Vehicle emission testing:** It is the measurement of the emissions from representative sample trucks under laboratory conditions. These vehicles vary in their empty weights, dimensions, loading conditions and emission legislation, and are tested in different speeds to simulate different traffic conditions. Fuel consumptions are monitored over these cycles and converted to carbon emissions using standard ratios.
- **Continuing survey of road goods transport (CSRGT):** This survey covers around 16,000 trucks operated in the U.K. with a gross weight of minimum 3.5 tons. GSRGT also includes the monitoring of the activities and fuel consumption of the sample trucks during the survey week.
- **National road traffic survey (NRTS):** This involves the manual and automated measurements of traffic flow at numerous locations across the U.K. road network, disaggregated by vehicle type to measure road freight traffic activity.

– **Records of diesel fuel purchases:** This involves the collection of the annual diesel fuel consumption from road freight vehicles

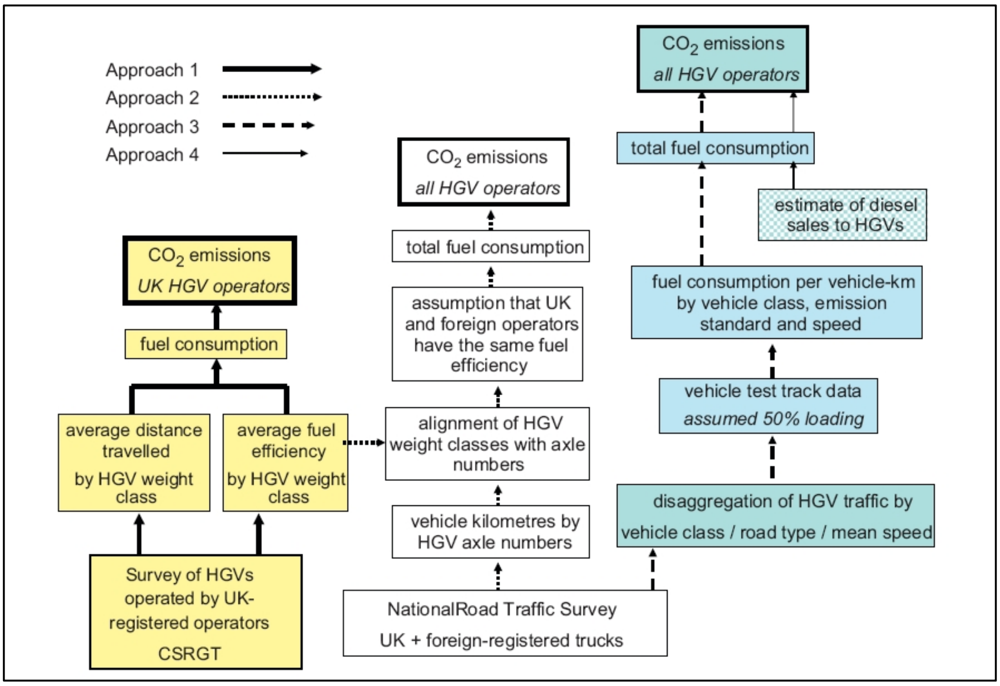


Figure 2.5 Four approaches to the calculation of territorial estimates of CO_2 emissions from HDVs (Source: McKinnon and Piecyk, 2009)

Approach 1: Used survey data collected from the CSRGT. The average fuel efficiency and average distance travelled by freight trucks were multiplied to obtain total fuel consumption for different vehicle classes. This was converted to CO_2 using the standard conversion ratio for the diesel fuel. This approach estimated 18.6 million tons of CO_2.

Approach 2: Integrated count based NRTS estimates with survey based fuel efficiency estimates derived from CSRGT. This approach estimated 23.2 million tons of CO_2.

Approach 3: Used disaggregate NRTS survey data. This approach estimated 19.5 million tons of CO_2.

Approach 4: Used the estimates of the total diesel fuel sale. This approach estimated 25.8 million tons of CO_2.

Facanha and Horvath (2007) evaluated life cycle emission analysis of freight transportation in the US. Results indicated that total life cycle analysis of freight transportation modes were underestimated, if only tailpipe emissions are considered. In the case of CO_2 and NO_X, tailpipe emissions underestimated the total emissions up to 38% depending on the mode. Total life cycle emissions of CO and SO_2 were up to seven times higher than tailpipe emissions. Spielmann and Scholz (2005) provided a comprehensive life-cycle inventory assessment of road, rail and waterborne freight transportation modes in Europe. The results of the assessment showed that emissions from movement of road freight vehicles contribute the largest proportion of the total life cycle-emissions from road freight sector. Facanha and Horvath (2007) concluded that CO_2 emissions due to fuel consumption constitute the largest share of life cycle CO_2 emissions of road freight transportation in the US, even if infrastructure construction works are included in the lifecycle assessment. Similarly, a study performed by Gaines et al. (1998) confirmed the conclusion that largest proportion of environmental impacts of road freight transportation is associated with vehicle operations. On the other hand, vehicle and fuel production have limited contribution on the life cycle environmental assessment of freight transportation.

Freight Emission Estimations in Turkey

In Turkey, unfortunately, neither the nationwide road freight demand modeling nor the consequent emissions have been studied in detail, so far. Main reason is the lack of commodity flow data and a contributing factor is the lack of national freight transportation modeling. Unal (2009) provided the only national level forecasts for the trip generation and distribution of freight transportation for 1996 to 2004. Soylu (2007) estimated the level of several emissions from truck transportation in Turkey. These emissions include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), particulate matter (PM), nitrogen oxide (NO_X) and sulfur dioxide (SO_2) (see Table 2.3). That study specially focused on personal transportation and its emission reduction potentials. Soylu (2007) estimated 11.1 million tons of CO_2 emission from road freight transportation for 2003. Similarly, Agacayak (2007) used two different approaches to estimate nitrogen oxides (NO_x), particulate matter (PM), sulphur dioxide (SO_2), volatile organic compounds (VOC) and ammonia (NH_3) emissions from truck movements in Turkey for 2003. Both study mentioned the use of COPERT III inventory model without details of the emission calculation and input data. There are some differences between estimation provided by Soylu (2007) and Agacayak (2007), even though both study reports the usage COPERT III, which brings the issue of input data assumptions. However, the lack of detailed information on the input data by either author, makes it difficult to provide any further comments on these comparisons.

Table 2.3 Emission estimates of road freight transportation in Turkey in 2003 (in kt) (Source: Soylu, 2007 and Agacayak, 2007)

	CO_2	CH_4	N_2O	CO	PM	NO_x	SO_2	NH_3	VOC	NMVOC
Soylu (2007)										
	11,108	0.66	0.48	54.00	9.72	107.00	49.56	---	---	23.00
Agacayak (2007)										
Estimate 1	---	---	---	---	6.31	100.27	10.39	2.30	14.37	---
Estimate 2	---	---	---	---	9.55	135.43	10.99	33.00	24.36	---

There are also some studies dealing with road transportation emissions of Turkey without any specific focus on freight transportation. According to TurkStat (2011a), nationally direct CO_2 emissions of 299.1 million tons in Turkey were noted, and transportation sector accounted for 15.6% of these emissions which can be found as 46.7 million tons. In another study, Vestreng et al. (2009) estimated that road transportation accounted for 42% of the national NO_2 emissions in Turkey in 2005.

2.2.3 Modeling Road Freight Emissions

Road vehicles emit atmospheric pollutants as a result of combustion and other processes. Exhaust emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM) and evaporate emissions of volatile organic compounds (VOCs) are regulated by UE directives. Some of the pollutants are not regulated, including greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The legislative standards for vehicle emissions had a large impact on the emissions like many other parameters, including vehicle related factors such as model, fuel type, technology level, and mileage, and operational factors (e.g. speed, acceleration, gear selection, road gradient and ambient temperature). Exhaust emissions models have been improved in terms of amount, type and quality of available data. All emission models must consider the factor affecting emission; even though, the detail in which they will be used can differ substantially. Emissions models can be classified according to a combination of the graphical scale of application, the generic type of model and the nature of the emission calculation approach (Boulter and Barlow, 2005). In all road transport emissions models, total emissions for a single vehicle of a given type and for a given pollutant are calculated by summing the emissions from following three different sources: a) hot exhaust emissions during thermally stabilized engine, b) cold start exhaust emissions during warming up phase and c) evaporation emissions (Boulter and Latham, 2009).

$$E_{\mathrm{Total}} = E_{\mathrm{Hot}} + E_{\mathrm{Cold}} + E_{\mathrm{Evap}} \qquad (2.6)$$

where, E_{Total} = total emissions of pollutant (g), E_{Hot} = hot exhaust emissions (g), E_{Cold} = cold start exhaust emissions (g) and E_{Evap} = emissions of volatile compounds (VOCs) due to evaporation, for only petrol vehicles. The general principle in estimating emissions from road traffic is the summation of the product of an emission factor and the amount of traffic, for each type of vehicle and each type of vehicle operation, as expressed by the following equation (Hickman et al., 1997).

$$E_i = \sum_{j=1}^{n} \sum_{k=1}^{n} e_{i,j,k} \times T_{j,k} \qquad (2.7)$$

where, E_i is the amount of pollutant i emitted; e is an emission factor; T is the amount of traffic, j identifies different types of vehicle, k identifies different types of vehicle operation. This expression shows the broad categories of data that are required in emission modeling, but hides the large number of variables in each category. For instance, there are numbers of types of vehicles in service and each has different characteristics in terms of emissions. The detailed review of road freight emission modeling is presented in Appendix B. The following section presents the COPERT model, which is a type of average speed model that will be used later in the truck emission calculations of this study.

The COPERT Model

COPERT 4 is the latest version of the COPERT methodology (Gkatzoflias et al., 2007). It is a commonly used computer programme to calculate emissions from road transport within the European Union. It is used to calculate the quantities of regulated emissions, such as (carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOC), particulate matter (PM) and unregulated, such as (nitrous oxides (N_2O), ammonia (NH_3), sulphur dioxide (SO_2), non-methane volatile organic compounds (NMVOC) pollutants of greenhouse gas emissions emitted by road transport vehicles. The emissions from road vehicles are calculated as the summation of the cold start emissions emitted during transient thermal engine operation and hot emissions emitted during normal operating temperature of engine. As different driving conditions imposes different engine operation, the COPERT 4 program also calculates the emissions separately for urban, rural and highway (motorway) driving modes. Different activity data and emission factors are attributed to each driving condition. Cold-start emissions are mainly attributed to urban driving mode and hot emissions are attributed to rural and highway driving conditions. Therefore, total emissions can also be calculated by:

$$E_{\mathrm{Total}} = E_{\mathrm{Urban}} + E_{\mathrm{Rural}} + E_{\mathrm{Highway}} \tag{2.8}$$

where, E_{total}, E_{Urban}, E_{Rural}, E_{Highway} are emissions of the relevant driving conditions.

Total emissions are calculated by combining activity data with appropriate emissions factors for each vehicle category. The emission factors vary according to the input variables, such as driving and climatic conditions. The flow chart below presented in Figure 2.6 summarizes the required variables to calculate annual emissions of all pollutants.

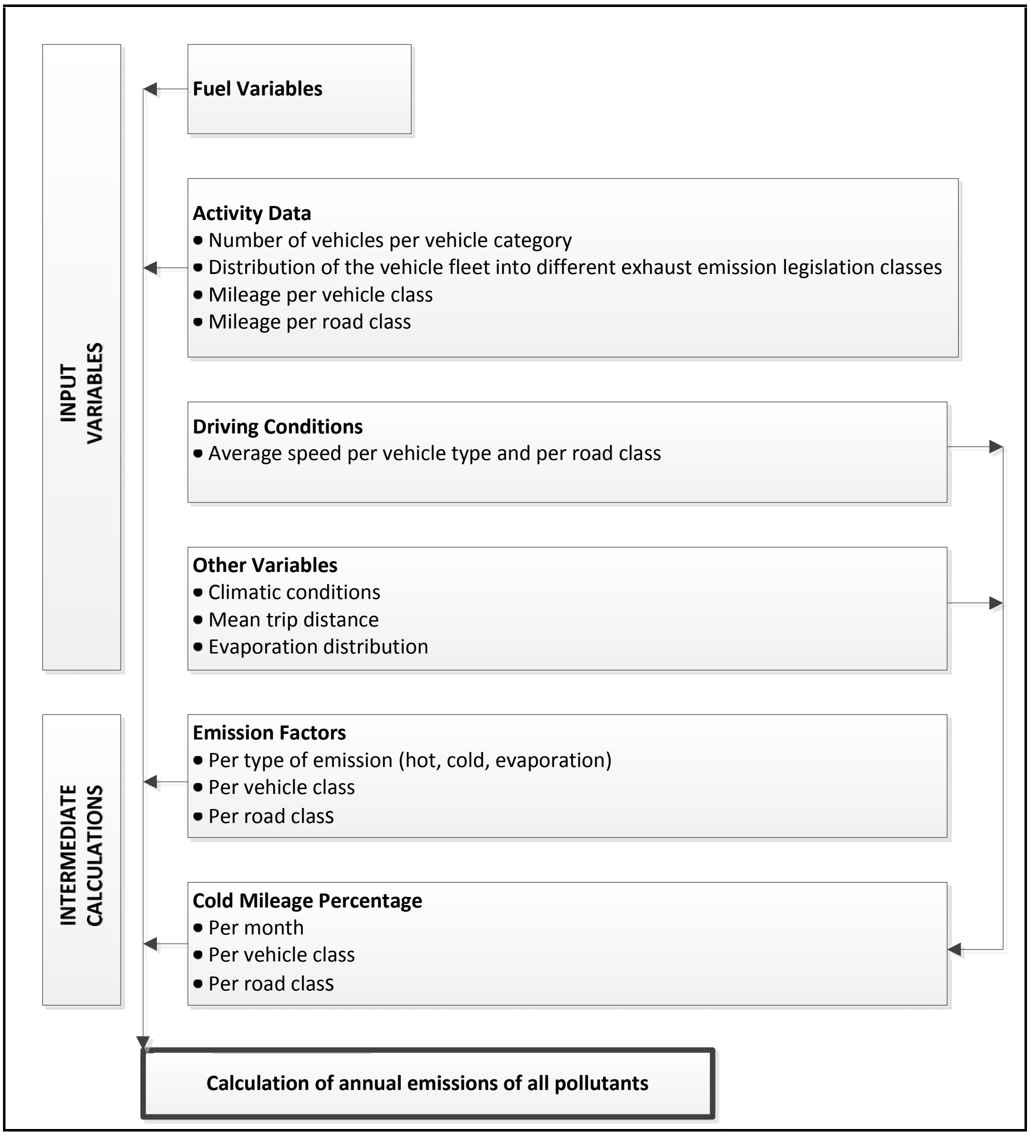


Figure 2.6 Flow of the application of the baseline methodology
(Source: Ntziachristos and Samaras, 2000)

The following input data are required by COPERT 4 to calculate transportation emissions on a yearly base:

- **Climatic Conditions:** Monthly average minimum and maximum ambient temperatures are required to calculate cold-start emissions.
- **Fuel specifications and consumption:** There are six fuel types: specifically leaded and unleaded gasoline, diesel, liquefied petroleum gas (LPG), compressed natural gas (CNG) and biodiesel.

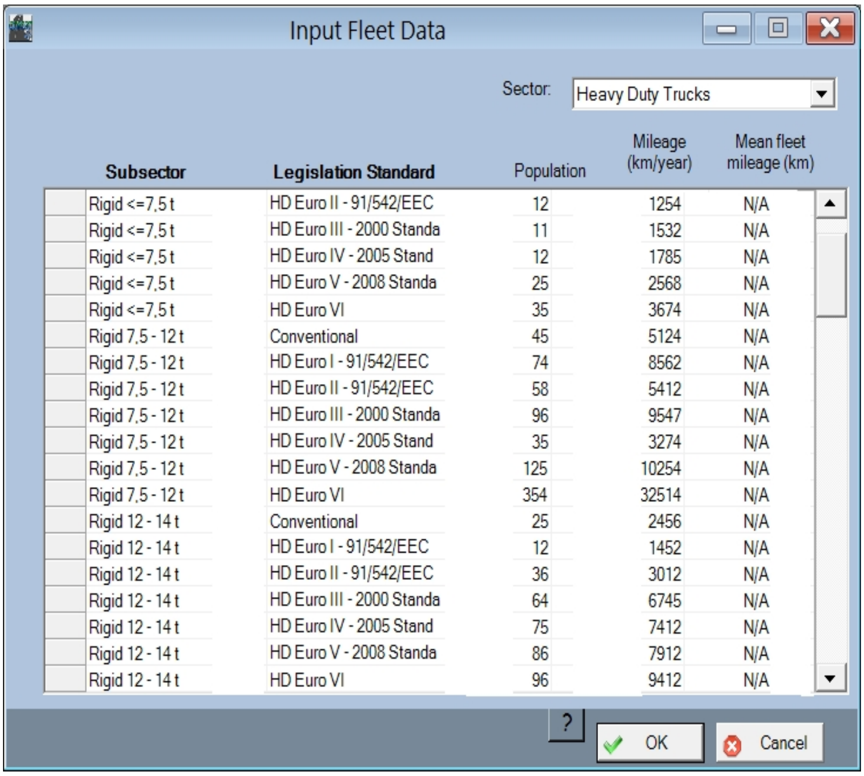
- **Fleet configuration and circulation data:** It has to be provided for different classification groups of the each vehicle type.

The further details of the COPERT 4 program's data requirements will be discussed in Chapter 4. Due to the technological developments of truck engines and their wide spread usage with a number of different vehicle types, a detailed classification scheme shown in Table 2.4 is used to calculate their exhaust emissions accurately. Gross vehicle weight is the tare weight plus payload. Payload is the maximum amount of commodity weight that can be carried by a truck. The loading conditions are applicable to heavy duty vehicles. A default value of 50% is suggested to correspond to the baseline emission factors. In order to apply a different load percentage, the user needs to specify load percentages between 0 and 100 denoting a totally empty or a fully loaded vehicle respectively.

Table 2.4 COPERT 4 truck classification scheme

Truck Type	Gross Vehicle Weight	Loading Condition	Legislation
Rigid Trucks	< = 7.5 t	0% to 100%	Conventional Euro I Euro II Euro III Euro IV Euro V
	7.5 – 12 t		
	12 – 14 t		
	14 – 20 t		
	20 – 26 t		
	26 – 28 t		
	28 – 32 t		
	> 32 t		
Articulated Trucks	14 – 20 t		
	20 – 28 t		
	28 – 34 t		
	24 – 40 t		
	40 – 50 t		
	50 – 60 t		

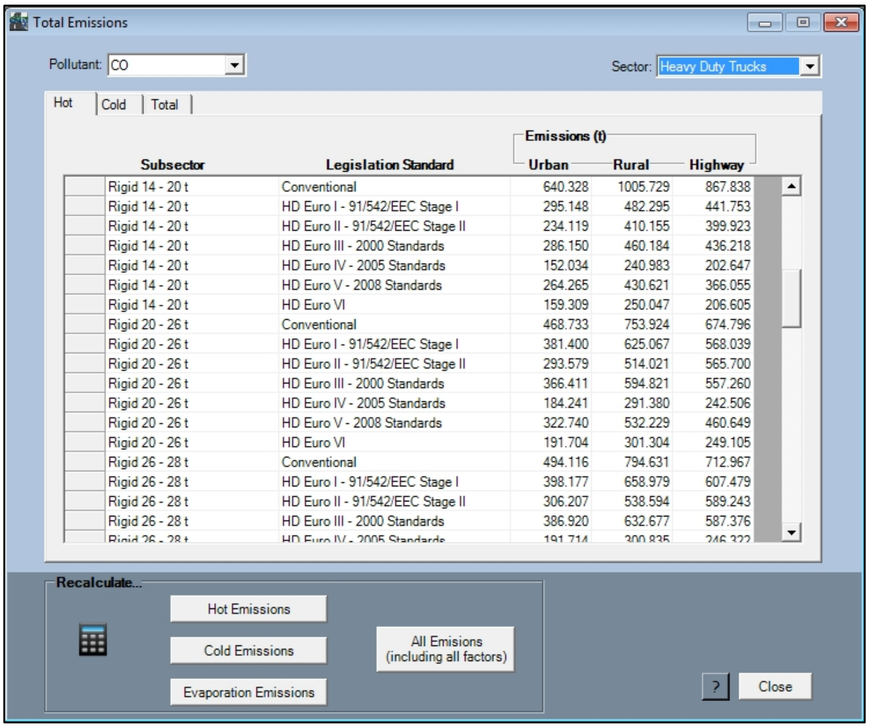
Figure 2.7 provides screenshot of the COPERT 4 fleet configuration window. “Mean fleet mileage” is the mean distance travelled by fleet. It is used to calculate evaporative emissions and estimate mileage degradation parameters. The program user has to provide mileage percentage driven by each subsector for urban, rural and highway driving modes. COPERT 4 requires average speed and the mileage percentage driven by each subsector per driving mode. As shown in the output screenshot in Figure 2.8, the program user can view and save the cold, hot and total emission results of specified pollutant oriented by urban, rural and highway driving modes. COPERT 4 estimates emissions of all regulated air pollutants as a function of average speed. It also includes functions for fuel consumption and unregulated pollutants. COPERT 4 speed dependent emission factors for diesel heavy vehicles are taken from the Artemis project (see Appendix B). Further details of the emission calculations can be obtained from EMEP EEA Guidebook website (EEA, 2012).



Sector: Heavy Duty Trucks

Subsector	Legislation Standard	Population	Mileage (km/year)	Mean fleet mileage (km)
Rigid <=7,5 t	HD Euro II - 91/542/EEC	12	1254	N/A
Rigid <=7,5 t	HD Euro III - 2000 Standa	11	1532	N/A
Rigid <=7,5 t	HD Euro IV - 2005 Stand	12	1785	N/A
Rigid <=7,5 t	HD Euro V - 2008 Standa	25	2568	N/A
Rigid <=7,5 t	HD Euro VI	35	3674	N/A
Rigid 7,5 - 12 t	Conventional	45	5124	N/A
Rigid 7,5 - 12 t	HD Euro I - 91/542/EEC	74	8562	N/A
Rigid 7,5 - 12 t	HD Euro II - 91/542/EEC	58	5412	N/A
Rigid 7,5 - 12 t	HD Euro III - 2000 Standa	96	9547	N/A
Rigid 7,5 - 12 t	HD Euro IV - 2005 Stand	35	3274	N/A
Rigid 7,5 - 12 t	HD Euro V - 2008 Standa	125	10254	N/A
Rigid 7,5 - 12 t	HD Euro VI	354	32514	N/A
Rigid 12 - 14 t	Conventional	25	2456	N/A
Rigid 12 - 14 t	HD Euro I - 91/542/EEC	12	1452	N/A
Rigid 12 - 14 t	HD Euro II - 91/542/EEC	36	3012	N/A
Rigid 12 - 14 t	HD Euro III - 2000 Standa	64	6745	N/A
Rigid 12 - 14 t	HD Euro IV - 2005 Stand	75	7412	N/A
Rigid 12 - 14 t	HD Euro V - 2008 Standa	86	7912	N/A
Rigid 12 - 14 t	HD Euro VI	96	9412	N/A

Figure 2.7 COPERT 4 input fleet data window



Pollutant: CO

Sector: Heavy Duty Trucks

Subsector	Legislation Standard	Emissions (t) Urban	Rural	Highway
Rigid 14 - 20 t	Conventional	640.328	1005.729	867.838
Rigid 14 - 20 t	HD Euro I - 91/542/EEC Stage I	295.148	482.295	441.753
Rigid 14 - 20 t	HD Euro II - 91/542/EEC Stage II	234.119	410.155	399.923
Rigid 14 - 20 t	HD Euro III - 2000 Standards	286.150	460.184	436.218
Rigid 14 - 20 t	HD Euro IV - 2005 Standards	152.034	240.983	202.647
Rigid 14 - 20 t	HD Euro V - 2008 Standards	264.265	430.621	366.055
Rigid 14 - 20 t	HD Euro VI	159.309	250.047	206.605
Rigid 20 - 26 t	Conventional	468.733	753.924	674.796
Rigid 20 - 26 t	HD Euro I - 91/542/EEC Stage I	381.400	625.067	568.039
Rigid 20 - 26 t	HD Euro II - 91/542/EEC Stage II	293.579	514.021	565.700
Rigid 20 - 26 t	HD Euro III - 2000 Standards	366.411	594.821	557.260
Rigid 20 - 26 t	HD Euro IV - 2005 Standards	184.241	291.380	242.506
Rigid 20 - 26 t	HD Euro V - 2008 Standards	322.740	532.229	460.649
Rigid 20 - 26 t	HD Euro VI	191.704	301.304	249.105
Rigid 26 - 28 t	Conventional	494.116	794.631	712.967
Rigid 26 - 28 t	HD Euro I - 91/542/EEC Stage I	398.177	658.979	607.479
Rigid 26 - 28 t	HD Euro II - 91/542/EEC Stage II	306.207	538.594	589.243
Rigid 26 - 28 t	HD Euro III - 2000 Standards	386.920	632.677	587.376
Rigid 26 - 28 t	HD Euro IV - 2005 Standards	191.714	300.835	246.322

Figure 2.8 COPERT 4 emission output window

2.2.4 Road Freight Emission Reduction Strategies

A detailed literature review of the road freight transportation emission reduction strategies are presented in detail in Appendix D. A summary of these studies is presented below. Road freight emissions are expected to increase and this requires the implementation of technological, operational, and modal policies (Vanek and Morlok, 2000). According to McKinnon (2003), improvements in the logistic supply chains and transportation process, such as more back loading, have the potential to reduce environmental impacts of freight transportation while maintaining the economic growth. Ahman (2004) pointed out the following measures to achieve the decoupling of economic growth and road freight transportation CO_2 emissions: a) more efficient logistics systems, b) use of more energy efficient vehicles, c) shifting to less transport intensive economic growth, d) promoting modal shift to less carbon-intense modes, and e) shifting to non-carbon fuels.

Road freight transportation CO_2 emissions are closely related to the type and amount of fuel used. Because almost all freight transportation trucks are diesel powered, the energy consumption and related carbon emissions equate directly to the amount of diesel fuel consumption (Léonardi et al., 2006). Léonardi and Baumgartner (2004) classified fuel efficiency measures into following categories: a) vehicle efficiency, b) driver efficiency, c) route efficiency, and d) logistic efficiency. There are some studies focusing on specifically vehicle efficiency of road freight transportation. It has been estimated that average fuel efficiency of the trucks has been improving at an annual rate of 0.8% to 1.0% over the past 40 years (Duleep, 2007). Today, regulated pollutants levels (carbon monoxide, nitrogen oxides, hydrocarbons, and particulate matter) of vehicles are much less than the vehicles manufactured two decades ago (Ntziachristos and Samaras, 2010). Modifications in vehicle design are another way to improve efficiency in fuel consumption by reducing air resistance (McKinnon, 2010a). Utilization of the lower resistance tires, maintaining of proper tire pressure, reducing idle truck engine operations, maximum speed reduction, and lower truck tare weights can lead to up to 7.6% improvements in fuel efficiency (Gaines et al, 1998; Woodrooffe et al., 2010; Léonardi and Baumgartner, 2004; Ang-Olson and Schroeder, 2002).

Driving style is another factor to influence fuel consumption (EEBPP, 2001). Driving with frequent gear changes, accelerating and breaking increases fuel consumption (Eibl, 1996). On the other hand, efficient training of the freight vehicle drivers can achieve emission reductions (McKinnon, 2007). In 2003, the UK government initiated Safe and Fuel Efficient Driving (SAFED) training program, and 12,000 truck drivers were trained until 2008. Following the training, companies experienced an average 4-5% improvement; some of the companies had improvements in fuel consumption up to 12%, as a result of the efficient driving techniques, reduced waiting times and selection of the uncongested routes (Freight Best Practice, 2008). Along with improving driver skills, one should also consider the use of information and communication systems, such as optimized vehicle routing, positioning, and navigation, which have positive effects on the environmental impacts of freight transportation by minimizing travel distance (Léonardi and Baumgartner, 2004). On the other hand, minimizing the distance travelled do not necessarily minimize fuel consumption, as the shortest route may include hilly terrain, urban areas and the congested sections of the road network (McKinnon, 1999).

Logistic efficiency of road freight transportation can be measured by the following key variables: empty running, loading factor, and average truck payload (McKinnon, 2010b). Approximately 25% of the truck kilometers are empty in the EU countries. As the freight trips are generally performed from point of production to consumption, empty running is partly unavoidable. However, if all freight movements are performed by fully laden trucks, the negative environmental impacts of road freight transportation can be greatly reduced (McKinnon and Edwards, 2010). Loading factor can be defined as a ratio of actual weight of goods to the maximum weight that can be transported on a fully loaded trip (Piecyk, 2010b). The UK Department for Transport (DfT, 2009) reported that average loading factor decreased from 66% to 58% between 1984 and 2008, which can be regarded as a measure of decreasing vehicle utilization efficiency in freight transportation. It should be noted that loading factor is a weight based measure and it may underestimate actual utilization of vehicle in some sectors, such as automobile, food and parcels where utilization of vehicles are limited by volume rather than weight (McKinnon, 2009). The average truck payload was found 10 tons in 2007 in the EU (Piecyk, 2010b); and it varied greatly among member states from 7 tons to 16 tons (Piecyk and McKinnon, 2009). There are number of factors creating empty and inefficient movements in the freight sector, such as demand fluctuations, unreliable delivery schedules, vehicle size and delivery restrictions, incompatibility of vehicles and products (McKinnon and Edwards, 2010). Zanni and Bristow (2010) presented detailed literature review on policy measures to reduce empty and inefficient movements from road freight sector, such as collection-and-delivery points, urban distribution or consolidation centers, back loading initiatives and load sharing.

In a recent report by International Energy Agency (IEA, 2009), one of the major findings revealed that average trucking efficiency has steadily improved in recent years, even though performance of trucks varies considerably in different countries, and even across similar truck classes in the same county. The report mentioned a potential of considerable fuel savings, if all fleets achieved the efficiency of the best fleet. One way to change fuel efficiency is incentivizing scrappage of older vehicles as reported by McKinnon (2010c). Providing an example from Canada on the low efficiency of older trucks, the report proposed retiring elderly vehicles and replacing them with newer models, as a mean of substantial fuel savings, as done by Spain. There are some studies focusing on emission reduction by shifting less carbon intensive modes and fuels. According to Vanek and Morlok (2000), shifting road freight transportation to rail, waterborne or pipeline leads to a reduction in CO_2 emissions, which can be also achieved by increasing the share of intermodal services (Piecyk, 2010b). Savy (2009) reported that the volume of intermodal transportation represents only 5% of total freight in Europe. It is said that the alternative freight transportation modes become competitive and economically viable, only if large volumes are moved over longer distances. For Western European countries this would mean a minimum of 500 km. (Van Klink and Van den Berg, 1998; EC, 2011 and OECD/ITF, 2009).

CHAPTER 3

ROAD FREIGHT TRANSPORTATION IN TURKEY

This chapter presents a road freight transportation profile of Turkey. First, aggregate level statistics are presented. Then, roadside axle surveys, which are the main data source for road freight transportation, are introduced. Finally, roadside axle survey data collected between 2007 and 2009 are analyzed at different disaggregate levels based on truck type, commodity type, loading condition and trip distance.

3.1 Freight Transportation in Turkey

In Turkey, between 2000 and 2009, total volume of freight transportation increased by 13.6% (see Table 3.1). In 2009, road transportation constituted the 89.0% of the freight transportation in Turkey. Road freight volume increased by 16.5% in this period, while the volume of railway increased by 35.5% and the volume of maritime decreased by 24.0%. In 2009, the share of maritime and railway transportation was 5.8% and 5.2%, respectively. Air transportation has almost negligible freight transportation share in Turkey. There are two main reasons behind the dominance of road freight. The first one is the advantage of door-to-door service. The other one is the improvements in the capacity of vehicles, safety issues and supply chain management. Therefore, it is difficult to compete with road transportation especially on short distances (TGDH, 2011).

Table 3.1 Freight transportation volumes, 2001-2009 (in billion) (Source: TurkStat, 2012a)

Year	Road		Maritime		Railway		Air		Total
	Ton-Km	%	Ton-Km	%	Ton-Km	%	Ton-Km	%	Ton-Km
2001	151.4	86.9	15.0	8.6	7.6	4.3	0.3	0.2	174.5
2002	150.9	89.3	10.6	6.3	7.2	4.3	0.3	0.2	169.2
2003	152.2	88.9	10.0	5.8	8.7	5.1	0.3	0.2	171.4
2004	156.9	90.2	7.3	4.2	9.4	5.4	0.4	0.2	174.2
2005	166.8	91.3	6.4	3.5	9.2	5.0	*	*	182.4
2006	177.4	91.4	7.1	3.6	9.7	5.0	*	*	194.2
2007	181.3	90.3	9.6	4.8	9.9	4.9	*	*	200.8
2008	181.9	89.3	11.1	5.5	10.7	5.3	*	*	203.7
2009	176.5	89.0	11.4	5.8	10.3	5.2	*	*	198.2

* There is no published data for this year.

3.2 Road Network in Turkey

Turkish road network includes approximately 65,256 km of well maintained main roads. Of this network, 48.1% is state roads, 48.1% is provincial roads and 3.8% is motorways. The length of the dual carriageway is 13,926 km, of which 1,987 km is motorways, 10,450 km is state roads and 1,489 km is provincial roads (TGDH, 2012a). The density of the Turkish road network, including rural roads, is approximately 48 km/100 km^2 area. In the European Union (EU-25), the average density of the overall road network is 110 km/100 km^2 area. The approximate length of the international road network running through Turkey is about 9, 000 km. 8,878 km of which consist of E-Roads connecting the east and west through the country, and have high standards. The E80 and E90 are the two main roads leading to Turkey from European borders; which also link the Iran and Iraq borders (OICD/ITF, 2009). International routes passing through Turkey, by length, are presented in Table 3.3.

Table 3.2 Road network in Turkey (km) (Source: OICD/ITF, 2009; TGDH, 2012a)

	Motorways			State Roads	Provincial Roads	Total
	Motorway	Access Roads	Junction Leg			
Dual Carriageway	1,652	335	---	10,450	1,489	13,926
Single Carriageway	---	25	459	20,945	29,901	51,330
Total	2,471			31,395	31,390	65,256

Table 3.3 International road network in Turkey (km) (Source: OICD/ITF, 2009)

International Road Network in Turkey	Length (Km)
Trans European Motorway (TEM)	6,896
Agreement on Main International Traffic Arterials (AGR) – E ROADS	8,878
Black Sea Economic Cooperation (BSEC)	4,472
Economic Cooperation Operation (ECO)	7,982
UN-ESCAP	5,247
TRACECA	1,500
Euro-Asian Linkages	3,020
Pan European Corridors (Corridor IV)	261

3.3 Road Freight Transportation in Turkey

The annual road freight transportation travelled in the period 2000-2009 is displayed as ton-km and vehicle-km in Table 3.4 and Table 3.5, respectively. In the study period, the vehicle-km flow stayed almost constant, while an overall growth of 9.2% was observed in terms of ton-km. Decomposition of the freight transportation among truck types shows that the market share of rigid truck has been decreasing both in terms of ton-km and vehicle-km. Between 2000 and 2009, rigid truck ton-km share decreased from 86.1% to 60.3%, its share in vehicle-km decreased from 91.7% to 69.1%. On the other hand, the share of articulated trucks in freight sector has tripled during this period. As articulated trucks have higher load carrying capacity, this fact might be the reason behind the increasing overall ton-km values despite the constant vehicle-km values.

Table 3.4 Trucking ton-km in Turkey, 2000-2009 (in million) (Source: TGDH, 2011)

Year	Rigid Trucks		Articulated Trucks		Total
	Ton-Km	%	Ton-Km	%	
2000	139,152	86.1	22,400	13.9	161,552
2001	129,901	85.8	21,520	14.2	151,421
2002	128,225	85.0	22,688	15.0	150,913
2003	128,799	84.6	23,364	15.4	152,163
2004	121,952	77.7	34,901	22.3	156,853
2005	127,297	76.3	39,534	23.7	166,831
2006	130,853	73.8	46,547	26.2	177,400
2007	128,751	71.0	52,579	29.0	181,330
2008	124,190	68.3	57,745	31.7	181,935
2009	107,473	60.3	68,804	39.7	176,455

Table 3.5 Trucking vehicle-km in Turkey, 2000-2009 (in million) (Source: TGDH, 2011)

Year	Rigid Trucks		Articulated Trucks		Total
	Vehicle-Km	%	Vehicle-Km	%	
2000	15,461	91.7	1,400	8.3	16,861
2001	14,384	91.4	1,345	8.6	15,729
2002	14,247	91.2	1,375	8.8	15,622
2003	14,311	91.0	1,416	9.0	15,727
2004	11,239	84.6	2,053	15.4	13,292
2005	11,982	83.3	2,396	16.7	14,378
2006	12,395	81.4	2,831	18.6	15,226
2007	12,748	79.2	3,349	20.8	16,097
2008	12,304	77.0	3,678	23.0	15,982
2009	11,305	69.1	5,061	30.9	16,366

Table 3.6 presents available data on freight transportation volumes at different road categories in Turkey. More than 70% of the road freight movements have been occurring on state roads. Recently, there is an increasing trend of motorway freight share. Motorways captured 23% of the freight movements in 2009. On the other hand, provincial roads which

are generally in urban regions, have limited freight transportation share, which was estimated around 5% (TGDH, 2012b).

Table 3.6 Freight transportation on different road segments (Source: TGDH, 2012b)

Year	Vehicle-Km (in billion)				Ton-Km (in billion)			
	State Roads	Motorways	Provincial Roads	Total	State Roads	Motorways	Provincial Roads	Total
2005	10.6 (74.0%)	2.9 (19.8%)	0.9 (6.2%)	14.4	128.3 (76.9%)	28.5 (17.1%)	10.0 (6.0%)	166.8
2006	11.0 (72.5%)	3.3 (21.7%)	0.9 (5.9%)	15.2	134.4 (75.7%)	32.9 (18.6%)	10.1 (5.7%)	177.4
2007	11.7 (72.6%)	3.5 (21.6%)	0.8 (5.7%)	16.1	137 (75.5%)	34.5 (19%)	9.9 (5.5%)	181.3
2008	11.5 (72%)	3.6 (22.5%)	0.9 (5.5%)	16.0	135.4 (74.5%)	36.9 (20.3%)	9.4%) (5.2%)	181.9
2009	11.7 (71.5%)	3.8 (23.1%)	0.9 (5.3%)	16.4	127.2 (72.1%)	40.5 (23.0%)	8.7 (4.9%)	176.5

3.4 Roadside Axle Surveys

TGDH is the responsible authority for collecting commodity flow data through roadside axle surveys on state roads. TGDH has 17 regional divisions and each regional division (except the 17th regional division) perform truck surveys at at least 2 or 3 stations annually. Annually more than 40 surveys are performed on state roads. During these surveys, trucks are stopped at the roadside according to predetermined sampling ratio, interviewed, and weighed. Survey time is 8 hours daily between 08:00 a.m. to 4:00 p.m. and all surveys are conducted in four days; two days on the east-west (north-south) direction and two days on west-east (south-north) direction. Surveys start on Tuesday and finish on Friday. Each TGDH Regional Division carries on surveys on different seasons. The locations of the surveys are selected considering the location of previous surveys to avoid overlaps. Figure 3.1 shows locations of the roadside axle surveys between 2007 and 2009. As the winter conditions do not allow performing these surveys, surveys are not conducted in the winter.

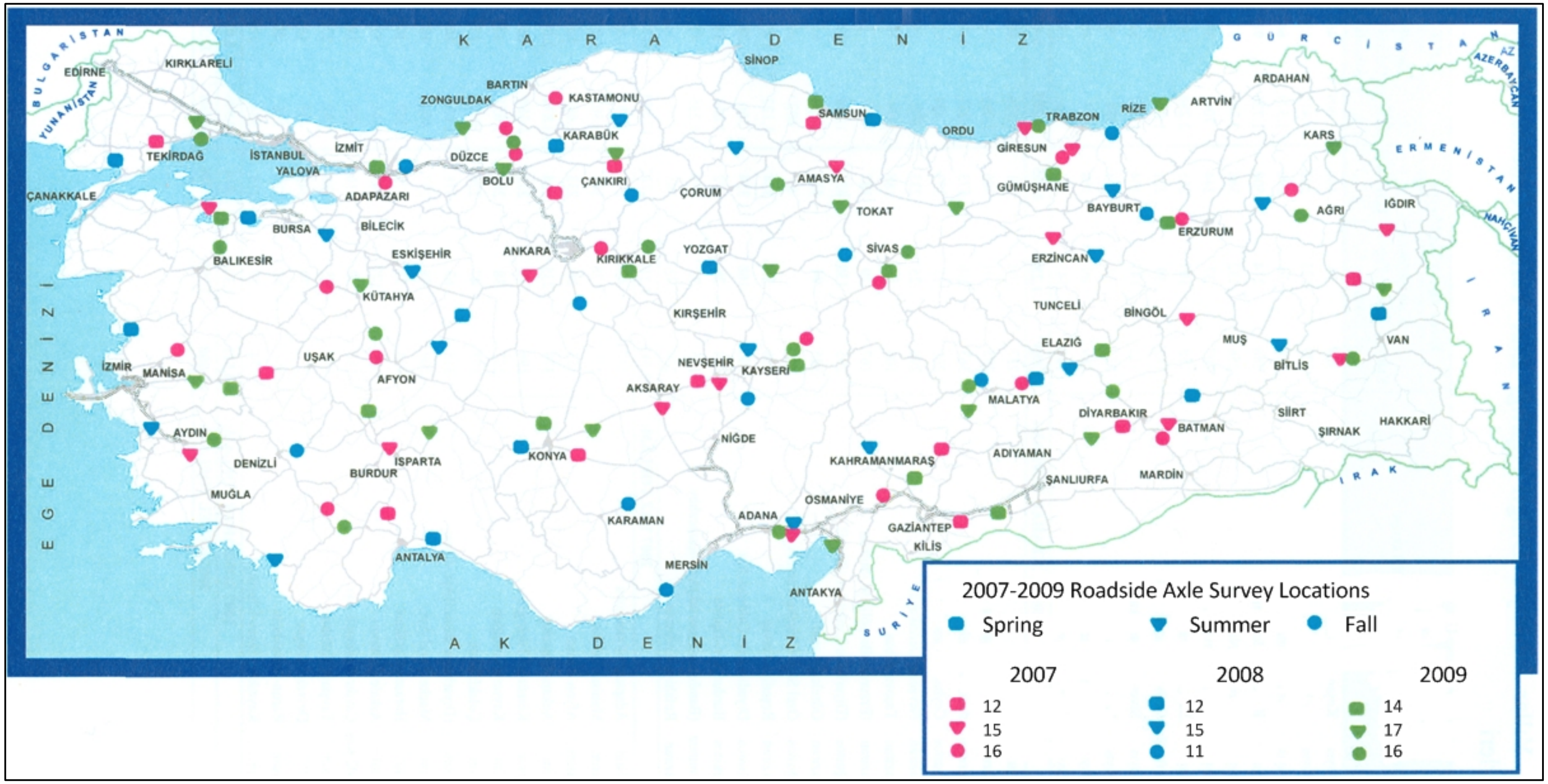


Figure 3.1 Roadside axle survey locations, 2007-2009 (Source: TGDH, 2011)

Table 3.7 summarizes the data structure of the information collected for each truck. These surveys are also regarded as single station Origin-Destination surveys, since origin and destination of the freight movement are also investigated. During the surveys, automatic traffic counting and classification are also performed at the location where the survey is conducted to check sampling ratio. Commodity types are classified according to "Standard Goods Classification for Transport Statistics-2000" (NST-2000) system as presented in the following section.

Table 3.7 Roadside axle survey data structure

Location	Vehicle	Trip	Commodity
Date Time Location Direction Hourly volume	Truck type Axle type Body type License number Production year Empty weight Load carrying capacity	Origin Destination Payload	Commodity Type

TGDH uses the following equation suggested by Ortuzar and Willumsen (1996) in order to obtain the sampling ratio for the road side surveys:

$$n > \frac{p(1-p)}{(e/z)^2 + p(1-p)/N} \tag{4.1}$$

where, n is the number of trucks to survey, p is the proportion of trucks with a given destination, e is the acceptable error (generally taken as 0.1), z is the z standard normal variate for required confidence level and N is the number of observed trucks at each survey station.

In the following sections, three years axle survey data from 2007 to 2009 will be studied individually and comparatively. Locations of these surveys are presented in Appendix E. Detailed analysis of roadside axle surveys will provide insights on types, payloads of the trucks as well as hauling distances and commodity types. It should be noted here that, as the roadside axle surveys are performed on state roads, they are not capable of capturing most of the intra-city movements. Therefore, intra-city movements are excluded from the scope of this study.

3.5 Truck Circulation Characteristics in Turkey

Table 3.8 presents number of surveyed trucks and their vehicle-km, ton-km and average payload values for each survey year. A total of 31,762 trucks were surveyed between 2007 and 2009. 67.3% of the surveyed trucks were rigid, while 32.7% of them were articulated. Assuming a shortest path assumption, vehicle-km and ton-km values can be calculated for all surveyed trucks. The validation of this assumption will be discussed in Chapter 5. In terms of vehicle-km, rigid trucks accounted for 60% of the vehicle-km and articulated trucks accounted for the remaining 40%. On the other hand, ton-km shares of the surveyed rigid and articulated trucks were almost equal. Rigid trucks accounted for the 51.9% of the ton-km of surveyed trucks, and articulated trucks accounted for the remaining part. As it is seen, in the recent years, articulated trucks have been observed more frequently in the surveys as parallel to their increase in national trucking vehicle-km and ton-km values (see Table 3.4 and Table 3.5).

According to aggregated surveys, between 2007 and 2009, the average trip distance was 519 km. The average trip distances of the rigid and articulated truck movements were 463 km and 635 km, respectively. It shows that articulated trucks serve longer distances than rigid trucks. Between 2007 and 2009, average trip distances decreased from 543 km to 492 km and average payload of all the surveyed trucks was 12.2 tons. Average payload per rigid trucks was 10.8 tons in 2007, and 10.4 tons in 2008 and 2009. Average payload per articulated trucks was 15.5 tons in 2007, 14.7 tons in 2008 and 14.0 tons in 2009. As expected, average payload of the articulated trucks was higher due to their higher load carrying capacity. TGDH (2011) explains the small decrease in average payload with the effects of the global economic crisis.

Table 3.8 Descriptive statistics of the roadside axle surveys, 2007-2009

Truck Type	Year	Surveyed Trucks		Vehicle-Km (%)	Ton-Km (%)	Trip Distance (Km)	Payload (Ton)
		Number	%				
Rigid Trucks	2007	8,102	70.0	61.6	52.8	477	10.8
	2008	5,453	67.3	60.2	51.8	468	10.4
	2009	7,817	64.7	58.2	50.9	443	10.4
	Total	21,372	67.3	60.0	51.9	463	10.6
Articulated Trucks	2007	3,470	30.0	38.4	47.2	696	15.5
	2008	2,651	32.7	39.8	48.2	638	14.7
	2009	4,269	35.3	41.8	49.1	583	14.0
	Total	10,390	32.7	40.0	48.1	635	14.7
All Trucks	2007	11,572	36.4	38.1	39.4	543	12.6
	2008	8,104	25.5	25.8	25.5	524	12.1
	2009	12,086	38.1	36.1	35.2	492	11.9
	Total	31,762	100.0	100.0	100.0	519	12.2

According to the Turkish Highway Transportation Regulation, trucks over 20 years old cannot be used for national and international freight transportation. Furthermore, the Official Gazette of the Republic of Turkey (published on 19 March 2009; No: 27174) banned 1979 model and older trucks from traffic. The Official Gazette of the Republic of Turkey (published on 4 November 2010; No: 27749) banned 1985 model and older trucks from traffic. The purpose of these regulations was to provide rapid, convenient, safe, efficient, economic and environmental friendly freight transportation. Table 3.9 presents ages of the truck in national vehicle fleet and roadside axle surveys. In 2009, the number of registered trucks was 727,302 in national fleet (TurkStat, 2011a). According to the above regulations, 24.2% of the trucks in national fleet should be banned from traffic. Furthermore, 31.0% of the trucks were older than 20 years old, and they cannot be used for national and international freight transportation. Despite their large share in the vehicle fleet, old trucks were rarely observed in roadside axle surveys. In 2009, the share of trucks with model years of 1989 and earlier (these trucks were 20 years old in 2009) was 3.9%.

Table 3.9 Model years of the trucks in national vehicle fleet and roadside axle surveys (TurkStat, 2011a)

Model Year	Vehicle Fleet		Roadside Axle Surveys							
	2009		2007		2008		2009		2007-2009	
	Trucks	%	Trucks	%	Trucks	%	Trucks	%	Trucks	%
Pre 1980	105,124	14.5	154	1.3	47	0.6	80	0.7	281	0.9
1980-1985	71,870	9.7	194	1.6	85	1.0	104	0.8	383	1.3
1986-1989	39,525	6.8	230	2.0	108	1.3	182	1.6	520	1.7
1990-1994	92,839	12.7	906	7.9	542	6.7	766	6.3	2,214	6.9
1995-1999	140,112	19.3	2,250	19.4	1,362	16.8	1,938	16.0	5,550	17.4
2000	23,370	3.2	567	4.9	355	4.4	529	4.4	1,451	4.6
2001	20,363	2.8	603	5.2	418	5.2	637	5.3	1,658	5.2
2002	7,790	1.1	264	2.3	219	2.7	246	2.0	729	2.3
2003	13,020	1.8	504	4.4	370	4.6	514	4.3	1,388	4.4
2004	34,121	4.7	1,491	12.9	1024	12.6	1,400	11.6	3,915	12.3
2005	35,402	4.9	1,491	12.9	882	10.9	1,189	9.8	3,562	11.2
2006	45,456	6.2	1,756	15.2	1106	13.6	1,593	13.2	4,455	14.0
2007	33,818	4.6	1,080	9.3	826	10.2	1,089	9.0	2,995	9.4
2008	31,637	4.3	82	0.7	730	9.0	1,151	9.5	1,963	6.2
2009	20,080	2.8	0	1.3	30	0.4	640	5.3	670	2.1
2010	2,555	0.4	0	0.1	0	0.6	28	0.2	28	0.1
Total	727,302	100	11,572	100	8,104	100	12,086	100	31,672	100

3.6 Commodity Characteristics

TGDH classifies commodity types according to “Standard Goods Classification for Transport Statistics-2000” (NST-2000) system. This classification system uses 20 different commodity groups from 1 to 20 (see Table 3.10). Empty trucks are also very important in freight transportation to evaluate efficiency of the system. During the surveys, trucks which had been stated as empty by truck drivers were accepted as completely empty. In addition, trucks below 5% loading condition by weight were also included into the category of empty trucks.

Table 3.10 Commodity classification system

Type	Commodity Type	Type	Commodity Type
0	Empty	11	Machinery and equipment n.e.c.
1	Products of agriculture, hunting, and forestry	12	Transport equipment
2	Coal and lignite; peat; crude petroleum	13	Furniture; other manufactured goods n.e.c.
3	Metal ores and other mining products	14	Secondary raw materials
4	Food products, beverages and tobacco	15	Mails and parcels
5	Textiles and textile products	16	Equip. and mat. utilized in the transport of goods
6	Wood and products of wood and cork	17	Goods moved in the course of household
7	Coke, refined petroleum products	18	Grouped goods
8	Chemicals, chemical products	19	Unidentifiable goods
9	Other non-metallic mineral products	20	Other goods n.e.c.
10	Basic metals; fabricated metal products		

Table 3.11 shows statistics of empty truck movements in term of the number of vehicles, vehicle-km and average trip distance. It was observed that 25-30% of the surveyed trucks were empty in roadside axle surveys. The shares of empty rigid and articulated movements were almost equal. The vehicle-km share of empty movements was around 19-22%. This value is close to 25% average empty running in EU countries (McKinnon and Edwards, 2010). Assuming the survey percentage as an estimator for the national market, it can be estimated that 3,645 million km of the truck movements was driven empty in 2009. Empty vehicle-km share was lower for rigid trucks for all survey years. The main reason of their lower vehicle-km share was their lower average trip distance than articulated trucks. Between 2007 and 2009, the average trips distance of empty trucks was 371 km. The average trip distance of all movements was 519 km during same period (see Table 3.8). Therefore, empty trucks served in shorter distances than other trucks. Furthermore, average trip distances of empty rigid and articulated movements were lower than their average trip distances. Average trip distance of empty rigid trucks was 308 km which can be considered as short haul in the Turkish freight transportation. On the other hand, the average trip distance of empty articulated trucks was 488 km which can be considered as long haul.

Table 3.11 Empty trucks in roadside axle surveys

Truck Type	Number of Trucks		Empty Trucks		
	All Trucks	Empty Trucks	%	Vehicle-Km (%)	Average Trip Distance (Km)
2007					
Rigid	8,102	2,180	26.9	17.4	303
Articulated	3,470	1,002	28.9	22.5	536
All Trucks	11,572	3,182	27.5	19.3	377
2008					
Rigid	5,453	1,386	25.4	18.6	336
Articulated	2,651	703	26.5	21.2	496
All Trucks	8,104	2,099	25.9	19.5	390
2009					
Rigid	7,817	2,295	29.4	19.8	295
Articulated	4,269	1,403	32.9	25.8	450
All Trucks	12,086	3,698	30.6	22.3	355
2007-2009					
Rigid	21,372	5,861	27.4	19.8	308
Articulated	10,390	3,108	29.9	25.8	488
All Trucks	31,762	8,979	28.2	22.3	370

Table 3.12 classifies the number of surveyed trucks according to commodity types. Empty trucks constituted the largest share of the surveyed trucks. 28.2% of all surveyed trucks were empty between 2007 and 2009. Annual share of each commodity type did not show any significant variation between individual years. Food products (Type 4) was the main commodity types in the surveyed trucks with 11.4%. Products of agriculture (Type 1) and other non-metallic mineral products (Type 9) were the second and third most observed commodity types with the 10.0% and 7.8% shares, respectively. These three main commodity types accounted for 29.2% of the trucks movements. The remaining 17 commodity types constituted 43.6% of the movements in terms of surveyed trucks. Mails and parcels (Type 15), unidentifiable goods (Type 19) and secondary raw materials (Type 14) were the least observed commodity types with less than 1% shares.

Table 3.12 Number of surveyed trucks according to commodity types

Type	2007		2008		2009		2007-2009	
	Number of Trucks	%	Number of Trucks	%	Number of Trucks	%	Number of Trucks	%
0	3,182	27.5	2,089	25.8	3,698	30.6	8,979	28.2
1	1,112	9.6	927	11.4	1,140	9.4	3,179	10.0
2	420	3.6	260	3.2	324	2.7	1,004	3.2
3	484	4.2	451	5.6	636	5.3	1,571	4.9
4	1,370	11.8	961	11.9	1,292	10.7	3,623	11.4
5	231	2.0	136	1.7	244	2.0	611	1.9
6	318	2.7	279	3.4	390	3.2	987	3.1
7	538	4.6	422	5.2	652	5.4	1,612	5.1
8	459	4.0	243	3.0	376	3.1	1,078	3.4
9	999	8.6	651	8.0	821	6.8	2,471	7.8
10	356	3.1	284	3.5	485	4.0	1,125	3.5
11	429	3.7	271	3.3	248	2.1	948	3.0
12	175	1.5	50	0.6	141	1.2	366	1.2
13	325	2.8	208	2.6	293	2.4	826	2.6
14	81	0.7	70	0.9	101	0.8	252	0.8
15	43	0.4	82	1.0	23	0.2	148	0.5
16	143	1.2	40	0.5	145	1.2	328	1.0
17	185	1.6	140	1.7	188	1.6	513	1.6
18	342	3.0	225	2.8	328	2.7	895	2.8
19	67	0.6	30	0.4	65	0.5	162	0.5
20	313	2.7	285	3.5	496	4.1	1,94	3.4
Total	11,572	100	8,104	100	12,086	100	31,762	100

Table 3.13 was prepared to observe differences in the percentage of transported commodities by rigid and articulated trucks. It should be noted that there weren’t any surveyed articulated trucks transporting mails and parcels (Type 15) in 2009. There were significant differences in the share of rigid and articulated trucks for some commodity types, such as products of agriculture (Type 1), coal and lignite; peat; crude petroleum (Type 2), metal ores and other mining products (Type 3), food products (Type 4) and grouped goods (Type 18). Food products (Type 4), products of agriculture (Type 1) and other non-metallic mineral products (Type 9) were the main commodity types for rigid trucks. Unidentifiable goods (Type 19), mails and parcels (Type 15), transport equipment (Type 12) and secondary raw materials (Type 14) were the least observed commodity types for rigid trucks (see Table 4.19). On the other hand, main commodity types for articulated trucks were other non-metallic mineral

products (Type 9), food products (Type 4) and metal ores and other mining products (Type 3). Mails and parcels (Type 15), goods moved in the course of household (Type 17), secondary raw materials (Type 14) and unidentifiable goods (Type 19) were the least observed articulated truck commodity.

Table 3.13 Percentages of rigid and articulated trucks according to commodity types

Type	2007		2008		2009		2007-2009	
	Rigid (%)	Articulated (%)	Rigid (%)	Articulated (%)	Rigid (%)	Articulated (%)	Rigid (%)	Articulated (%)
0	26.9	28.9	25.4	26.5	29.4	32.9	27.4	29.9
1	11.9	4.4	13.2	7.8	11.0	6.6	11.9	6.2
2	3.1	4.9	2.8	4.1	2.0	3.9	2.6	4.3
3	3.8	5.0	4.1	8.6	4.0	7.5	4.0	7.0
4	12.6	10.1	12.8	10.0	12.1	8.1	12.5	9.2
5	1.8	2.4	1.6	1.9	1.9	2.3	1.8	2.2
6	3.1	2.0	4.0	2.3	4.0	1.8	3.7	2.0
7	4.1	5.8	5.8	4.0	5.5	5.2	5.0	5.1
8	3.8	4.4	2.5	4.1	3.0	3.3	3.1	3.9
9	8.0	10.1	7.0	10.3	5.9	8.4	7.0	9.5
10	2.4	4.6	2.7	5.2	3.0	5.8	2.7	5.2
11	3.1	5.2	3.1	3.9	2.0	2.1	2.7	3.6
12	0.8	3.2	0.4	1.1	0.5	2.3	0.6	2.3
13	2.8	2.9	2.6	2.5	2.6	2.1	2.7	2.5
14	0.9	0.3	0.9	0.8	0.9	0.8	0.9	0.6
15	0.4	0.2	1.2	0.5	0.3	---	0.6	0.2
16	1.4	0.8	0.6	0.3	1.1	1.4	1.1	0.9
17	2.0	0.5	2.4	0.3	2.1	0.5	2.2	0.5
18	3.8	1.1	3.4	1.5	3.8	0.8	3.7	1.1
19	0.3	1.2	0.1	0.9	0.5	0.7	0.3	0.9
20	3.0	2.0	3.6	3.4	4.5	3.5	3.7	3.0
All	100	100	100	100	100	100	100	100

Table 3.14 presents average trip distance values for each commodity types. As presented before, the average trip distance of all the surveyed trucks was 519 km (see Table 3.8). In addition, average trip distance decreased from 543 km to 493 km between 2007 and 2009. In this period, significant changes were observed in the average trip distance of some commodity types, such as textiles and textile products (Type 5), grouped goods (Type 18)

and unidentifiable goods (Type 19). Empty trucks had the lowest average trip distance among all commodity types. Among the laden trips, transport equipment (Type 12) (accounted for 1.2% of the surveyed trucks as one of the least observed commodity type) had the longest average trip distance with 943 km. On the other hand, metal ores and other mining products (Type 3) (accounted for 4.9% of the surveyed trucks) had the lowest average trip distance with 376 km.

Table 3.14 Average trip distance of the trucks according to commodity types

Type	Average Trip Distance (Km)			
	2007	2008	2009	2007-2009
0	377	390	354	370
1	612	605	602	607
2	360	358	419	379
3	362	388	378	376
4	624	553	549	578
5	886	965	739	845
6	611	525	538	558
7	427	373	393	399
8	767	724	650	717
9	527	490	478	501
10	653	664	544	609
11	776	702	721	741
12	970	821	953	943
13	662	652	658	658
14	556	522	460	508
15	736	655	719	689
16	452	507	354	416
17	756	783	782	773
18	759	816	625	724
19	573	559	694	619
20	593	576	624	603
All	543	524	493	513

Table 3.15 presents average trip distances of the rigid and articulated trucks for each commodity type. As discussed earlier, average trip distance of the articulated trucks was higher than rigid trucks for all commodity types. Goods moved in the course of household

(Type 17) had the longest average trip distance for rigid trucks with 757 km. Mails and parcels (Type 15) had the longest average trip distance for articulated trucks with 1264 km. Food products (Type 4) had the shortest average trip distance for both rigid and articulated trucks between 2007 and 2009.

Table 3.15 Average trip distance of the rigid and articulated trucks according to commodity types

Average Trip Distance (km)								
Type	Rigid Trucks				Articulated Trucks			
	2007	2008	2009	2007-2009	2007	2008	2009	2007-2009
0	303	336	295	308	536	496	450	488
1	572	571	570	571	868	725	699	748
2	373	301	369	353	341	438	465	411
3	316	363	322	330	444	412	433	429
4	564	491	490	519	798	713	711	743
5	794	828	612	732	1,045	1,199	927	1,028
6	541	502	497	512	858	609	707	730
7	370	317	309	330	523	538	552	538
8	669	587	562	616	963	894	794	885
9	436	391	420	420	694	628	553	624
10	577	606	545	572	748	725	543	649
11	616	550	623	599	1,000	949	900	962
12	634	547	673	632	1,168	1,037	1072	1,112
13	544	570	599	570	918	832	789	851
14	535	522	405	484	679	521	572	576
15	642	526	719	594	1,221	1,286	---	1,264
16	451	489	376	428	459	576	322	384
17	742	773	759	757	880	944	947	921
18	730	774	605	694	1,000	1,008	799	942
19	398	389	604	503	691	611	806	707
20	536	530	553	542	788	676	790	756
All	477	468	443	463	696	638	583	635

Table 3.16 presents average payload and loading condition of the surveyed trucks for each commodity type. Average payload was calculated dividing ton-km by vehicle-km. Loading condition was calculated with dividing payload by maximum load carrying capacity for each truck. Coal and lignite; peat; crude petroleum (Type 2) and metal ores and other mining

products (Type 3) had the highest average payloads with more than 20 tons among all surveyed trucks. On the other hand, equipment and materials utilized in the transport of goods (Type 16) and goods moved in the course of household (Type 17) had the lowest average payloads with less than 8 tons. Between 2007 and 2009, average loading condition of the all surveyed trips was 58%. It should be remembered that loading factor is a weight based measure and it may underestimate actual utilization of vehicle in sectors where vehicle capacity is defined by volume rather than weight. If only laden trips are considered, average loading condition of all the surveyed trucks was 75% between 2007 and 2009. Coal and lignite; peat; crude petroleum (Type 2) and metal ores and other mining products (Type 3) had the highest average loading factors with more than 90%. On the other hand, average loading factor was 39% for equipment and materials utilized in the transport of goods (Type 16), and 48% for goods moved in the course of household (Type 17).

A separate analysis for average payload and loading condition of the rigid and articulated trucks are presented in Table 3.17 and Table 3.18. Average payloads were higher for articulated trucks, as they have higher load carrying capacity. Coal and lignite; peat; crude petroleum (Type 2), metal ores and other mining products (Type 3) and other non-metallic mineral products (Type 9) had the highest average payloads for rigid trucks. For articulated trucks, coal and lignite; peat; crude petroleum (Type 2), metal ores and other mining products (Type 3) and product of agriculture (Type 1) had the highest average payloads. On the other hand, equipment and materials utilized in the transport of goods (Type 16), goods moved in the course of household (Type 17) and furniture; other manufactured goods (Type 13) had the lowest average payloads for both rigid and articulated trucks. If the average loading conditions are considered, crude petroleum (Type 2), metal ores and other mining products (Type 3) had the highest average loading condition for both rigid and articulated trucks. On the other hand, average loading condition were the lowest for equipment and materials utilized in the transport of goods (Type 16) and goods moved in the course of household (Type 17) for both rigid and articulated trucks. Furthermore, significant differences were observed between average loading condition of the rigid and articulated trucks for some commodity types, such as basic metals; fabricated metal products (Type 10), grouped goods (Type 18) and textiles and textile products (Type 5) (see Table 3.17 and Table 3.18).

Table 3.16 Average payload and loading condition of the trucks according to commodity types

Type	2007		2008		2009		2007-2009	
	Payload (Ton)	Loading (%)	Payload (Ton)	Loading (%)	Payload (Ton)	Loading (%)	Payload (Ton)	Loading (%)
1	16.4	84	15.7	80	16.4	83	16.2	82
2	19.9	91	21.4	87	22.1	97	21.1	92
3	22.1	93	20.2	87	20.5	90	20.9	90
4	16.4	82	15.4	77	15.9	81	16.0	80
5	15.8	76	14.0	66	14.7	69	15.0	71
6	15.8	75	14.9	69	15.6	74	15.5	73
7	19.5	87	17.2	82	17.7	83	18.2	84
8	15.5	74	15.9	70	14.9	72	15.4	72
9	18.0	85	18.2	82	17.8	88	18.0	85
10	16.9	74	16.2	74	16.2	82	16.4	77
11	11.4	55	11.0	56	11.0	60	11.2	57
12	16.2	66	12.6	59	11.7	54	14.0	60
13	10.7	56	10.5	53	9.3	54	10.2	55
14	16.1	82	15.5	79	15.2	76	15.6	79
15	17.5	71	10.7	58	5.8	40	12.0	59
16	7.0	39	9.6	49	8.2	42	7.8	42
17	7.2	48	8.2	51	8.2	53	7.8	51
18	11.8	65	12.6	63	11.8	65	12.0	65
19	14.0	58	13.7	50	11.4	58	12.8	57
20	13.3	66	11.4	57	14.2	71	13.3	66
All*	12.6	60	12.1	58	11.9	58	12.3	58

* Includes empty trucks

Table 3.17 Average payload and loading condition of the trucks according to commodity types (rigid)

Type	2007		2008		2009		2007-2009	
	Payload (Ton)	Loading (%)	Payload (Ton)	Loading (%)	Payload (Ton)	Loading (%)	Payload (Ton)	Loading (%)
1	15.1	83	13.8	80	14.4	81	14.5	81
2	17.4	89	17.9	88	19.8	97	18.2	91
3	19.0	92	16.5	87	17.7	91	17.8	90
4	14.3	82	13.4	79	14.1	81	14.0	81
5	12.5	77	13.3	74	13.2	71	13.0	74
6	13.3	73	13.5	70	14.7	74	13.9	72
7	15.6	85	15.4	85	14.6	82	15.2	83
8	12.6	71	12.8	71	12.1	70	12.5	71
9	15.2	86	15.8	84	15.2	87	15.4	86
10	12.9	70	12.8	71	13.4	78	13.0	73
11	7.7	55	8.7	59	8.8	60	8.2	57
12	8.5	58	10.0	59	7.0	54	8.2	57
13	7.1	55	8.2	54	7.6	53	7.5	54
14	14.8	81	13.7	80	12.9	74	13.9	78
15	14.1	69	7.6	58	5.8	40	9.2	57
16	6.5	40	9.5	49	6.8	41	7.1	42
17	6.9	48	7.9	52	7.2	51	7.3	50
18	10.5	64	10.9	62	10.9	64	10.7	63
19	10.3	56	9.0	46	10.1	58	10.1	56
20	11.8	66	9.9	58	11.4	68	11.2	65
All*	10.8	60	10.4	60	10.4	58	10.6	59

* Includes empty trucks

Table 3.18 Average payload and loading condition of the trucks according to commodity types (articulated)

Type	2007		2008		2009		2007-2009	
	Payload (Ton)	Loading (%)	Payload (Ton)	Loading (%)	Payload (Ton)	Loading (%)	Payload (Ton)	Loading (%)
1	22.2	88	21.0	83	21.3	90	21.4	87
2	24.1	95	24.7	85	23.7	97	24.1	93
3	26.2	93	23.4	87	22.6	90	23.7	90
4	20.7	80	19.1	73	19.4	83	19.9	79
5	20.0	76	14.8	54	16.2	67	17.3	67
6	21.4	85	19.0	67	18.2	75	19.7	76
7	24.1	91	20.1	74	20.9	87	21.9	86
8	19.5	78	18.4	69	18.1	76	18.8	75
9	21.1	82	20.3	80	20.3	89	20.6	84
10	20.8	80	19.1	76	18.9	86	19.6	82
11	14.7	57	13.3	50	13.7	60	14.1	55
12	18.7	70	13.6	59	13.0	54	15.8	62
13	15.4	58	14.0	51	12.1	55	14.0	55
14	22.4	88	19.8	78	18.7	81	19.8	81
15	26.5	83	16.9	63	---	---	20.0	70
16	9.2	34	9.9	50	10.7	43	10.1	41
17	9.2	43	11.9	50	13.9	70	11.9	56
18	19.5	74	18.7	66	18.0	79	18.8	72
19	15.5	60	14.6	51	12.5	57	14.2	57
20	16.9	65	14.0	56	18.9	76	17.2	68
All*	15.5	59	14.7	56	14.0	59	14.7	59

* Includes empty trucks

Table 3.19 to Table 3.21 compares vehicle-km and ton-km shares of the laden trucks for each commodity type. Between 2007 and 2009, food products (Type 4), products of agriculture (Type 1) and other non-metallic mineral products (Type 9) had the highest vehicle-km and ton-km shares for all laden trucks as well as laden rigid and articulated trucks. On the other hand, secondary raw materials (Type 14), unidentifiable goods (Type 19), mails and parcels (Type 15) and equipment and materials utilized in the transport of goods (Type 16) had the lowest vehicle-km and ton-km share for all laden trucks. Significant differences were observed between vehicle-km shares of the rigid and articulated trucks for some commodity types, such as product of agriculture (Type 1) (17.9% for rigid trucks, 9.4% for articulated trucks), food products (Type 4) (17.1% for rigid trucks, 14.1% for articulated trucks), other non-metallic mineral products (Type 9) (7.7% for rigid trucks, 12.1% for articulated trucks, transport equipment (Type 12) (1.0% for rigid trucks and 5.2% for articulated trucks) and grouped goods (Type 18) (6.7% for rigid trucks and 2.0% for articulated trucks). For these commodity types, the difference between ton-km shares of the rigid and articulated trucks was also higher than the others (see Table 3.20 and Table 3.21).

Table 3.19 Vehicle-km and ton-km shares of the laden trucks according to commodity types

Type	Vehicle-Km Share (%)				Ton-Km Share (%)			
	2007	2008	2009	2007-2009	2007	2008	2009	2007-2009
1	13.4	16.4	14.8	14.7	14.1	17.1	15.9	15.5
2	3.0	2.7	2.9	2.9	3.8	3.9	4.2	4.0
3	3.4	5.1	5.2	4.5	4.9	6.8	7.0	6.1
4	16.8	15.5	15.3	15.9	17.7	15.9	16.0	16.6
5	4.0	3.8	3.9	3.9	4.1	3.6	3.7	3.8
6	3.8	4.3	4.5	4.2	3.9	4.2	4.6	4.2
7	4.5	4.6	5.5	4.9	5.7	5.2	6.4	5.8
8	6.9	5.1	5.3	5.9	6.9	5.4	5.1	5.9
9	10.3	9.3	8.5	9.4	11.9	11.3	9.9	11.0
10	4.6	5.5	5.7	5.2	4.9	5.9	6.0	5.6
11	6.6	5.5	3.9	5.3	4.8	4.1	2.8	3.9
12	3.3	1.2	2.9	2.6	3.5	1.0	2.2	2.4
13	4.2	4.0	4.1	4.1	2.9	2.8	2.5	2.7
14	0.9	1.1	1.0	1.0	0.9	1.1	1.0	1.0
15	0.6	1.6	0.4	0.8	0.7	1.1	0.1	0.6
16	1.3	0.6	1.1	1.0	0.6	0.4	0.6	0.5
17	2.8	3.2	3.2	3.0	1.3	1.7	1.7	1.5
18	5.1	5.4	4.4	4.9	3.8	4.5	3.4	3.9
19	0.8	0.5	1.0	0.8	0.7	0.4	0.7	0.6
20	3.7	4.8	6.7	5.0	3.1	3.6	6.2	4.3

Table 3.20 Vehicle-km and ton-km shares of the laden trucks according to commodity types (rigid)

Type	Vehicle-Km Share (%)				Ton-Km Share (%)			
	2007	2008	2009	2007-2009	2007	2008	2009	2007-2009
1	17.1	19.7	17.5	17.9	19.7	21.3	19.5	20.1
2	2.9	2.2	2.1	2.4	3.9	3.1	3.2	3.4
3	3.1	3.9	3.6	3.5	4.4	5.0	5.0	4.8
4	17.9	16.4	16.6	17.1	19.6	17.2	18.1	18.5
5	3.6	3.4	3.2	3.4	3.5	3.6	3.3	3.4
6	4.2	5.3	5.6	4.9	4.2	5.6	6.4	5.3
7	3.9	4.8	4.7	4.4	4.6	5.8	5.3	5.2
8	6.4	3.8	4.7	5.1	6.2	3.8	4.4	4.9
9	8.8	7.1	7.0	7.7	10.3	8.8	8.2	9.2
10	3.6	4.2	4.7	4.1	3.5	4.2	4.8	4.1
11	4.8	4.4	3.6	4.3	2.8	3.0	2.4	2.7
12	1.3	0.6	1.0	1.0	0.8	0.5	0.5	0.6
13	3.8	3.9	4.3	4.0	2.1	2.5	2.5	2.3
14	1.2	1.2	1.0	1.1	1.3	1.3	1.0	1.2
15	0.7	1.7	0.6	0.9	0.8	1.0	0.3	0.7
16	1.6	0.7	1.2	1.2	0.8	0.6	0.6	0.7
17	3.8	4.9	4.5	4.3	2.0	3.0	2.5	2.4
18	6.9	6.9	6.4	6.7	5.6	5.9	5.4	5.6
19	0.3	0.1	0.8	0.4	0.3	0.1	0.6	0.3
20	4.0	4.9	6.9	5.3	3.7	3.8	6.1	4.5

Table 3.21 Vehicle-km and ton-km shares of the laden trucks according to commodity types (articulated)

Type	Vehicle-Km Share (%)				Ton-Km Share (%)			
	2007	2008	2009	2007-2009	2007	2008	2009	2007-2009
1	7.0	11.2	10.6	9.4	7.8	12.6	12.1	10.5
2	3.1	3.6	4.2	3.6	3.7	4.7	5.3	4.5
3	4.1	7.0	7.5	6.1	5.4	8.8	9.0	7.6
4	14.9	14.1	13.2	14.1	15.5	14.5	13.7	14.6
5	4.7	4.5	4.9	4.7	4.7	3.6	4.2	4.3
6	3.2	2.7	2.9	3.0	3.4	2.8	2.8	3.0
7	5.6	4.3	6.7	5.7	6.8	4.6	7.4	6.5
8	7.8	7.3	6.1	7.1	7.7	7.2	5.9	6.9
9	13.0	12.7	10.7	12.1	13.7	13.9	11.6	13.0
10	6.3	7.5	7.2	7.0	6.6	7.7	7.3	7.1
11	9.5	7.3	4.3	7.0	7.0	5.2	3.1	5.2
12	6.8	2.2	5.7	5.2	6.4	1.6	3.9	4.3
13	5.0	4.0	3.9	4.3	3.9	3.0	2.5	3.2
14	0.4	0.8	1.0	0.7	0.5	0.9	1.0	0.8
15	0.5	1.3	0.0	0.5	0.6	1.2	---	0.5
16	0.7	0.3	1.0	0.7	0.3	0.2	0.6	0.4
17	0.9	0.6	1.2	0.9	0.4	0.4	0.9	0.6
18	2.0	3.0	1.4	2.0	1.9	3.0	1.4	2.0
19	1.5	1.0	1.3	1.3	1.1	0.8	0.8	1.0
20	3.0	4.6	6.3	4.6	2.5	3.4	6.4	4.1

Additional analysis on trip distance distribution of the survey trucks are provided in Figure 3.2. Of all the surveyed trucks between 2007 and 2009, trip distances was less than 250 km for 35% of them, and less than 500 km for 58% them. Only 14% of the surveyed trucks had trip distance higher than 1000 km. Trip distance was on the short haul (i.e. less than 500 km) for 63% of the rigid and 48% of the articulated trucks. As it is seen, articulated trucks served more frequently in longer distances than rigid trucks. Trip distances of almost 25% of the articulated trucks were longer than 1000 km.

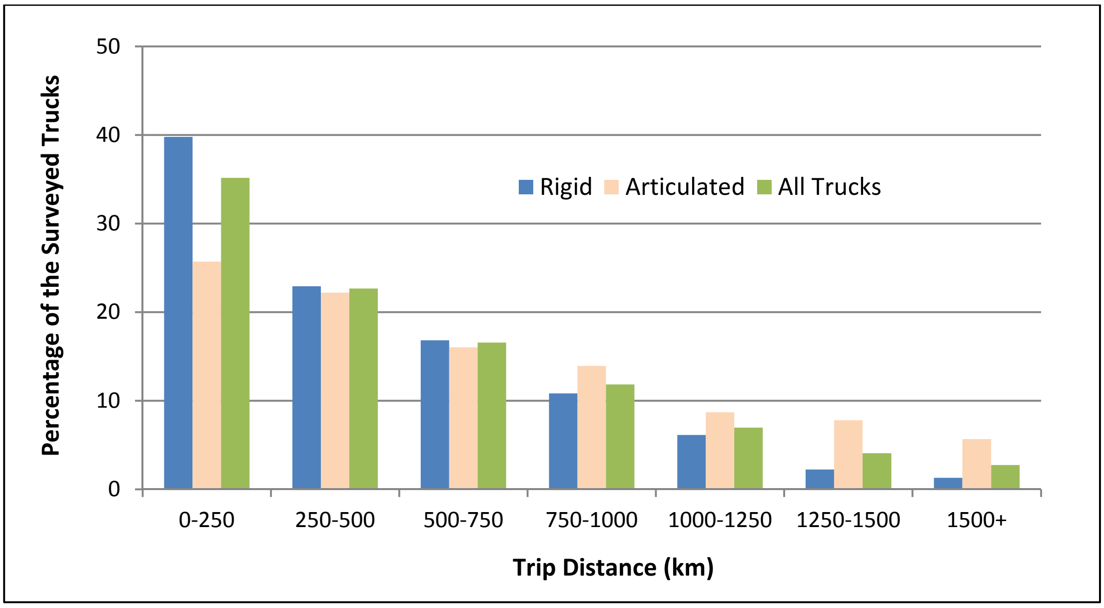


Figure 3.2 Trip distance distribution of the rigid and articulated trucks

Figure 3.3 compares the distance distribution of empty and laden trucks. As expected, laden trips more frequently served on long hauls than empty trucks. Furthermore, the share of the empty and laden truck trips decreases as the trip distance increases. 75% the empty trucks were on the short haul. The percentage of the laden trips on short haul was 50%. Figure 3.4 considers the only trip distance distribution of the empty trucks. Trip distances of majority of the trucks were less than 250 km. Empty articulated trucks were more frequently observed on the long haul than rigid trucks. Trip distances of only 17.1% of the rigid trucks were on the long haul, while 36.5% was for articulated trucks.

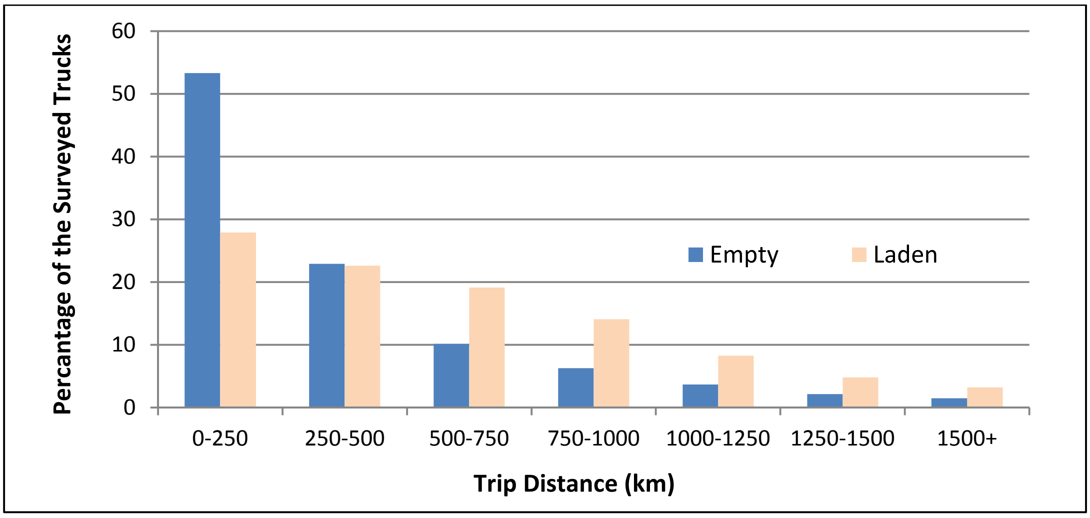


Figure 3.3 Trip distance distribution of the empty and laden trucks

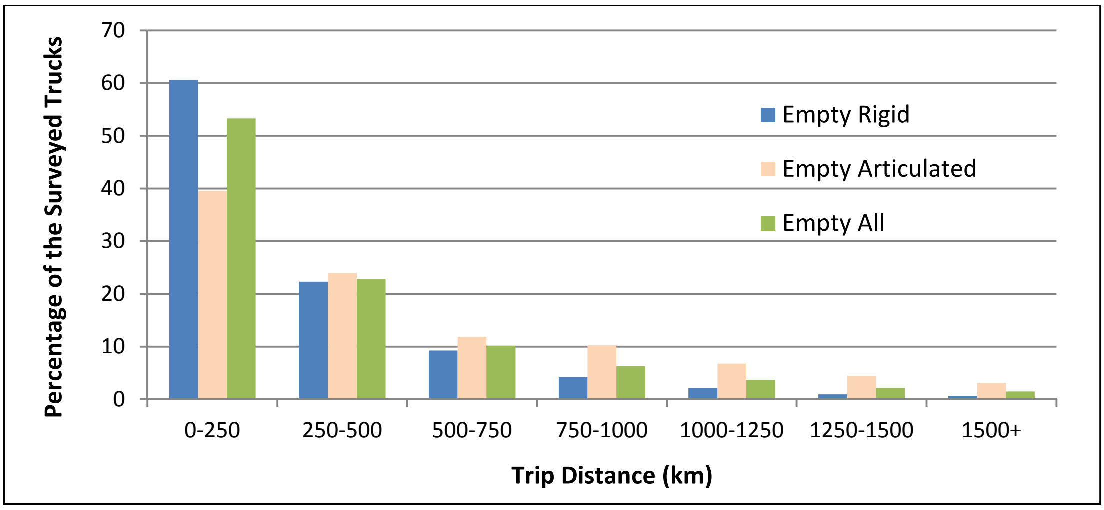


Figure 3.4 Trip distance distribution of the empty trucks

CHAPTER 4

ESTIMATION OF ROAD FREIGHT EMISSIONS IN TURKEY

Chapter 2 presented a detailed literature review of the road freight emission calculation methodologies and reduction strategies. But, as discussed before, a more customized methodology is needed to estimate road freight emissions for Turkey to the most possible disaggregate level, so that some emission reduction scenarios can be analyzed, as well. This chapter first presents the framework of the proposed methodology, and then provides the emission estimation values for a decade of 2000-2009. Potential of emission reductions are evaluated at the end.

4.1 Framework for Estimation of Road Freight Emissions for Turkey

The basic steps of a generic approach providing the truck freight emission estimation is summarized in Table 4.1, which also shows the current status of available data and models in Turkey. Following a traditional models, the first step is generally trip generation which focuses on estimation of the number of produced and attracted. Trip and attraction equations are generally estimated through regression analyses, in which independent variable included socioeconomic measures, such as GDP, population, employment and industrial production. In Turkey, Unal (2009) developed province level trip production and attraction functions for 2004 based on aggregation of all commodity types using roadside axle survey data and socioeconomic variables, such as population, employment and passenger car ownership (see Chapter 2).

Table 4.1 Evaluation of availability of data and models for truck freight emission estimations in Turkey

Steps	Data Requirements/Characteristics	Status in Turkish Literature
Trip Generation	– Commodity flow data/roadside axle surveys – Socioeconomic variables Output: Generation of productions and attractions	– Trip generation and distribution models developed by Unal (2009) for 2004 using roadside axle survey data and limited number of socioeconomic variables
Trip Distribution	– Gravity models Output: Generation of O-D matrix	
Mode Choice	– Mode choice models	– Redundant for Turkey due to dominance of trucks in freight transportation
Network Assignment	– Assignment principle	– Not developed for Turkey
Determination of the Vehicle-Km	– Network assignment/Continues link counts	– Link volumes for all state roads are either counted or estimated
Truck Freight Emission Estimation	– Data requirement depends on the model	– Limited contribution from studies on private car emissions
Estimation of Emission Reduction Potential	– Data requirement depends on the estimation model and reduction strategy	– No study specifically on truck emission reductions

The generated trips must be assigned to destinations, which is basically done in the second step, the trip distribution. Most commonly used model is the gravity model, which was also employed Unal (2009) for Turkey. The third step is the mode choice, which can be between truck freight, rail or intermodal options; however, it is redundant for Turkey due to dominance of the trucks in freight transportation. The fourth step is the network assignment. Network assignment step focuses on assignment of flows on routes for each O-D pair, which requires a network assignment principle. While there are available assignment principles developed for truck freight in the global literature, it is not possible to use them directly for Turkey, as the economic measures and assignment principle may vary greatly between different regions and countries. So, truck freight network assignment principle has to be determined for Turkey specifically, which had not been done before. The next step is the determination of the truck vehicle-km for the study area, which can be calculated from network assignment or continues link counts. Turkish General Directorate of Highways (TGDH) annually publishes link counts for rigid and articulated trucks only for state roads. However, there isn’t any published data for provincial roads and motorways. Estimation of emissions, depends on the available data. The more detailed data is available, the more comprehensive models can be used. However, due to lack of detailed data, truck freight emissions has not been studied in detail in Turkey, yet. Finally, to study the emission reduction potential from truck freight, any developed scenario will eventually be bounded by the availability of the detailed data and the used estimation model. The lack of any study in the previous step also prevented any further study in this step in Turkey.

Following the above mentioned steps and considering the only available truck freight data in Turkey, the truck freight emission and potential reduction can be studied most comprehensively as shown in Figure 4.1.

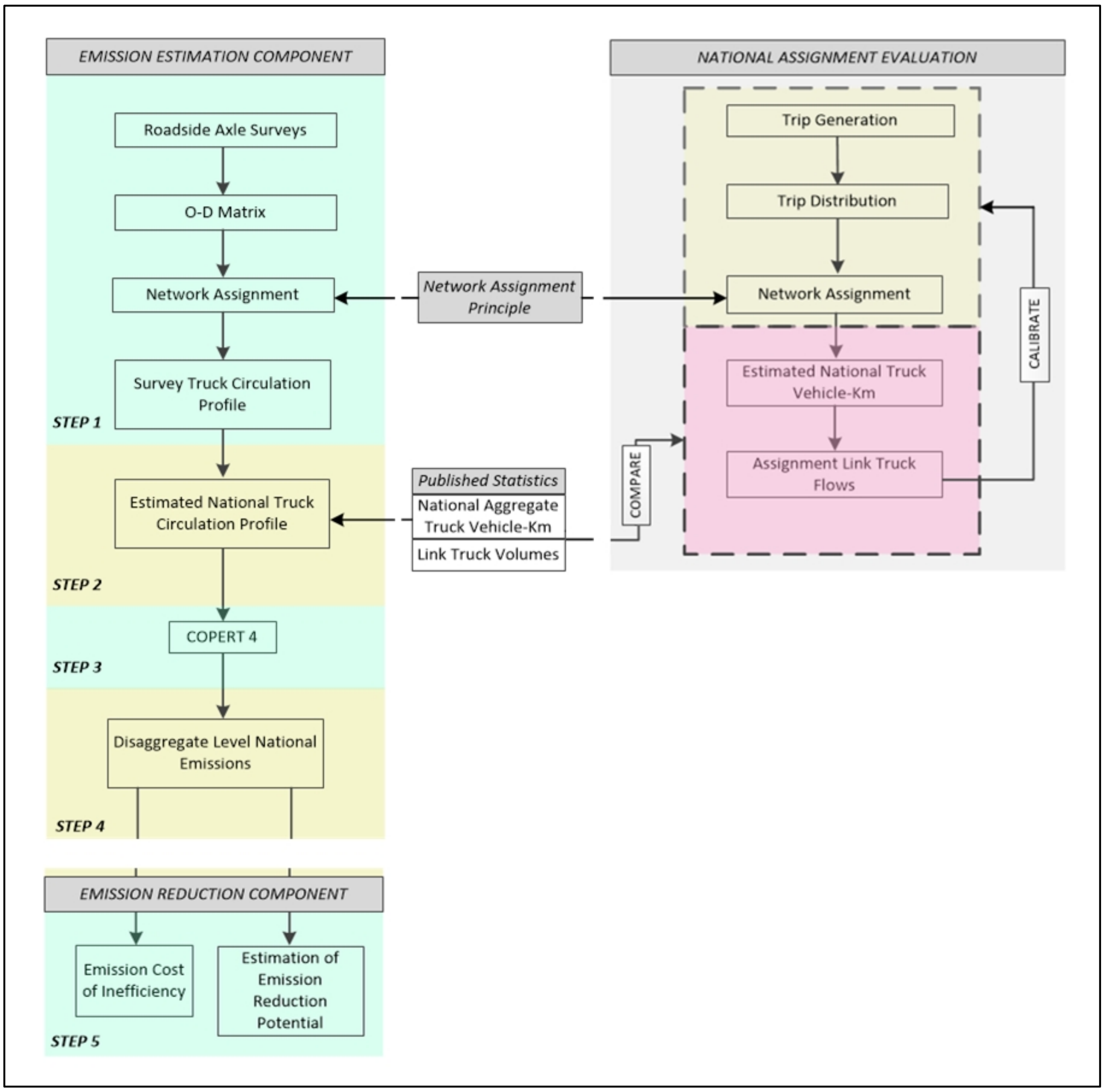


Figure 4.1 A framework to analyze truck freight emissions in Turkey

Such a study needs the development of an emission estimation component, which provides detailed statistics to be used in the emission reduction analyses. These two components will be discussed in detail in the following sections. However, the proposed model for emission estimation primarily rely on estimation of survey truck circulation profile, which requires network assignment of the O-D matrix obtained from roadside axle survey data. As this step requires a truck network assignment principle, it must be determined as a perquisite. This assignment principle is obtained from the survey O-D matrix, and its appropriateness is studied in further detail as a separate study, which is presented in Chapter 5 in detail.

4.2 Proposed Emission Estimation Methodology

As mentioned above, a proposed methodology integrates both disaggregate level roadside axle survey data and national aggregate level truck transportation statistics is developed with the following steps (see Figure 4.2):

Step 1 Surveyed trucks are be assigned to the highway network using an all-or-nothing shortest path assumption between origin and destination points. Then, vehicle-km values of the different rigid and articulated truck profiles can be obtained for different loading conditions from roadside axle surveys. For each loading condition, there are 24 rigid truck profiles (8 Gross Vehicle Weight Category x 3 Emission Legislation) and there are 18 articulated truck profiles (6 Gross Vehicle Weight Category x 3 Emission Legislation) (see Table 2.4).

Note 1: Loading conditions are defined in 11 levels between 0% and 100% by 10% increments. Such detailed modeling of the loading distribution enables to differentiate emissions from different loading conditions (empty trucks, less-than-half loaded trucks, etc.).

Note 2: As the truck emission legislations are not collected during surveys, vehicle production year information can be used to estimate emission legislation standards of the surveyed trucks (Liimatainen and Pöllänen, 2010). Besides, European emission legislations have not been followed in a timely manner in Turkey. Truck diesel engine emissions were first regulated with Euro I technology in 2001. Thus, diesel vehicles of pre-Euro I can be all grouped together under the Conventional legislation. However, Euro II and Euro III legislations were not introduced. Finally, Euro IV legislation was introduced in 2008. Today, in 2012, Euro V legislation still has not been introduced for diesel engines, yet. Therefore, trucks are classified into Conventional, Euro I and Euro IV legislation standards in correspondence with their production year and implementation of the Euro legislation dates.

Step 2 The annual aggregated for rigid and articulated truck vehicle-km values are distributed among the derived profiles in Step 1 using their shares in roadside axle surveys.

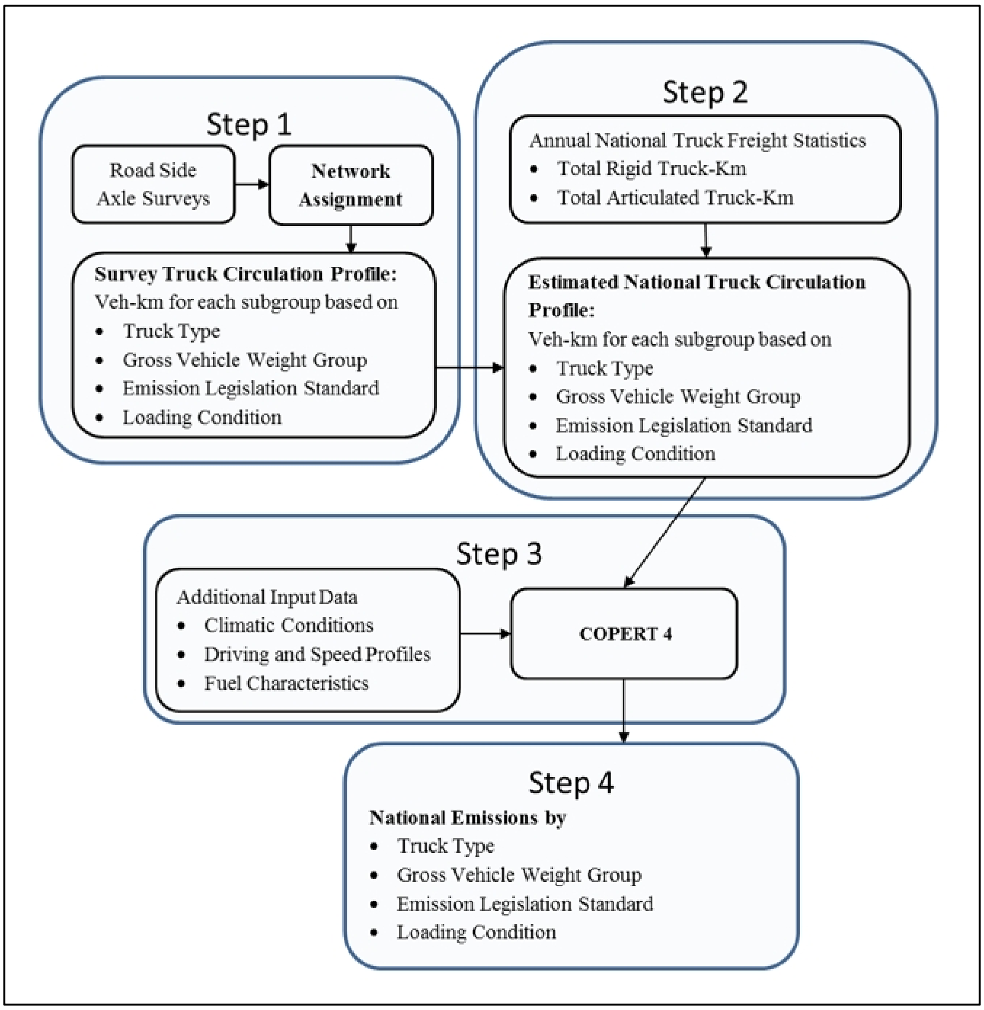


Figure 4.2 Proposed methodology to calculate truck freight emissions in Turkey

Step 3 COPERT 4 is used to calculate the annual national truck emissions using the input values calculated in Step 1 and Step 2. The data for diesel fuel characteristics are obtained from Turkish Petroleum Industry Association (TPIA, 2011) and the most appropriate option is selected in COPERT 4.

Note 3: COPERT 4 is run for 11 different loading levels (0% to 100%) separately with corresponding truck activity data. For each loading level, emissions for different legislations standards (Conventional, Euro I and Euro IV) are calculated together due to the programme requirement (see Figure 2.8).

Step 4 Emissions from all COPERT 4 runs of different loading levels are summed up to get the national level freight emissions for a year. The results can be grouped based on the size and legislation standards for articulated and rigid trucks.

4.3 Input Data Processing for COPERT 4

COPERT 4 program, used for emission calculations, is selected due to its common usage in European Union and moderate level of data requirements. COPERT 4, which is the latest version of the COPERT inventory model, can integrate various level and source of freight information (truck types, emission legislations and loading conditions, etc.) and enables policy makers to observe freight transportation emission trends in different market segments (urban, rural and highway) to develop comparative studies of possible emission reduction scenarios. The details of COPERT 4 were discussed in Chapter 2. The biggest challenge the proposed methodology is the lack of detailed freight activity data. There is no annual truck activity data to meet the requirements of COPERT or any other emission inventory model, as a matter of fact. Available national statistics provides only aggregate level statistics for rigid and articulated trucks. Loading levels, another critical input parameter for truck emissions as discussed in detail in Chapter 2 and Appendix A to Appendix C, are missing. Although it is preferred to use national commodity flow data to better represent freight transportation flows, in the absence of such data, roadside axle surveys provide a valuable source of disaggregate data sample for national truck transportation and enables to estimate required flow parameters for COPERT 4. Table 4.2 summarizes the producers for input data generation in the proposed methodology.

Table 4.2 Generating input data for COPERT 4

Activity Data:	
Number of vehicles per vehicle category	Vehicle classification scheme in Table 2.4 was used. There are 8 gross vehicle weight category for rigid trucks and 6 gross vehicle weight category for articulated trucks.
Loading conditions	Loading conditions were defined in 11 levels between 0% and 100% by 10% increments.
Emission legislation	Conventional, Euro I and Euro IV legislation standards were used.
Distribution of the vehicle fleet into different exhaust emission legislation classes	See numerical example in Table 4.3.
Mileage per vehicle class	
Mileage distribution per road class	COPERT requires vehicle-km shares on *rural roads*, *motorways* and *urban roads* separately for each profile. In this study, a single vehicle-km distribution was used for rigid and articulated trucks independent of gross vehicle weight categories, emission legislation and loading conditions. For instance, in 2009, it was 73% *rural roads*, 20% *motorways* and 7% *urban roads* for *rigid trucks*; and 69% *rural roads*, 30% *motorways* and 1% *urban roads* for articulated trucks (TGDH, 2012b).
Driving Conditions	
Average speed per vehicle type and per road class	COPERT requires average speed *rural roads*, *motorways* and *urban roads* separately for each profile. In this study, a single speed was used for rigid and articulated trucks independent of gross vehicle weight categories, emission legislation and loading conditions. For *rural roads and motorways* average values published by TGDH was used for each year. On the other hand, as there is no published speed data for *urban roads*, 40 km/h was assumed for rigid and articulated trucks.
Other Variables	
Climatic Conditions	COPERT 4 requires average monthly minimum and maximum temperatures independent of other activity data and driving conditions. National monthly average minimum and maximum temperatures were used as input climatic data (TSMS, 2011).
Mean Trip Distance	For each loading condition, COPERT 4 requires single average trip distance value regardless of vehicle profiles. Average trip distances were calculated from roadside axle surveys.
Evaporation Distribution	COPERT 4 default values were used.

COPERT 4 requires number of vehicles and their vehicle-km values based on truck types, emission legislations and loading conditions (see Table 2.4). Note that only Conventional, Euro I and Euro IV emission legislations has been introduced in Turkey. Therefore, for each loading condition, there are 24 rigid truck profiles (8 Gross Vehicle Weight Category x 3

Emission Legislation) and there are 18 articulated truck profiles (6 Gross Vehicle Weight Category x 3 Emission Legislation). For any loading condition, a program user can input parameters of all of these 42 profiles and run COPERT 4 (see Figure 2.7). COPERT 4 separately reports emission estimates of each profile (see Figure 2.8).

The following numerical example is presented to explain details of the Step 1 and Step 2. This example presents the estimation of national profile for Conventional and 0% loaded trucks in 2009. Similar examples can be prepared for other combinations of 11 loading levels (0% to 100% by 10%) and 3 emission legislations (Conventional, Euro I and Euro IV) as a part of the proposed methodology:

Table 4.3 Estimation of national profile for Conventional and 0% loaded trucks

Truck Type	Survey Data		National Estimators		National Estimated Profile	
	No. of Vehicles	Vehicle-Km	Vehicle-Km (%)	Avg. Trip Distance (Km)	Vehicle-Km (10^6)	No. of Vehicles
	(A)	(B)	(C)	(D)	(E)	(F)
R. < = 7.5 t	61	18,605	0.54	305	60.7	199,029
R.7.5 - 12 t	32	10,272	0.30	321	33.5	104,409
R. 12 - 14 t	11	3,894	0.11	354	12.7	35,891
R. 14 - 20 t	62	20,832	0.60	336	68.0	202,292
R. 20 - 26 t	51	19,227	0.56	377	62.7	166,402
R. 26 - 28 t	6	2,430	0.07	405	7.9	19,577
R. 28 - 32 t	61	24,888	0.72	408	81.2	199,029
R. > = 32 t	5	2,335	0.07	467	7.6	16,314
A. 14 - 20 t	8	1,872	0.08	234	8.5	36,343
A. 20 - 28 t	9	3,321	0.13	369	15.1	40,886
A. 28 - 34 t	22	9,306	0.37	423	42.3	99,944
A. 34 - 40 t	77	36,036	1.45	468	163.7	349,803
A. 40 - 50 t	24	11,592	0.47	483	52.7	109,030
A. 50 - 60 t	5	2,925	0.12	585	13.3	22,714

- Survey rigid truck vehicle-km 3,464,841
- Survey articulated truck vehicle-km 2,488,500
- National rigid truck vehicle-km 11,305x10^6
- National articulated truck vehicle-km 5,061x10^6

i. From the survey data, number of vehicles in each truck category are compiled (Column A). Vehicle-km values of each truck category are obtained assuming shortest path assignment between their origin and destination points (Column B). National vehicle-km share estimators (Column C) are calculated by dividing the values in Column B by the corresponding total survey vehicle-km value in the last part of the table. National average trip distance estimators (Column D) calculated by dividing the values in Column B by Colum A.

ii. National level vehicle-km values (Column E) estimated by distribution of annual aggregated rigid and articulated vehicle-km values using the shares calculated in Step 1 (See Column C). The corresponding total number of trucks (Column F) are calculated by assuming the survey average trip distances (Column D) as estimators for the national movements.

4.4 Evaluation of Emission Estimations

The proposed methodology was used to calculate trucking emissions in the period of 2000 to 2009 in Turkey (see Table 4.4). These emissions can be studied in two sections: a) local emissions (CO, PM, and NO_x) which may cause climate change and be harmful for human life, b) global emissions (CH_4 and CO_2), which are also called direct greenhouse gases and have attracted attention in all countries (see Appendix A). Looking at the overall picture, it is seen that, in 2009 the quantities of all emissions were lower than in 2000. The level of all emissions decreased to their minimum level in 2004, which is parallel to the decrease in truck vehicle-km in this period. In 2009, the level of CO emissions was as low as the minimum level observed in 2004; however, the levels of the other local emissions were higher than 2004 level. CO_2 emissions started to increase after 2004 and reached the maximum level in 2007. In 2009, annual level of CO_2 emissions was slightly lower than its 2000 level. The annual level of CH_4, another global emission, remained almost constant after 2004. It is also important to find the emissions based on contributing truck types, to see the impact of change in the trucking sector. Annual CO_2 shares of the rigid and articulated trucks are presented in Table 4.5. In 2009, rigid trucks constituted 68.1% of the CO_2 emissions, while articulated trucks constituted 31.9% of them. It is also seen that the share of the articulated truck emissions tripled and reached their maximum level in 2009, as parallel to the increase in their vehicle-km values over the years. On the other hand, CO_2 emission share of rigid trucks decreased from 89.6% to 681% (see Table 3.5).

Table 4.4 Trucking emissions in Turkey (in kiloton)

Year	Local Emissions			Global Emissions	
	CO	PM	NO_x	CH_4	CO_2
2000	32.9	5.4	158.2	1.2	12,129
2001	30.3	5.0	146.1	1.1	11,405
2002	29.8	4.8	142.9	1.2	11,241
2003	29.8	4.8	143.1	1.1	11,362
2004	24.8	4.0	116.6	0.9	9,575
2005	26.4	4.2	122.6	1.0	10,383
2006	28.0	4.5	127.8	1.2	11,027
2007	27.9	5.6	144.5	1.1	12,081
2008	26.1	5.1	137.4	1.0	12,041
2009	24.8	4.9	133.6	1.0	12,076

Table 4.5 CO_2 emissions based on truck type in Turkey (in kiloton)

Year	Rigid		Articulated		Total
	Kton	%	Kton	%	Kton
2000	10,869	89.6%	1,260	10.4%	12,129
2001	10,173	89.2%	1,232	10.8%	11,405
2002	10,005	89.0%	1,236	11.0%	11,241
2003	10,093	88.8%	1,269	11.2%	11,362
2004	7,784	81.3%	1,791	18.7%	9,575
2005	8,335	80.3%	2,048	19.7%	10,383
2006	8,628	78.2%	2,399	21.8%	11,027
2007	9,334	77.3%	2,747	22.7%	12,081
2008	8,886	73.8%	3,155	26.2%	12,041
2009	8,224	68.1%	3,852	31.9%	12,076

Estimated annual trucking emissions by the proposed methodology can be compared with the values provided by Soylu (2007) only for the year 2003 (although Soylu presented estimations for the year 2004, the input vehicle-km and ton-km values in the study belonging to 2003), and by Agacayak (2007) (see Table 2.3 and Table 4.6). Estimation of 11,362 kiloton CO_2 emissions for 2003 (using COPERT 4) is very close to 11,108 kiloton CO_2 by Soylu (2007). Similarly, estimation of 143.1 kiloton for NO_x emissions (using COPERT 4) in the current study is close to 135.4 kiloton estimated by Agacayak (2007). There are major differences in the remaining emissions, but it is not easy to comment on these variations. These differences may be due to methodological differences between COPERT III and COPERT 4. COPERT 4 adopted the ARTEMIS project emission functions for heavy duty vehicles, whereas COPERT III used its own emission functions for heavy duty vehicles. It is important to note that, there are more truck categories in COPERT 4 as compared COPERT III. More precisely, a wider range of weight classes are presented in the ARTEMIS project and COPERT 4. Furthermore, there are also differences in the NO_x estimations by Soylu (2007) and Agacayak (2007), even though both studies report using COPERT III, which brings the issue of input data assumptions in the estimations. However, the lack of detailed information on the input data by either author, makes it difficult to provide any further comments on these comparisons.

Table 4.6 Comparison of truck emission estimates in Turkey for the year 2003 (in kiloton)

Study	Tool	CO	PM	NO_x	CH_4	N_2O	CO_2
Current Study	COPERT 4	29.8	4.8	143.1	1.1	0.6	11,362
Soylu (2007)	COPERT III	54.0	9.7	107.0	0.7	0.5	11,108
Agacayak (2007)							
Estimate 1	COPERT III	---	---	100.2	---	---	---
Estimate 2	COPERT III	---	---	135.4	---	---	---

The following additional comparisons are provided for validation of the CO_2 estimations in Table 4.4. First, COPERT 4 diesel fuel consumption and CO_2 emissions for a given input data can be used to calculate the CO_2 conversion ratio (kg CO_2 per liter of diesel consumption). Then, this value can be checked against published values in the literature for consistency purposes. The estimated CO_2 ratio for per liter of diesel fuel consumption was

2.66 kg in 2009. This value is very close to 2.65 kg of CO_2 emission per liter suggested by DEFRA in the UK (2011), for heavy good vehicles.

For a second validation, the share of trucking emissions in the transportation sector emissions can be calculated and compared with published values. Intercity trucking CO_2 emissions were estimated as 12,076 kilotons (see Table 4.4). Besides, national transportation sector CO_2 emissions were reported as 46.7 million tons by Turkish Statistical Institute (TurkStat, 2011b). Therefore, the share of intercity trucking emissions in the national transportation sector can be estimated as 25.9%. This share seems very close to market share of trucking published by international organizations, such as 23.2% by the OECD/ITF (2008a). It should be noted that the latter includes emissions from both intercity and intracity movements, while emissions presented in this study include only intercity movements. This suggests that if intracity movements are included, the total share of road freight in Turkey might be much more than the published value by the OECD/ITF (2008a). This provides a supporting evidence to show the truck dominancy in Turkish freight sector. However, it is hard to forecast the real share of total road freight emissions from the numbers presented here, as intercity freight movements are the most efficient ones in terms of emissions per vehicle-km, as they performed at higher speeds and with newer vehicles. Furthermore, intra-city freight movements are performed at lower speed and subject to congestion, which increase the emission rates, sometimes more than twice (See Appendix B and Appendix C).

Another control measure is the comparison of fuel consumption estimated by COPERT 4 against national diesel fuel consumption. Total truck share in diesel fuel consumption of India, another developing country, was reported as 37% for 2008-2009 (Bhaskar, 2013), while it was 71.0% in the USA in 2011 (EIA, 2013; ATA, 2013). For Turkey, COPERT 4 estimated a total diesel consumption of 3.8 million tons for inter-city trucking in 2009. For the same year, Turkish Petroleum Industry Association (TPIA, 2011) published a national diesel consumption of 13.5 million tons. The share of inter-city trucking in diesel consumption seemed to be 28.1%. This estimate seems close to the share for India, but cannot be directly compared as a strong validation. Because, first, it accounts for only the inter-city truck freight, not the total truck movements. In addition, the number and type of diesel vehicles (trucks, buses, light duty vehicles, etc.), their vehicle-km shares, and sectors using diesel fuel in each country may vary greatly.

4.5 Sensitivity of Estimators to Input Data

To test the sensitivity of the proposed model to the input data, two alternative scenarios were developed based on assumptions on the availability of disaggregate level; a) vehicle-km and b) loading condition data. As all Euro IV trucks began to be observed only after 2007, sensitivity analysis was performed for the surveyed trucks only after 2007.

Scenario A: This scenario assumes known disaggregate level vehicle-km distribution (based on truck type, maximum gross weight and emission legislation) from the roadside axle surveys. But, it assumes unknown loading condition data, which is assumed to be 50% as default value of the COPERT 4 program.

Scenario B: This scenario assumes no disaggregate level data availability. As there is no any disaggregate level data, the trucking vehicle-km values can be assumed as uniformly distributed among all different classes of 24 rigid trucks (8 maximum gross weight x 3 legislation type) and 18 articulated trucks (6 maximum gross weight x 3 legislation type). Similarly, in the absence of any loading information, all trucks are taken as 50% loaded.

Table 4.7 Sensitivity analysis of the proposed methodology for the surveyed trucks (CO_2 emissions)

Scenario	2007			2008			2009		
	R*	**A****	**Total**	**R***	**A****	**Total**	**R***	**A****	**Total**
Base Model Emissions (tons)	2,774	2,000	4,774	1,858	1,470	3,328	2,518	1,947	4,466
	58%	42%	100%	56%	44%	100%	53%	47%	100%
Scenario A Emissions (tons)	2,799	1,881	4,680	1,765	1,421	3,186	2,400	1,884	4,285
	60%	40%	100%	55%	45%	100%	56%	44%	100%
Deviation from Base Model	1%	-5%	-3%	-5%	-3%	-4%	-5%	-3%	-4%
Scenario B Emissions (tons)	2,123	1,901	4,024	1,527	1,299	2,826	2,072	1,913	3,985
	53%	47%	100%	54%	46%	100%	52%	48%	100%
Deviation from Base Model	-23%	-5%	-16%	-18%	-12%	-16%	-18%	-2%	-11%

*R: Rigid Trucks; **A: Articulated Trucks

Roadside axle survey truck emissions were first calculated by the proposed methodology taking the advantages of available disaggregate data to the fullest (see Table 4.7). As the control cases, Scenario A and Scenario B presents emission calculations for the surveyed trucks with the aforementioned assumptions. The results showed that Scenario A that assumes 50% average loading condition introduces only small changes in CO_2 estimates of the surveyed trucks. This can be explained by the fact that a default of 50% average loading is very close to 58% calculated average loading of the intercity truck movements (see Table 3.16). On the other hand, the model in Scenario B, which does not use any vehicular profile, significantly underestimated the carbon emissions up to 23%. This result implies that the importance of the availability of disaggregate level data. Furthermore, any emission estimation that does not use any disaggregate level data should be regarded with concern. Secondly, the values presented in this study may be changed, if the commodity flow data were used. However, in the absence of commodity flow surveys, proposed emission calculation methodology uses the most available disaggregate data in the estimation of the input data, which affects the emission estimations significantly.

4.6 Emission Cost of Inefficiency in Trucking

The main advantage of the proposed methodology is the capability of estimating emissions at different levels, such as rigid trucks and articulated trucks, and loading conditions, etc. A more detailed analysis of these results provide opportunity to calculate the level of inefficiency and the emission cost of this inefficiency. Consequently, the potential of emission reduction in road freight movements in Turkey can be calculated to support further discussion on potential emission reduction policies. Actually, in the literature, there is no single inefficiency definition. Different inefficiency levels can be defined based on different threshold values of vehicle capacity utilization level. For instance, in an analysis, one can assume inefficiency as less than half loaded movements or an analysis can assume inefficiency as less than average loading condition. The following subsections discuss the efficiency of the roadside axle survey trucks based on emission legislations, loading conditions and trip distances.

4.6.1 Emission Legislation Analysis

It is important to know emission legislations of the trucks. As discussed in the proposed methodology, truck production year data can be used to estimate emission legislations of the vehicles in the national fleet. Table 4.8 presents truck production year data published by TurkStat (2011b) in the national vehicle fleet. It is seen that, 65.3% of trucks had Conventional legislation in 2009. On the other hand, penetration of the Euro I and Euro IV legislations have been slow, with shares of 26.9% and 7.8%, respectively. Similarly, emission legislations can be estimated for surveyed trucks (see Table 4.9). In Table 4.9, vehicle-km value of the surveyed trucks was calculated using the origin and destination information from the survey and assuming a shortest path assignment. The survey data showed a continuous decrease in the use of Conventional trucks in freight transportation. In 2009, even though Conventional trucks captured the highest share with 65.3% in the truck vehicle fleet, they accounted for only 29.8% of the survey sample. Euro I trucks were observed more frequently in the surveys, despite their relatively slow penetration into the vehicle park. Euro IV trucks were captured with an increasing rate after 2007. Their survey share was 15.1% in 2009, which was almost twice of their percentage in the national vehicle fleet (see Table 4.9). In 2009, the average trip distance, calculated dividing the total vehicle-km by total number of trucks, was calculated as 520.0 km for Euro I trucks. It was 482.3 km and 447.3 km for Euro IV and Conventional trucks, respectively. This may be an indication of a trend, of using the new and cleaner trucks in longer distances. In addition, it shows the employment of more efficient technologies in the longer hauls as a natural evolution of the commercial freight sector.

Table 4.8 Emission legislation of the trucks in the national vehicle fleet in 2009 (Source: TurkStat, 2011b)

Production Year	Number of Trucks	Legislation
2000 and earlier	457,711 (65.3%)	Conventional
2001 to 2007	188,809 (26.9%)	Euro I
2008 to 2009	54,706 (7.8%)	Euro IV

Table 4.9 European emission legislations of the surveyed trucks

Production Year	Number of Vehicles (%)			Vehicle-Km (%)			Average Trip Distance (Km)		
	Conv.	Euro I	Euro IV	Conv.	Euro I	Euro IV	Conv.	Euro I	Euro IV
2000	99.2%	0.8%	---	99.2%	0.8%	---	511	528	---
2001	91.5%	8.5%	---	91.6%	8.4%	---	524	514	---
2002	87.0%	13.0%	---	87.5%	12.5%	---	519	495	---
2003	83.7%	16.3%	---	84.0%	16.0%	---	540	528	---
2004	68.5%	31.5%	---	67.9%	32.1%	---	492	506	---
2005	56.9%	43.1%	---	54.6%	45.4%	---	462	507	---
2006	47.9%	52.1%	---	46.7%	53.3%	---	491	514	---
2007	37.2%	62.1%	0.7%	36.3%	63.1%	0.6%	531	551	435
2008	30.8%	59.8%	9.4%	29.0%	61.4%	9.6%	493	538	533
2009	29.8%	55.8%	15.1%	27.0%	58.2%	14.8%	447	520	482

4.6.2 Loading Condition Analysis

It is also possible to tabulate loading conditions of the surveyed trucks. Table 4.10 presents the trends in empty running (defined as vehicles with less than 5% loading condition) vehicle-km, average loading condition, and payload for the surveyed trucks between 2000 and 2009. Empty running dipped in 2007 at 19.3%, from a base value of 27.7% in 2000. It reached 22.3% again in 2009. Empty vehicle-km share of articulated trucks was higher than the share of rigid trucks during the study period. Assuming the same percentage as an estimator for the national market, it can be estimated that 3,645 million-km of the road freight movements was driven empty in 2009. In the literature, Liimatainen and Pöllänen (2011) studied the trends in the empty road freight movements for different sectors in Finland. However, such analysis is not possible for Turkey, in the absence of commodity flow data and since roadside axle survey data includes only commodity type information, but not the sectorial information. Average loading condition and payload are closely related factors and depend on the composition of vehicles in the freight market. The average loading condition of the laden trips, as defined by Piecyk (2010b), remained constant between 2000 and 2009. In 2009, loading condition of the laden trips was 75%. If the all trips were considered including empty movements, the average loading condition was 58.4% in 2009. The average payload per truck increased from 9.3 tons to 11.9 tons between 2000 and 2009. These values had been within the range of payload observed in the EU states (Piecyk and McKinnon, 2009). A continuous increase in the average payload of rigid trucks has been observed, whereas average payload for articulated trucks showed fluctuations in the same period.

Table 4.10 Empty running, average loading and average payload of the surveyed trucks

Year	Empty Running [a] (%)			Average Loading Condition [b] (%)			Average Payload [c] (Ton)		
	Rigid	Articulated	All	Rigid	Articulated	Total	Rigid	Articulated	All
2000	26.2	39.0	27.7	72.5	71.8	72.5	8.7	14.7	9.3
2001	22.1	31.6	23.1	73.3	74.6	73.4	9.5	16.2	10.2
2002	23.3	37.5	25.0	73.7	70.7	73.4	9.4	14.9	10.1
2003	20.6	34.2	22.2	73.9	69.9	73.5	9.7	15.7	10.7
2004	19.6	30.0	21.1	74.6	71.4	74.2	9.6	15.6	10.4
2005	19.8	33.2	22.1	72.1	66.6	71.4	9.8	14.8	10.6
2006	21.8	26.5	22.7	73.3	70.9	72.9	9.9	15.7	11.0
2007	17.4	22.5	19.3	74.1	77.1	75.0	10.8	15.5	12.6
2008	18.6	21.2	19.5	72.6	71.7	72.3	10.4	14.7	12.1
2009	19.8	25.8	22.3	73.1	78.7	75.0	10.4	14.0	11.9

[a] Includes only road freight movements with less than 5% loading
[b] Excludes empty running
[c] Calculated by dividing ton-km by vehicle-km

4.6.3 Trip Distance Analysis

Table 4.11 presents distribution of surveyed trucks based on loading condition and trip distance in 2009. As the average loading condition of the laden trips was 75% in 2009, loading conditions under 70% were considered inefficient. These inefficient movements were divided into seven subcategories between 10% and 60% by 10% increments, which represent midpoints of the loading ranges, such as 55% to 65%, etc. The loading conditions of more than 70% were considered as efficient, and aggregated into one category (see Table 4.11). Trip distance categories are selected as multiples of 250 km intervals, to capture differences between short and long hauls, which can be defined as less than and more than 500 km, respectively. Very long haul distances beyond 1,250 km were grouped together and accounted for only 18.8% of the movements.

Table 4.11 Distribution of the truck vehicle-km by loading condition and trip distance in 2009

Loading	**Trip Distance (Km)**						**Cum. %**	**Avg. Haul (Km)**
	0-250	**251-500**	**501-750**	**751-1000**	**1001-1250**	**1251+**		
Empty <5%	5.2%	5.3%	3.5%	2.9%	2.5%	2.9%	22.3%	355
10%	0.2%	0.3%	0.4%	0.3%	0.3%	0.5%		524
20%	0.4%	0.4%	0.7%	0.8%	0.4%	1.0%		574
30%	0.4%	0.6%	0.8%	0.9%	0.6%	1.2%		573
40%	0.5%	0.7%	1.1%	1.1%	1.1%	1.6%		617
50%	0.4%	0.7%	1.0%	1.2%	1.0%	1.7%		629
60%	0.5%	0.7%	1.0%	1.0%	1.2%	1.9%		631
Inefficient	2.4%	3.4%	5.0%	5.3%	4.6%	7.9%	28.6%	602
70%	0.6%	1.1%	1.6%	1.7%	1.1%	1.9%	8.0%	597
75+%	3.9%	6.6%	10.9%	8.0%	5.6%	6.1%	41.1%	535
All Movements	12.%	16.5%	21.0%	17.9%	13.8%	18.8%	100.0%	492

The average trip distance of the all freight movements was found to be 492 km in 2009. 22.3% of the movements were empty runs and almost half of them were in the short haul (i.e. less than 500 km). For empty runs, average trip distance was calculated to be 355.2 km. Average trip distance of the all inefficient movements was 602 km; and the more loaded the trucks were, the longer the average trip distance was. This trend was also observed for higher long haul shares of the inefficient movements. The average trip distance of the 70% loaded group (i.e. in the range of 65% to 75%) was 597 km. Efficient movements category had an average trip distance of 535 km. Trip distance distribution of these movements varied between very short to very long hauls (see Table 4.11).

4.7 Potential of Emission Reductions

Table 4.12 and Table 4.13 present trucking emissions at different disaggregate levels for 2009. It is seen that efficient movements accounted for 50.5% of the CO_2 emissions in 2009. The emission share of efficient movements varied from 41.2% for CH_4 to 50.5% for PM. Empty trucks produced 17.2% of the CO_2 emissions. Furthermore, inefficiently loaded trucks accounted for 25.7% of the CO_2 emissions. Consequently, emission cost of empty and inefficiently loaded movements corresponded to 42.9% of the CO_2 emissions in 2009. Similarly, the share of empty and inefficiently loaded movements varied from 42.4% for NO_X to 51.0% for CH_4. Rigid trucks were responsible for almost 70% of the CO_2 emissions in 2009 (see Table 4.13). This share was not unexpected considering the market share of rigid trucks in vehicle-km and ton-km (see Table 3.4 and 3.5). If the emission legislations were considered, Euro I trucks were responsible for the largest share of the emissions. The definitions of inefficiency for truck and emission legislation types are not as straightforward as the loading factor case. However, some values can be estimated based on scenarios developed for emission reduction, which will be discussed in the following subsections.

As described above, it may be possible to detect inefficiency in freight movements, and if some of the disaggregate data is used, emissions from different subgroups of truck freight movements can be determined. In the following subsections, potential of reducing road freight emissions in Turkey will be discussed for three scenarios regarding empty movements, inefficiently loaded movements, and truck replacement. Improvements in vehicle loading and minimizing empty running were also considered in the pursuit of a sustainable transport system in the UK (DfT, 2008). It should be noted here again that even if it is possible to calculate the emission cost of inefficiency for road freight, it is not always possible to avoid it totally (McKinnon, 2007). There are some attempts to increase infrastructure capacity of the highway network in Turkey. The length of divided highways tripled during the last decade. In addition, the number of beltways around the cities were increased. All these may have a positive influence on further reductions from freight transportation emissions. Furthermore, driver efficiency scenarios can be considered for future policies. However, the estimation of emission reduction potential of these improvements require more detailed data, for not only commodity flows but network geometry, etc., too. Thus, such options were kept out of scope for this study.

Table 4.12 Trucking emissions at different loading condition in 2009

	CO	CH_4	NO_X	PM	CO_2
Total emissions (kton)	24.8	1.02	133.6	4.9	12,076
Empty movement emissions (kton)	4.1	0.21	22.5	0.8	2,077
Share of empty movement emissions	16.5%	20.6%	16.8%	16.3%	17.2%
Laden movement emissions (kton)					
Loading Condition					
10%	0.4	0.02	2.1	0.1	180
20%	0.8	0.04	4.3	0.2	370
30%	1.1	0.05	5.7	0.2	483
40%	1.4	0.06	7.2	0.3	678
50%	1.4	0.07	7.2	0.3	674
60%	1.7	0.07	7.7	0.3	722
Inefficient movement emissions (kton)	6.8	0.31	34.2	1.4	3107
Share of inefficient movement emissions	27.4%	30.4%	25.6%	28.6%	25.7%
70%	2.1	0.08	9.4	0.3	912
Share of 70% loaded movement emissions	8.5%	7.8%	7.0%	6.1%	7.6%
75+%	11.8	0.42	67.5	2.4	5980
Share of efficient movement emissions	47.6%	41.2%	50.5%	49.0%	49.5%

Table 4.13 Trucking emissions based on truck type and emission legislations in 2009

	CO	CH4	NO_X	PM	CO_2
Total emissions kton	24.8	1.02	133.6	4.9	12,076
Truck Type					
Rigid truck emissions kton	17.6	0.71	94.7	3.5	8224
Share of rigid truck emissions	71.0%	69.6%	70.9%	71.4%	68.1%
Articulated truck emissions kton	7.2	0.31	38.9	1.4	3852
Share of articulated truck emissions	29.0%	30.4%	29.1%	28.6%	31.9%
Emission Legislations					
Conventional truck emissions kton	9.0	0.33	50.4	1.9	3,673
Share of Conventional truck emissions	36.3%	32.2%	37.2%	38.8%	30.4%
Euro I truck emissions kton	15.6	0.67	74.6	2.9	6,941
Share of Euro I truck emissions	%62.9	65.6%	55.8%	59.2%	57.5%
Euro IV truck emissions kton	0.2	0.02	8.6	0.1	1,462
Share of Euro IV truck emissions	0.8%	2.0%	6.4%	2.0%	12.1%

Scenario 1: Empty Movements

Even though there is a substantial emission share of empty movements in Turkey, these movements are almost unavoidable due to the nature of freight transportation. However, IEA (2009) reported that empty movements are likely to decrease over time for several reasons, including the development of load matching agencies and online freight exchanges, back loading initiatives by retailers and manufacturers, and strengthening flow of products going back along the supply chain for recycling and remanufacture. As an example, Piecyk and McKinnon (2010) forecasted that the empty movements would decrease from 27% to 22% in the UK in 2020. Although it is not very likely to eliminate empty movements in the short haul, a policy that penalizes empty runs in long haul (i.e. longer than 500 km) can be considered in Turkey. If such a policy could be implemented, 11.8% of the empty trip distances would be eliminated (see Table 4.10) and the corresponding 9.3% of CO2 emissions could be reduced (see Scenario 1 in Table 4.14).

Scenario 2: Inefficient Movements

Although collection-and-delivery points, urban distribution or consolidation centers, or load sharing are some of the options to reduce inefficiency in road freight transportation, it is difficult to manage such policies, as they involve many decision makers and require detailed analysis of logistic costs, just-in-time delivery structure and technical issues (see Appendix C). However, disregarding such implementation issues for the time being, it may be helpful to see the potential of emission reduction that can be achieved by reorganizing such inefficient movements. A key issue is the definition of the inefficient movements, which is not clearly stated in the literature. In Turkey, the average loading factor excluding the empty runs is 75%, and 70% and less loaded movements can be considered as inefficient (see Table 4.12). Alternatively, the average loading factor including the empty runs was 58% in 2009. Therefore, loading factors below 50% can be considered inefficient. Both of these definitions were used in the second emission reduction scenario.

To quantify the emission reductions, it is important to model the rearrangement of these “inefficient” movements as “efficient” ones, and calculate the corresponding change in emissions. This means the consolidation of many “inefficiently loaded” truck movements into smaller number of “efficiently loaded” ones; which would reduce total vehicle-km and corresponding emissions. However, higher loading factors would cause higher emissions. The mathematical formulation of this scenario, Scenario 2, would require development of a set of scenarios for province level 81x81 Origin-Destination pairs for all combinations of rigid and articulated truck subgroups and emission legislations (Conventional, Euro I and Euro IV), and can be better explained by the numerical example (see Table 4.15).

Table 4.14 Emission reduction potentials in road freight transportation in Turkey

	CO	CH_4	NO_X	PM	CO_2
Base year emissions in 2009 (kton)	24.8	1.0	133.6	4.9	12,076
Scenario 1: No empty run in the long haul For base year input data, assume no empty run for long haul trips; deduct the corresponding vehicle-km values from the input data directly. (Corresponding elimination in national vehicle-km km is 11.8%)					
Emission reduction share %	8.5%	10.0%	8.9%	8.2%	9.3%
Scenario 2: No inefficient loading For every origin-destination OD pair, assume a proposed freight system that enables regrouping of "inefficient loading" movements excluding empty runs into equivalent truck movements with a predefined "efficient loading factor" with same truck type and emission legislations. Inefficient loading→less than 50% expected decrease in national vehicle-km is 1.4%					
Emission reduction share %	1.3%	1.3%	1.4%	1.8%	1.3%
Inefficient loading →less than average loading 70% (Corresponding elimination in national vehicle-km km is 2.7%)					
Emission reduction share %	2.4%	2.4%	2.5%	2.8%	2.5%
Scenario 3: Truck replacement Assume all the Conventional trucks are replaced by cleaner Euro IV trucks in 2009.					
Emission reduction share %	14.5%	30.0%	25.4%	40.8%	4.4%

Let's assume, City X and City Y which are 640 km apart. Table 4.15 presents 284 surveyed rigid trucks with Conventional emission legislation ranging from 10% to 60% loading condition. Column C and Column E represent, respectively, the average of the maximum payload and total number of the surveyed trucks for each category. Column F represents their total load for each category (i.e., 35 trucks with less than 7.5 ton gross vehicle weight carries 62.9 tons of commodity between City of X and City of Y). If all these truck loads are reorganized as trips with 70% loading factor, the equivalent number of trucks would be found by dividing Column F by 70% of the values in Column C (i.e., a total of 62.9 ton commodity can be transported by approximately 29 trucks at %70 loading level). Consequently, the commodity of the 284 inefficiently loaded trucks could be transported 200 trucks at 70% loading condition. As a result, the total vehicle-km values corresponding to the transportation of the inefficient movements will be reduced. On the other hand, the trucks will be travelled at a higher loading level, which would increase emissions to some extent as they have higher emission rate per ton-km.

Table 4.15 A numerical example of Scenario 2

Gross Vehicle Weight	**Avg. Max. Payload (Ton)**	**Number of Surveyed Trucks**							**Actual Commodity (Ton)**	**No. of Equiv. Trucks**
		Loading Conditions						**Total**		
		10%	**20%**	**30%**	**40%**	**50%**	**60%**			
B	**C**[a]	**D**[a]						**E**[a]	**F**[a]	**G**[b]
<= 7.5 t	3.2	1	2	5	8	8	11	35	62.9	29
7.5 - 12 t	4.9	2	2	3	5	9	11	32	78.0	23
12 - 14 t	7.0	3	2	2	4	7	10	28	84.5	18
14 - 20 t	10.3	1	2	7	8	13	11	42	204.3	29
20 - 26 t	16.2	1	2	6	8	8	13	38	278.0	25
26 - 28 t	17.1	1	1	3	6	8	12	31	268.4	23
28 - 32 t	20.8	1	3	6	9	12	15	46	455.4	32
>32 t	20.7	2	1	2	7	9	11	32	300.1	21
Total		12	15	34	55	74	94	284	1,731.5	200

[a] Determined from individual truck data in the roadside axle survey
[b] Calculated based on the scenario

The results showed that potential saving of this scenario is very limited (see Table 4.14). CO_2 emissions can be reduced by only 2.5%, if all the inefficient movements were replaced by an equivalent of 70% loaded trucks. Even lower emission savings are expected if inefficient movements are defined as those less than 50% loading. The potential reasons behind this low emission reduction potential can be explained as follows: If loading conditions less than 70% are rearranged to get 70% loading factors, it practically results in a case, where truck movements with 10%, 20%, and 30% loading are combined with movements with 60%, 50% and 40% loading, respectively. As the vehicle-km share of 10%, 20% and 30% loaded trucks are very small (see Table 4.11); the corresponding potential emission savings are limited, too.

Scenario 3: Truck replacement

This scenario may be the most probable one among the three options. As discussed above, there is already a trend to use new and cleaner trucks in the freight market in Turkey (see Table 4.8 and Table 4.9). Currently, Euro I and Euro IV trucks are more frequently used than their actual share in the vehicle park. Furthermore, in Turkey, vehicles including trucks older than 30 years were already banned from traffic by a legislation passed in 2010. With a little bit more legislative effort, it may be very possible to replace all the Conventional trucks with newer ones, such as Euro IV trucks. Similar approaches were discussed by Zanni and Bristow (2010), and Facanha and Ang-Olson (2008) (see Appendix C). In a way, this scenario is similar to the one in the IEA (2009) report that assumed all the fleets have the fuel efficiency of the best fleet and projected a saving of 20% by 2050. The time period required for such a replacement strategy should be discussed separately, considering other economical aspect, etc. For this study, the potential emission reduction shares are calculated by simple replacing all the Conventional trucks in the surveyed sample with Euro IV ones in 2009. The replacement of these older trucks with newer ones could significantly reduce regulated emissions, such as CO by 14.5%, NO_X by 25.4%, and PM by 40.8%. CO_2 emissions can be reduced only by 4.4%, by replacing Conventional trucks with the Euro IV trucks, as the CO_2 emissions are related with fuel consumption (see Table 4.14).

4.8 Evaluation of the Scenario Analysis

In this study, roadside surveys for the period of 2000 to 2009 were investigated first to capture inefficient movements for road freight transportation in Turkey. It was found that 22.3% of the road freight kilometers run empty in 2009. Furthermore, 28.6% of the road freight vehicle-km run inefficiently. Emission cost of empty and inefficiently loaded movements corresponded to 42.9% of the road freight CO_2 emissions in 2009. Three separate reduction scenario were developed based on empty movements, inefficient movements, and truck replacement disregarding policy details. The potential emission savings varied between 8.2% and 11.2% by penalizing empty movements even only in the long haul. On the other hand, emission reduction potential of reorganization of inefficient movements was found to be very small, for two reasons: a) the vehicle-km of these movements was relatively small in the sector, and b) trucks movements with higher loading factors corresponded to higher emission rate per ton-km. Thus, any policy regarding elimination of inefficiently loaded movements without targeting reduction of empty runs may not provide enough capacity to create emission reductions, and considering the difficulties in the implementation with many stakeholders, it may not be worth the effort. Replacement of old Conventional trucks with newer Euro IV trucks could significantly reduce regulated emissions, such as NO_x 25.4% and PM 40.8%, while CO_2 emissions could be reduced by only 4.4%. However, replacement of Conventional trucks with Euro IV trucks is the most probable one, which have been in process naturally.

CHAPTER 5

DETERMINATION OF THE TRUCK NETWORK ASSIGNMENT PRINCIPLE

As mentioned in Chapter 4, estimation of road freight transportation emission requires development of network assignment methodology. However, network assignment principle of the truck transportation has not been studied in Turkey, yet. Therefore, this chapter will discuss determination of the truck network assignment principle for Turkey in detail.

In the literature, for freight movements, mostly a simple static all-or-nothing assignment procedure is considered, as they are mostly on state roads and motorways, and not subject to capacity restraints. The situation is similar in Turkey where average trip distances are around 500 km and only 5% of them are on provincial roads (see Table 3.6). Briefly, a static all-or-nothing assignment puts all the truck demand between a given O-D pair to the shortest path (SP) according to a predefined path cost measure. Finding the SP between a given O-D pair can be done using a well-known Dijkstra SP algorithm (label setting or label correcting) (Dijkstra, 1959).

Network assignment step requires digitization of the highway network. General characteristics of Turkish road network were introduced in Chapter 3. This network was digitized in MapInfo® environment to provide visual support in the determination of network assignment principle. The total length of this digitized network is 62,785 km (31,395 km state roads and 31,390 km provincial roads). This network connects 872 counties (including 81 city centers), which produces a total of 759,512 possible Origin Destination (O-D) pairs for a county level assignment. Turkish highway network with county nodes (with red circles emphasizing city centers) is presented in Figure 5.1.

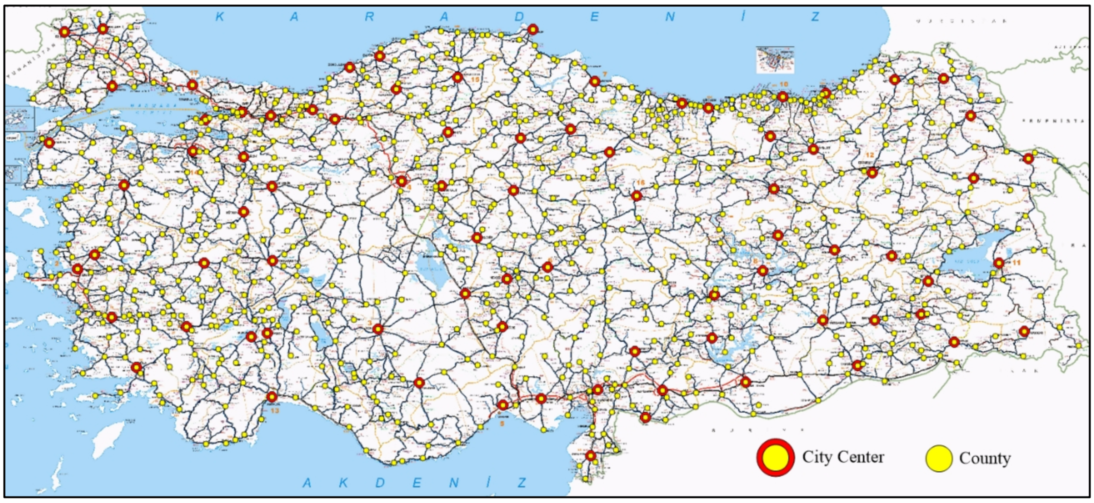


Figure 5.1 Digitized highway network

5.1 Shortest Path Definitions for Truck Assignment

Even for the all-or-nothing assignment, one has to define the shortest path (SP) that all the trucks would be assigned. In the absence of any study on the issue, it is possible to test some SP definitions and verify them by comparing the roadside axle survey location and stated O-D information of each surveyed truck. To start with, two different SP definitions were developed to differentiate travel time and travel distance measures as assignment principles:

Time-based SP (TbSP): TbSP was found as the path with the shortest truck travel time, which was simply calculated as the sum of the truck travel times of the links on the path. Link travel times were calculated by dividing the link lengths by average truck speeds on the links. On state roads links, space-mean speeds for trucks (articulated and rigid), are annually measured and published by Turkish General Directorate of Highways (TGDH), which were used in this study. Since there is no published speed data on provincial roads, average truck speed was taken as 40 km/h on these sections (TGDH, 2012b).

Distance-based SP (DbSP): DbSP was found as the path with the shortest travel distance, which was simply calculated as the sum of the lengths of the links on a path. State and provincial road section lengths published by TGDH were used to calculate DbSP (TGDH, 2012b).

Before discussing potential use for network assignment, TbSPs and DbSPs were calculated to observe characteristics of Turkish road network at a) province level (from 81 city center to 81 city center) and b) county level (from 872 county center to 872 county center) (see Figure 5.2 and Figure 5.3). As it is seen, majority of the TbSPs are between 8 and 16 hours, with an average travel time of 11 hours for both province and county level analysis. On the other hand, majority of DbSPs are between 500 and 1,000 km for both province and county level analysis, with an average SP distance of 750 km. It is found that out of 6,480 intercity O-D pairs, 2302 (35.5%) pairs have exactly the same path for TbSP and DbSP. Furthermore, out of 759,512 county level O-D pairs, 28.0% of them have exactly the same TbSP and DbSP.

Deviations between two SP definitions:

Then, length of TbSPs can be calculated for remaining O-D pairs to study the level of deviation between these two SP definitions based on the following formula:

$$\Delta \mathrm{d} = \text{Length of TbSP} - \text{DbSP} \tag{5.1}$$

At province level, the distribution of the Δd (difference between lengths of TbSP and DbSP) are presented in Figure 5.4, giving an average difference of 21 km, and the maximum difference of 159 km. For almost 85% of the O-D pairs, length difference is less than 50 km. On the other hand, at county level, average length difference is found as 29 km, while the maximum difference is 231 km, which is higher than the province level maximum difference. Similarly, for almost 85% of the county level O-D pairs, the length difference between TbSP and DbSP is less than 50 km.

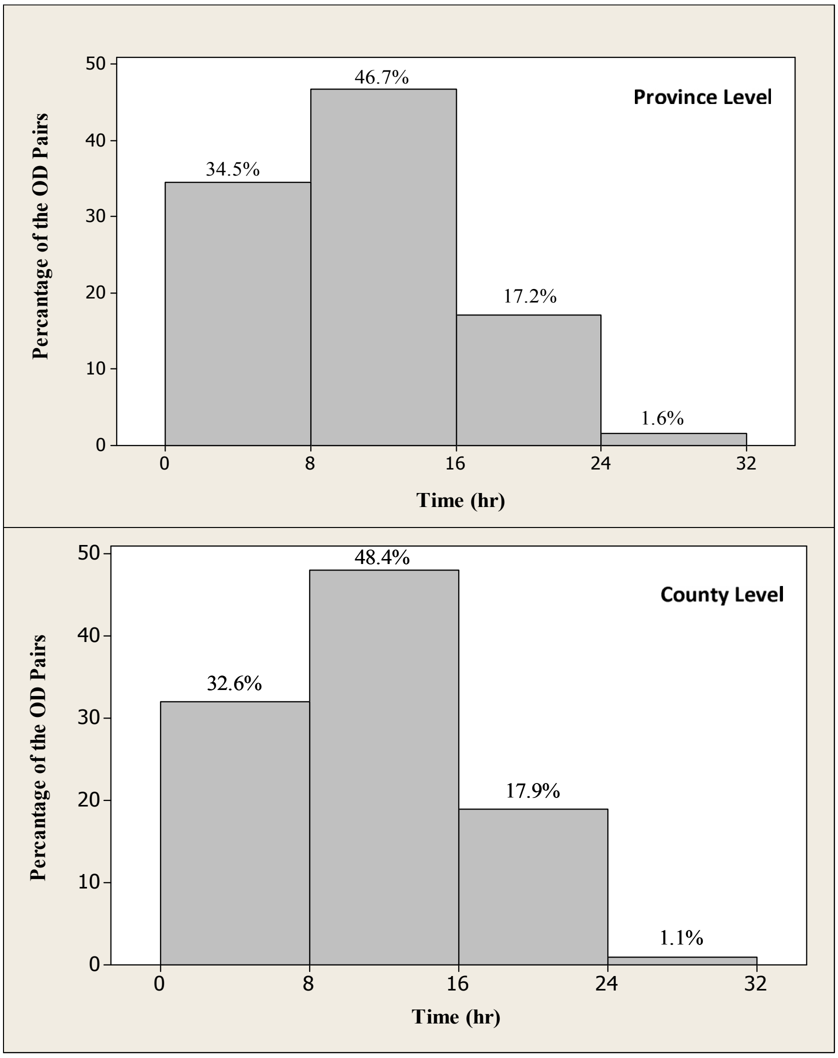


Figure 5.2 TbSP distributions for province and county level O-D pairs

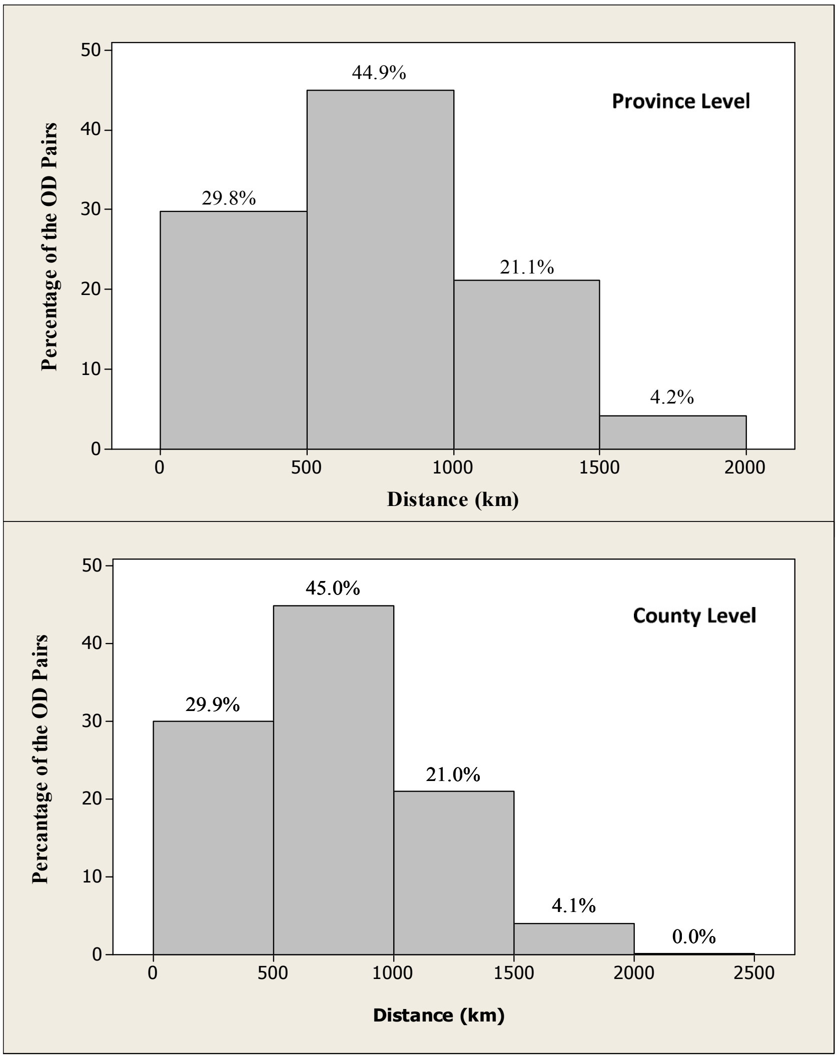


Figure 5.3 DbSP distributions for province and county level O-D pairs

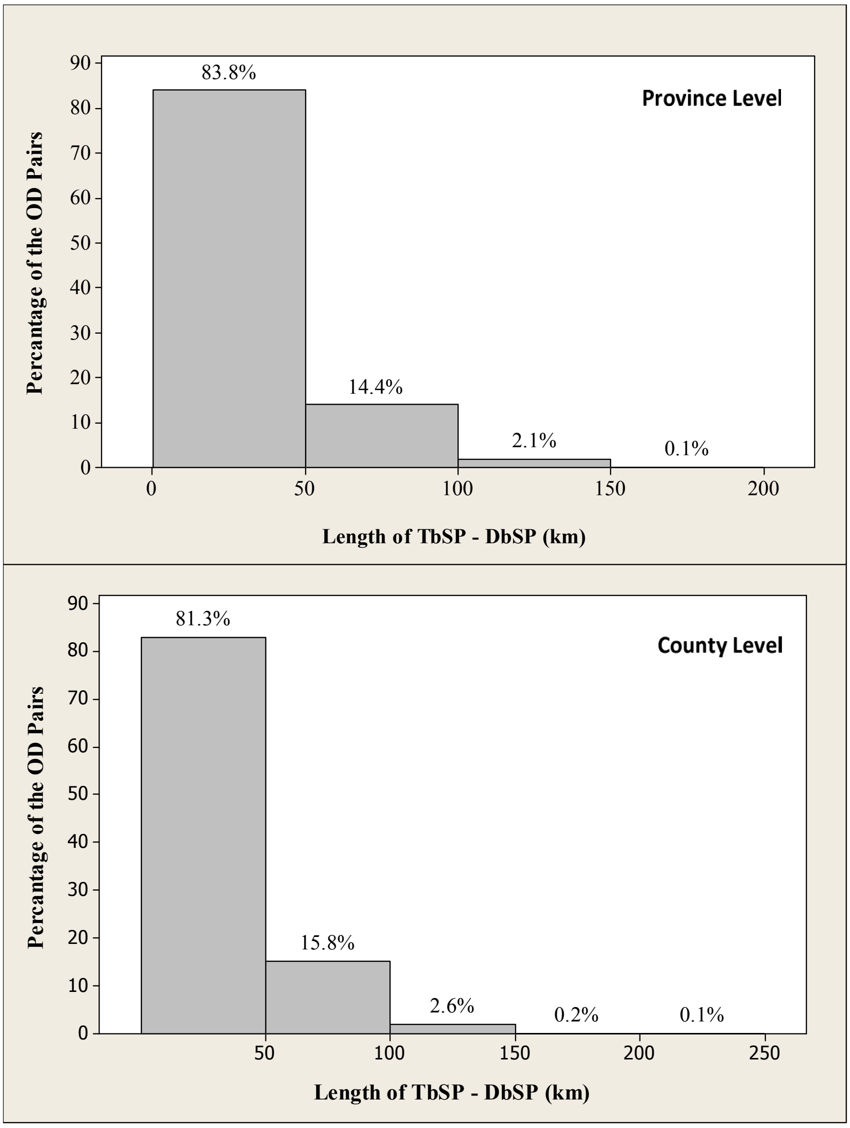


Figure 5.4 Δd distributions for province and county level O-D pairs

As a visual example, TbSP and DbSP trees for the City of Mersin are presented in Figure 5.5. Majority of SPs are coinciding and mostly on the main state road corridors. There are only minor differences between TbSP and DbSP trees. The small variations between TbSP and DbSP definitions can be explained by two factors: a) the lack of high level connectivity in the current road network in Turkey, and b) lack of congestion on majority of the intercity state roads.

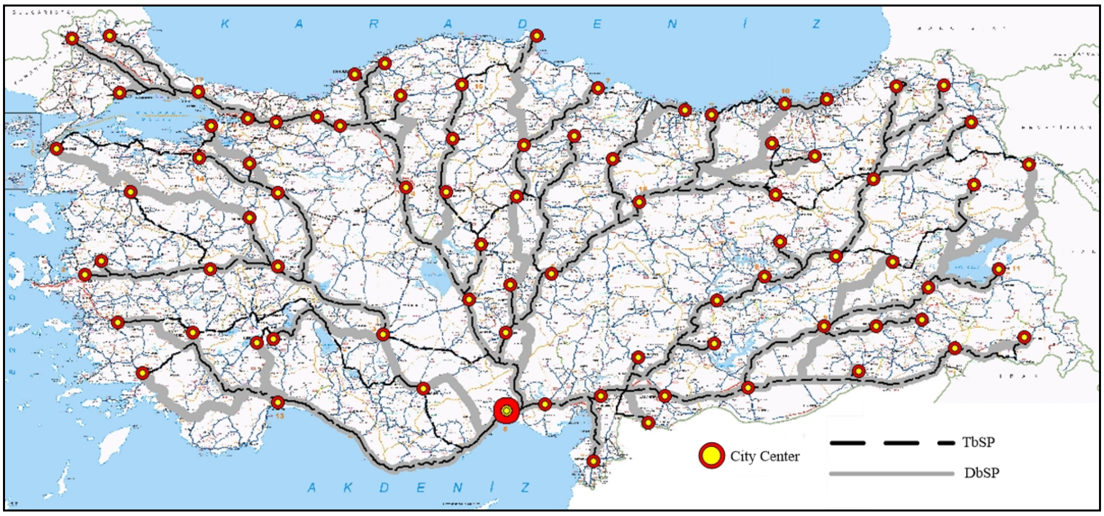


Figure 5.5 Province level TbSP and DbSP trees (Origin: City of Mersin)

5.2 Truck Assignment Principle(s)

To evaluate the appropriateness of the proposed SP definitions, survey location and stated O-D information of each truck were used to check whether the former was on the calculated TbSP and DbSP for a given truck. Survey location of each truck can be on a) both TbSP and DbSP, b) only TbSP, c) only DbSP, and d) none of the TbSP and DbSP between its O-D points. It should be noted that the condition where survey location falls on both TbSP and DbSP, does not mean the complete overlap of TbSP and DbSP. As an example, a truck trip within a small region can be displayed visually: For a truck trip from Salihli County (in the City of Manisa) to Yenisehir County (in the City of Bursa), both TbSP and DbSP are displayed with solid and dashed routes, respectively in Figure 5.6.

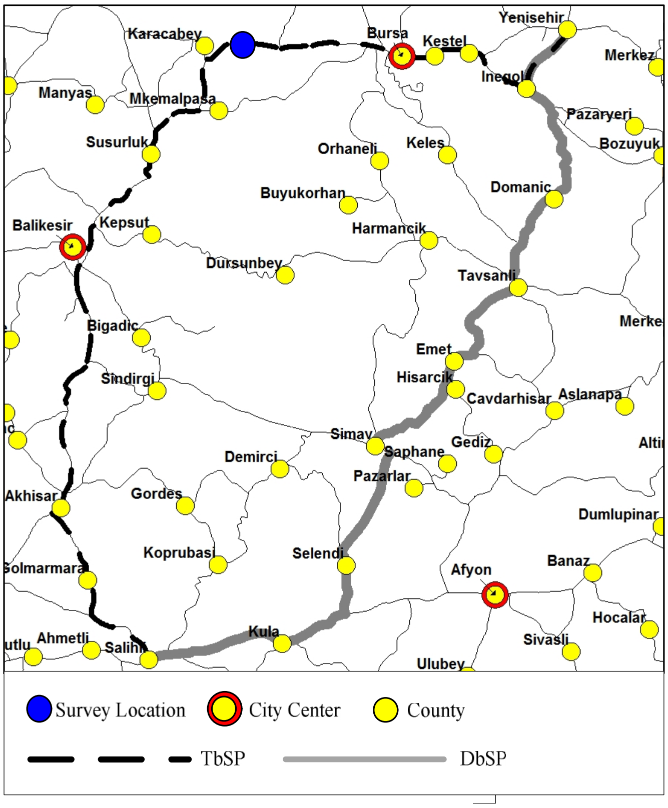


Figure 5.6 A surveyed truck captured traveling on only TbSP”

Survey location of this truck (shown in blue between in Karacabey County) is found on “only TbSP”, suggesting that this truck followed the TbSP. In this analysis, selection of the survey location is crucial in the success of determination of the TbSP or DbSP assignment principle. If the survey locations mostly correspond to overlapping portions of the two SPs, it is not possible to distinguish between the two options. For example, if the survey location was somewhere between short overlap portion of the two SPs (between Inegol County and Yenisehir County), this truck trip will be validated by both TbSP and DbSP definition. It should be reminded that as the O-D information was collected at county level, therefore, these evaluations required county level (county center to county center) SP determinations. This need can be displayed visually by the example in Figure 5.7. For a truck traveling form Selcuk County in Izmir to Alasehir County in Manisa, if the SPs are defined at city level (city center to city center), the calculated paths will be totally different from county level (county center to county center) SPs from Selcuk to Alasehir. For the specific case of Selcuk and Alasehir, TbSP and DbSP totally coincided and the survey location near Selcuk were found on “both TbSP and DbSP”.

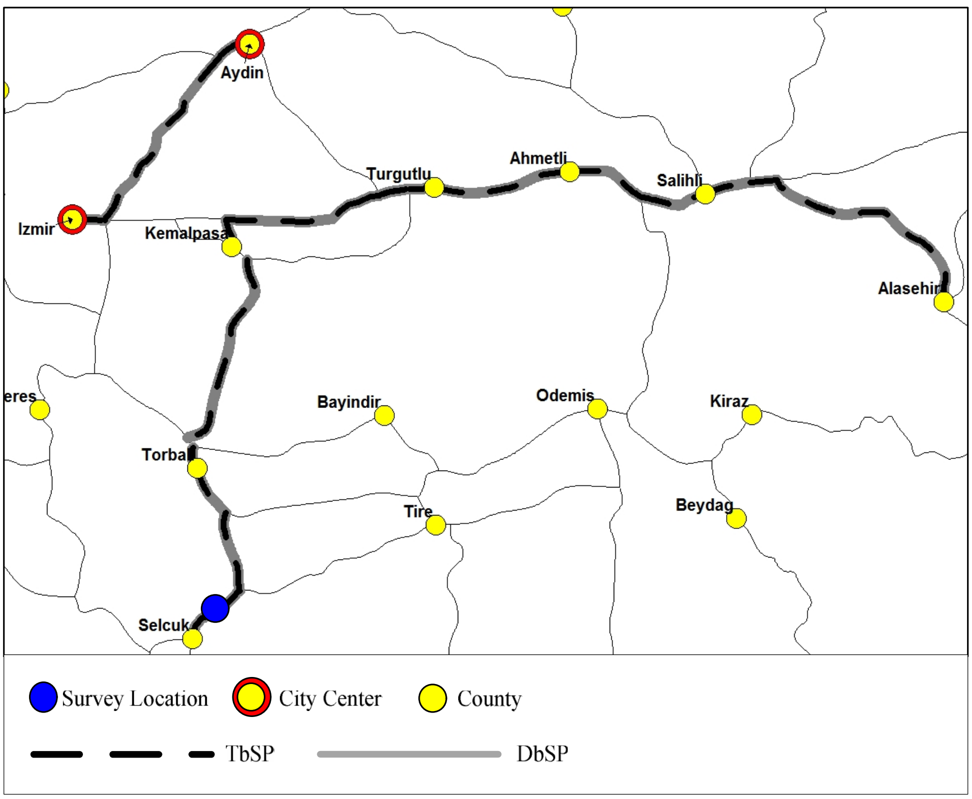


Figure 5.7 Difference between province and county level assignment

The outcomes of these assignment principle evaluations for intercity trucks surveyed between 2007 and 2009 are summarized in Table 5.1. Close to 70% of the trucks were surveyed at a location which was both on TbSP and DbSP. 7% to 10% of the trucks were captured at a location which was only on TbSP, while only approximately 2% of them were surveyed at a location which was only on the DbSP. TbSP assumption was able to capture 75% to 80% of the truck trips, while DbSP can capture70% to 75%. As a summary, it can be said that 76% to 83% of the trucks were on either TbSP or DbSP. Only 20% of the trucks were surveyed at a location that was neither on TbSP or DbSP. This group of trucks may provide further information about other factors affecting truck assignment, which needs further investigation.

Table 5.1 Evaluation of network assignment principles of surveyed trucks

	2007		2008		2009	
Number of Surveyed Intercity Trucks	11572		8104		12086	
Survey location on	**Number of Trips**	**(%)**	**Number of Trips**	**(%)**	**Number of Trips**	**(%)**
Both TbSP and DbSP	7814	(67.5%)	5857	(72.3%)	8123	(67.2%)
Only TbSP	853	(7.4%)	785	(9.7%)	863	(7.1%)
Only DbSP	248	(2.1%)	99	(1.2%)	230	(1.9%)
Either TbSP or DbSP	8915	(77.0%)	6741	(83.2%)	9216	(76.2%)
Neither TbSP nor DbSP*	2657	(23.0%)	1363	(16.8%)	2870	(23.8%)

*Cannot be validated by TbSP or DbSP assignment

5.3 Analysis of non-SP Truck Trips

An analysis of the origin cities of the truck trips non-validated by the two SP definitions above, may show if there are some clustering around certain cities or not. Table 5.2 lists the first five provinces with highest number of non-validated truck trips in this study for three years, which are generally port and/or industrial ones. Some of the provinces are repeatedly captured, which are Istanbul, Ankara, and Gaziantep. A similar analysis was performed for destination cities; though there was similar clustering around big or port cities. The top five cities showed variations from year to year, and did not provide any conclusive trend either. It is actually hard to explain fully the route choice behavior of these non-validated trucks trips using only roadside axle survey data. If the data included more information about the major stop points along the stated route, it could have been possible to distinguish different behaviors, such as trip chaining, visiting nearby cities, etc. It is also known that it is not easy to collect such details during roadside axle surveys, due to time limitations to keep heavy trucks on the roadside as well as negative perception of the drivers towards the collection of trip specific data. Furthermore, impact of other major factors such as loading condition, geographical difficulties and long term work zones, should be considered for these non-validated trips. If the company based commodity data, which is not available in Turkey yet, could be collected, such uncertainties in network assignment principle determination could be eliminated. Approximately 20% of trucks were surveyed at a location on neither the TbSP nor DbSP. Though small in percentage, this group deserved a further investigation to see other factors affecting route choice behavior, such as trip chaining. Until then, TbSP is a very good choice for truck assignment; if not, DbSP definition can be used safely for truck assignment, as long as truck movements are not subject to much congestion on the state roads.

Table 5.2 Major origination provinces of the "non-validated" truck trips

2007				
Origin Province	**Number of Non-SP Trips**	**Number of Surveyed Trips**	**(%)**	**Major Destination Provinces**
İstanbul	334	801	(41.7%)	Edirne (32), Ankara (30), Antalya (25),
Ankara	237	691	(34.3%)	Istanbul (71), Antalya (27), Kocaeli (22)
Kocaeli	129	293	(44.0%)	Ankara (26), Kirikkale (18)
Mersin	98	352	(27.8%)	Istanbul (22), Konya (15)
Gaziantep	96	257	(37.4%)	Istanbul (33)
2008				
Origin Province	**Number of Non-SP Trips**	**Number of Surveyed Trips**	**(%)**	**Major Destination Provinces**
Ankara	115	673	(17.1%)	Antalya (38)
Istanbul	107	550	(19.5%)	Gaziantep (14)
Izmir	97	379	(25.6%)	Manisa (32), Edirne (21)
Gaziantep	63	113	(55.8%)	Istanbul (22)
Edirne	61	156	(39.1%)	Izmir (18)
2009				
Origin Province	**Number of Non-SP Trips**	**Number of Surveyed Trips**	**(%)**	**Major Destination Provinces**
Istanbul	223	978	(22.8%)	Denizli (29), Ankara (27), Diyarbakır(16)
Ankara	184	459	(40.1%)	Istanbul (30), Bolu (18), Zonguldak (16)
Hatay	163	300	(54.3%)	Adana (66)
Izmir	146	523	(27.9%)	Manisa (33), Denizli (28), Balikesir (15)
Adana	109	328	(33.2%)	Hatay (27), Istanbul (16)

5.4 Evaluation of Network Assignment Principle

As presented in Figure 4.1, evaluation of network assignment principle requires development of consecutive steps of trip generation, trip distribution mode choice and network assignment within the traditional four-step modeling concept. Unal (2009) studied trip generation and distribution steps for 2004. Mode choice is redundant step due to dominance of trucking in road freight transportation in Turkey. As mentioned before, network assignment step of the truck transportation has not been studied, which is the main focus of this chapter. To evaluate network assignment principle, it is important to study the current validity of trip generation and distribution steps developed by Unal (2009) for 2004.

Unal (2009) developed province level trip generation attraction functions in terms of number of trips and total tonnage of transported commodities using economic and demographic variables such as Number of Employees, Population, Passenger Car Ownership per 1000 Households, Gross Domestic Product and International Port Existence (see Eq. 2.1 to Eq. 2.4). Unal (2009) considered only the following international ports: Trabzon Port, Samsun Port, Haydarpasa Port in Istanbul, Izmir Port, Antalya Port, Mersin Port, and Iskenderun Port in Hatay (see Figure 5.8).

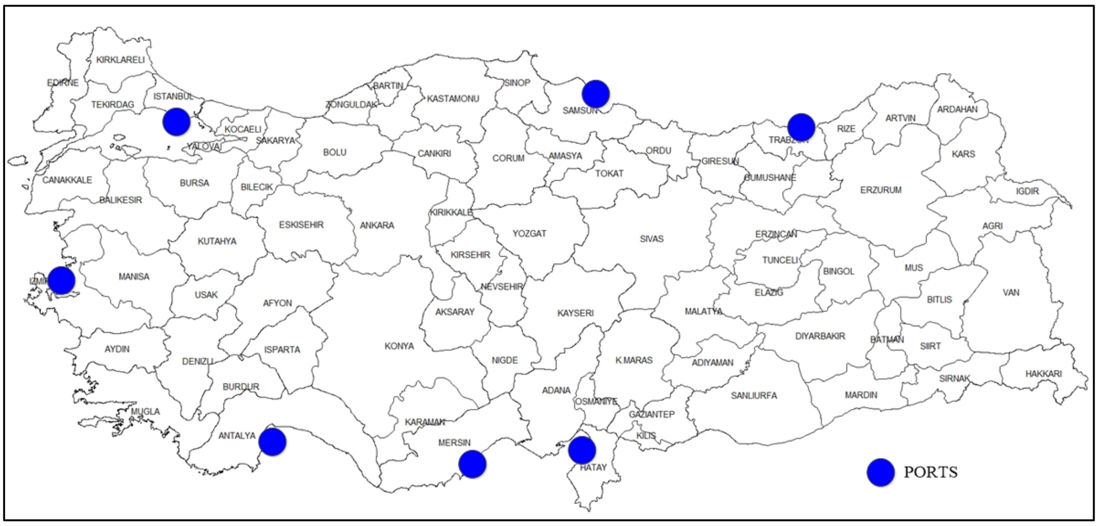


Figure 5.8 Locations of the international ports considered by Unal (2009)

5.4.1 Updating of the National Truck O-D Matrix

Current validity of these functions must be evaluated to estimate the current province level of trip production and attraction values. The latest values of "Number of Employees", 'Population" and "Passenger Car Ownership per 1000 Households" were available for 2011

(TurkStat, 2013a; TurkStat, 2013b, TurkStat, 2013c and TurkStat, 2013d) (see Appendix E). However, "Gross Domestic Product" has not been published in the recent years, therefore, trip generation and attraction functions for total tonnage of transported commodities cannot be updated. Therefore, existing trip generation and attraction functions will be updated only for the number of truck trips for 2011.

The results of the province level trip production and attraction functions are presented in Table E.2 and Table E.3 (see Appendix E). Trip production function in Eq. 2.1 annually estimated 31,723,037 truck trips for 2011. On the other hand, trip attraction function in Eq. 2.2 annually estimated 36,795,158 truck trips for 2011. TGDH (2012b) published a total of 19,722 million vehicle-km for trucks (rigid and articulated) for 2011. Average trip distance corresponded to 622 km in terms of annual 31,723,037 trip productions. On the other hand, it was 536 km in terms of annual 36,795,158 trip attractions. As it is seen, annual number of produced and attracted trips are not equal. Trip attraction function produced 5,072,121 more annual trips than attraction function, which corresponds to 16% of the produced trips. Therefore, there is a significant imbalance between production and attraction functions. Furthermore, it does not mean that the number of attracted trips is higher is higher for each province. Especially for the port provinces, number of estimated trip productions are higher. For instance, number of estimated trip productions is 46% higher in Trabzon and 44% higher in Samsun (see Appendix E).

Estimated annual province level truck trip productions or attractions over 500,000 trips are presented in Table 5.3. Istanbul (15.3%) is the by far the main truck trip production center. Izmir (5.3%), Ankara (5.1%), Antalya (3.6%) and Bursa (3.1%) are the other main production centers. Mersin (2.8%), Samsun (2.5%), Hatay (2.5%), Konya (2.2%), Adana (2.1%) and Trabzon (2.0%) have important trip production potentials. Similarly, Istanbul (11.6%) is the by far the main truck trip attraction center in Turkey. Ankara (5.0%), Izmir (3.8%), and Bursa (2.7%) are the other main truck trip attraction centers. Antalya (2.5%), Adana (2.3%), Konya (2.3%), and Gaziantep (2.0%) have important truck trip attraction potentials. As it is seen, the top production and attraction centers are mostly developed and port provinces of Turkey (see Figure 5.9 to Figure 5.10). These trends can also be seen from the bar chart of daily productions and attractions (see Figure 5.11). It is seen that daily truck productions and attraction are not distributed normally. Istanbul, Ankara, Izmir, Antalya and Bursa are the main production and attraction centers in Turkey. Among these provinces, total number of daily produced and attracted trips in Istanbul is 24,887. Whereas, for Ankara its 9459 trips, 8461 trips for Izmir, and 5655 trips for Antalya and 5339 trips for Bursa.

Table 5.3 Estimated annual truck trip productions or attractions over 500,000 trips in 2011

Code	Province	Produced Trips	(%)	Attracted Trips	(%)
1	Adana	654,386	2.1	859,574	2.3
6	Ankara	1,611,590	5.1	1,840,906	5.0
7	Antalya	1,148,017	3.6	916,126	2.5
9	Aydin	422,856	1.3	516,062	1.4
10	Balikesir	488,948	1.5	543,605	1.5
16	Bursa	969,140	3.1	1,001,482	2.7
20	Denizli	424,294	1.3	544,954	1.5
21	Diyarbakir	411,283	1.3	542,050	1.5
27	Gaziantep	521,839	1.6	737,907	2.0
31	Hatay	788,064	2.5	646,693	1.8
33	Mersin	880,004	2.8	703,990	1.9
34	Istanbul	4,851,892	15.3	4,231,708	11.6
35	Izmir	1,678,055	5.3	1,410,208	3.8
38	Kayseri	431,862	1.4	671,298	1.8
41	Kocaeli	563,296	1.8	660,662	1.8
42	Konya	707,999	2.2	856,870	2.3
45	Manisa	581,295	1.8	596,587	1.6
46	Kahramanmaras	371,764	1.2	505,164	1.4
48	Mugla	407,454	1.3	543,509	1.5
55	Samsun	798,895	2.5	554,173	1.5
61	Trabzon	648,675	2.0	383,041	1.0
63	Sanliurfa	463,652	1.5	666,655	1.8
TOTAL		31,723,037	100	36,795,158	100

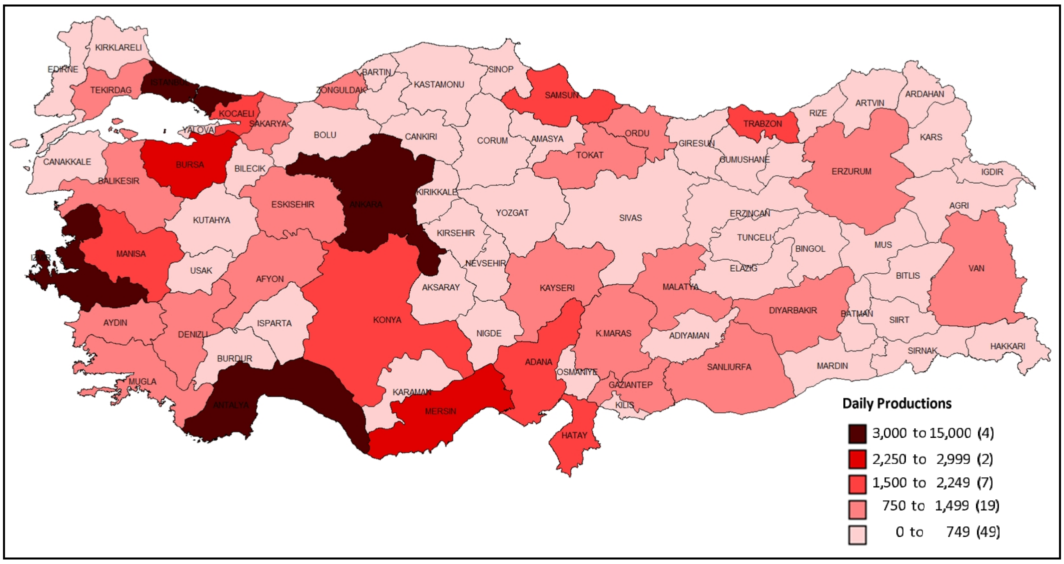


Figure 5.9 Province level daily productions in 2011

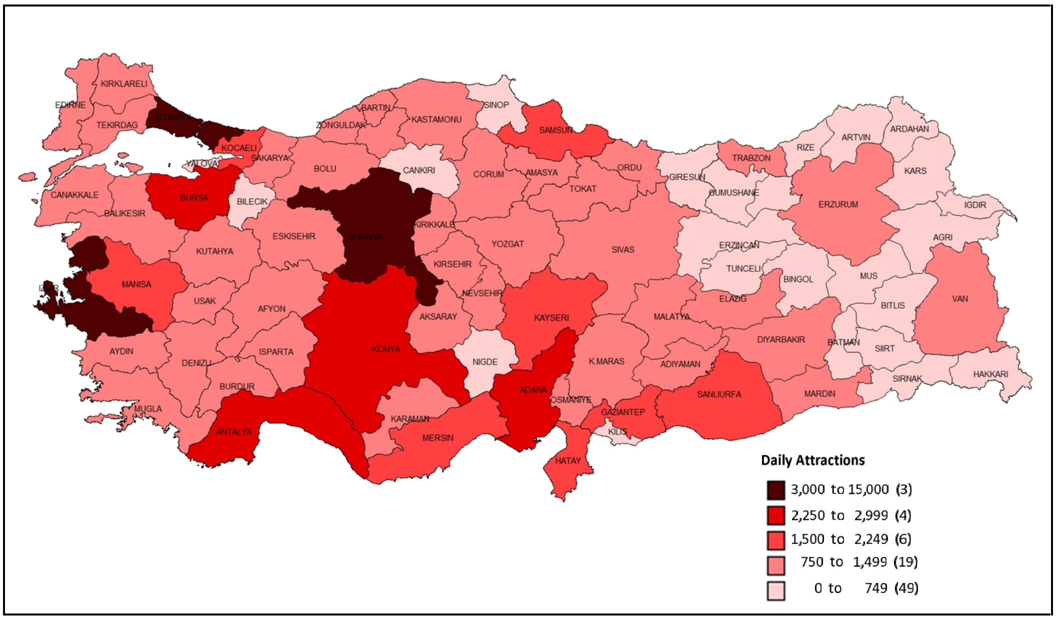


Figure 5.10 Province level daily attractions in 2011

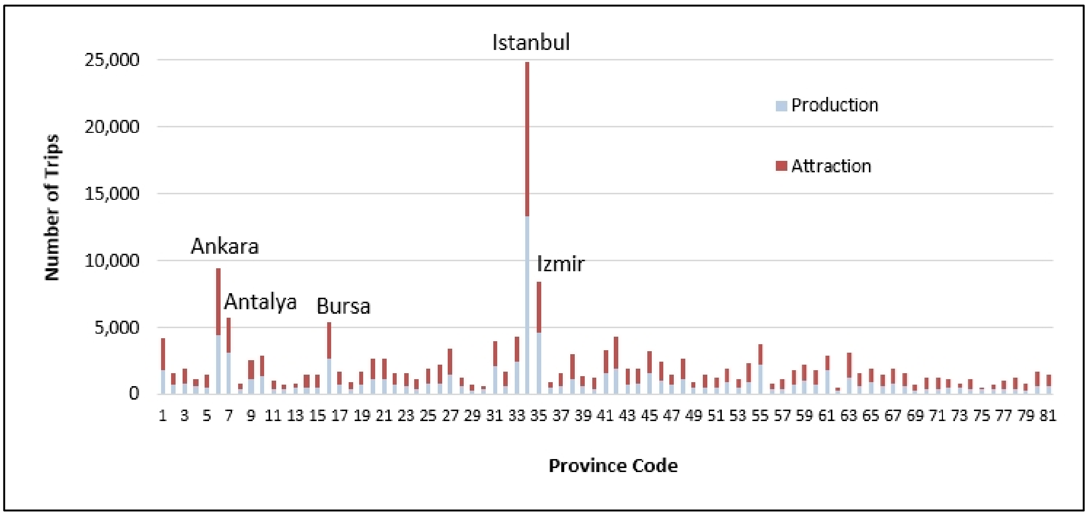


Figure 5.11 Daily province level trip productions and attractions in 2011

After estimation of the produced and attracted trips, the next step is the trip distribution. Province level generated and attracted trips can be distributed among the 81x81 province level O-D pairs by the gravity model developed by Unal (2009) (see Eq. 2.5). Therefore, annual number of truck trips between each province can be obtained. For each province, Table E.2 and Table E.3 presents annual number of produced and attracted trips estimated by gravity model (see Appendix E). The gravity model resulted in annual number of 138,994,361 truck trips for 2011. The following conclusions can be drawn based on the gravity model results:

- Gravity model resulted in 4.4 times more annual trip productions as compared to trip production function (see Table E.2).
- Gravity model resulted in 3.8 times more annual trip productions as compared to trip attraction function (see Table E.3).

After estimation of the national O-D matrix by gravity model, this matrix was assigned to the highway network excluding motorways. TbSP principle was used in the assignment as it captures 75% to 80% of the intercity truck trips. TbSP assignment resulted in 73.7 billion vehicle-km for 2011. It should be remained that TGDH publish Annual Average Daily Truck Traffic (AADTT) volumes only for state road sections. Therefore, assignment links flows can be compared only with the published volumes for state road sections. TGDH published 14.2 billion vehicle-km for trucks on state roads for 2011. Since, 14.2 billion vehicle-km corresponds to approximately 20% of the 73.7 billion vehicle-km, proportionality constant (k) of the Gravity Model developed by Unal (2009) was updated by dividing with 5 for simplicity. As a result, the following gravity model was obtained (see Eq. 2.5).

$$\mathrm{T}_{ij} = 0.0996 \frac{O_{\mathrm{i}}^{0.641} D_j^{0.628}}{d_{ij}^{0.894}} \tag{5.1}$$

where,

T_{ij}	number of annual truck trips from province i to province j
O_i	number of annual produced truck trips by Eq. 2.1 for province i
D_j	number of annual attracted truck trips by Eq. 2.2 for province j
d_{ij}	distance between province i and province j

5.4.2 Determination of the Truck Assignment Errors

After TbSP assignment, corresponding daily truck volumes on state road sections were compared with the AADTT volumes published by TGDH for 2011. Then, assignment error was calculated for each state road section as follows:

$$\text{Assignment Error} = \text{Daily Assignment Truck Volume} - \text{AADDT} \tag{5.2}$$

where; for a given state road section, Daily Assignment Truck Volume is the number of daily assigned trucks by assignment principle, and AADT is the published Annual Average Daily Truck Traffic volume by TGDH.

Furthermore, to evaluate developed assignment principles, several assignment principles were tried and assignment errors were calculated similarly (see Table 5.4). Figure 5.12 shows the distribution of the assignment errors for a) TbSP principle, b) 75% TbSP and 25% DbSP principle and c) 50% TbSP and 50% DbSP principle. As it is seen, all assignment principles have almost the same error distribution. It can be concluded that combination of the DbSP and DbSP assignment principles did not provide any improvements in error values.

As a result, TbSP principle was selected as the assignment principle. TbSP assignment resulted in 15.0 million annual vehicle-km. 14.2 million vehicle-km (94.7%) of this was on the 2186 state roads section and the remaining 0.8 million vehicle-km (5.3%) was on the provincial roads. Of the 2185 state road sections, TbSP assignment error values varied between (-10,969) and 10,234. Average error value and its standard deviation was (-15.1) and 1654.7, respectively. For 85.4% of the state road sections, error value was between (-2,000) and 2,000. Only for 3.8% of the sections, absolute assignment error was greater than 4,000 (see Figure 5.12).

Table 5.4 An excerpt of determination of link assignment errors for 2011

TGDH Section	AADTT*	Assignment			Errors		
		100% TbSP	75% TbSP 25% DbSP	75% TbSP 25% DbSP	100% TbSP	75%TbSP 25% DbSP	75% TbSP 25% DbSP
955-01,1	60	0	0	0	- 60	-60	-60
965-08,1	693	334	332	329	-359	-361	-364
010-15,6	5244	538	576	614	-4706	-4668	-4630
760-04,2	2571	6574	6104	5364	4003	3533	3063
550-09,3	5713	118	118	118	-5595	-5595	-5595
400-30,1	3064	431	467	503	-2633	-2597	-2561
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
350-01,1	650	0	71	141	-650	-589	-509
695-06,3	469	2413	2030	1647	1944	1561	1178
950-09,1	2806	2373	2131	1890	-433	-675	-916
370-02,3	1217	977	924	871	-240	-293	-396
965-14,3	455	417	415	412	-38	-40	-43
				Average	***-15.1***	***-56.3***	***-97.6***

* Published by TGDH (TGDH, 2012b)

Figure 5.13 presents daily TbSP assignment volumes for 2011. Figure 5.14 presents AADTT volumes published by TGDH for state road sections for 2011. Figure 5.15 presents TbSP link assignment errors. As AADTT volumes are published only for state roads, Figure 5.15 can provide error values only for state road sections. Furthermore, TbSP principle did not assign any truck volume for some of the state road sections (see Table 5.4). Assignment errors of these sections are presented in Figure 5.16. Motorways are illustrated with dotted lines in Figure 5.13 to Figure 5.16.

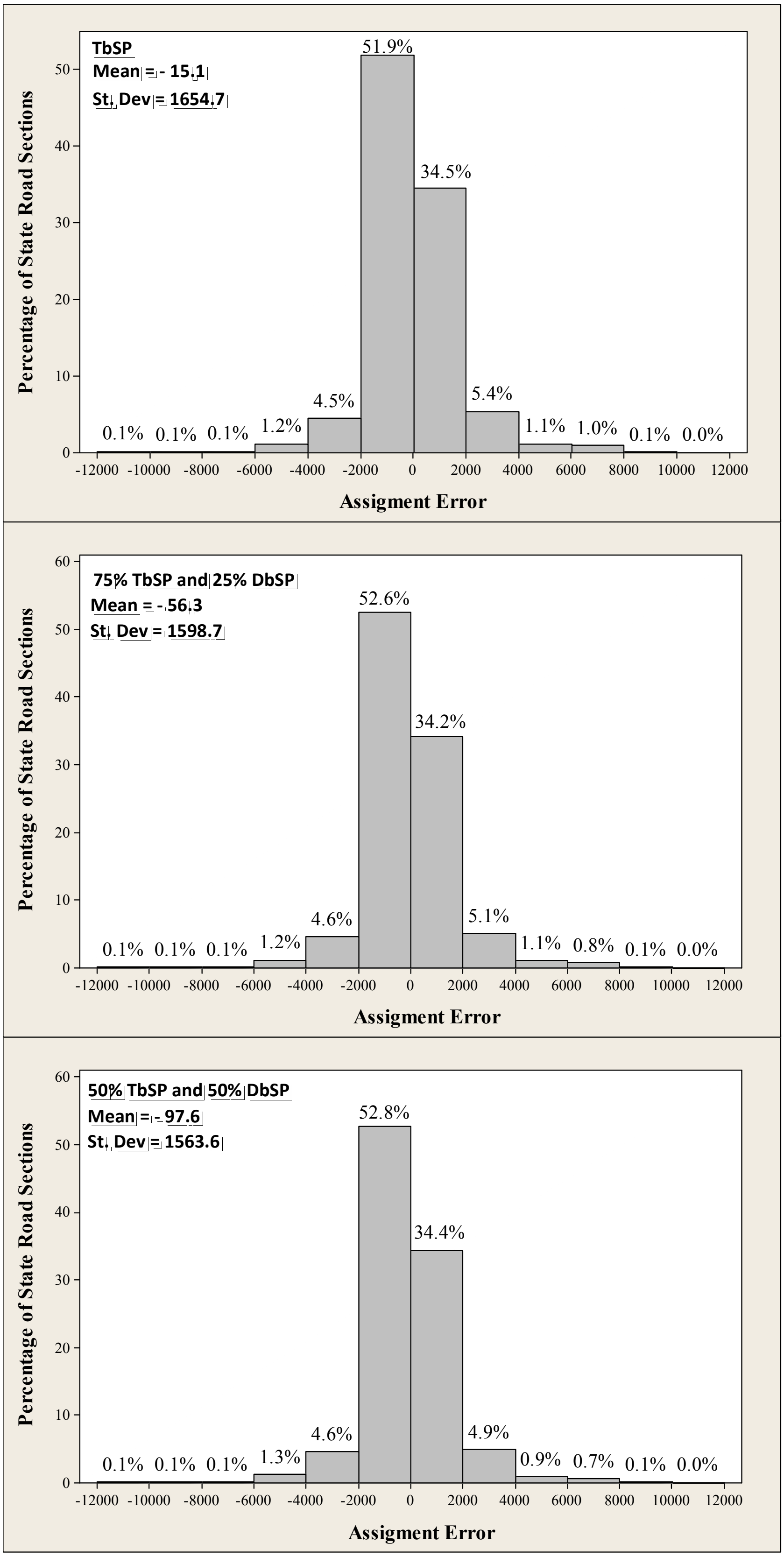


Figure 5.12 Histogram of the assignment errors

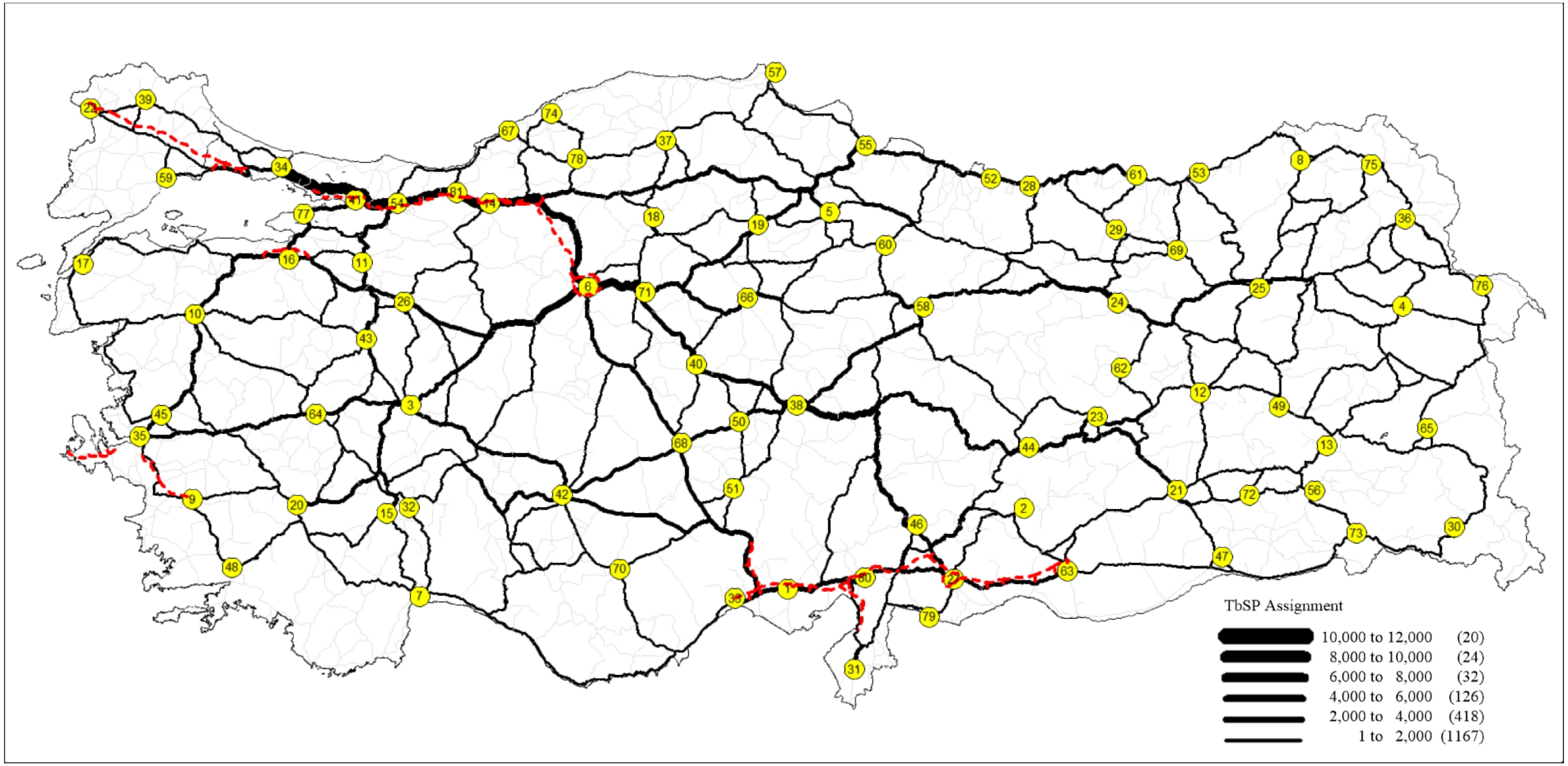


Figure 5.13 Daily TbSP assignment volumes on state and provincial road sections for 2011

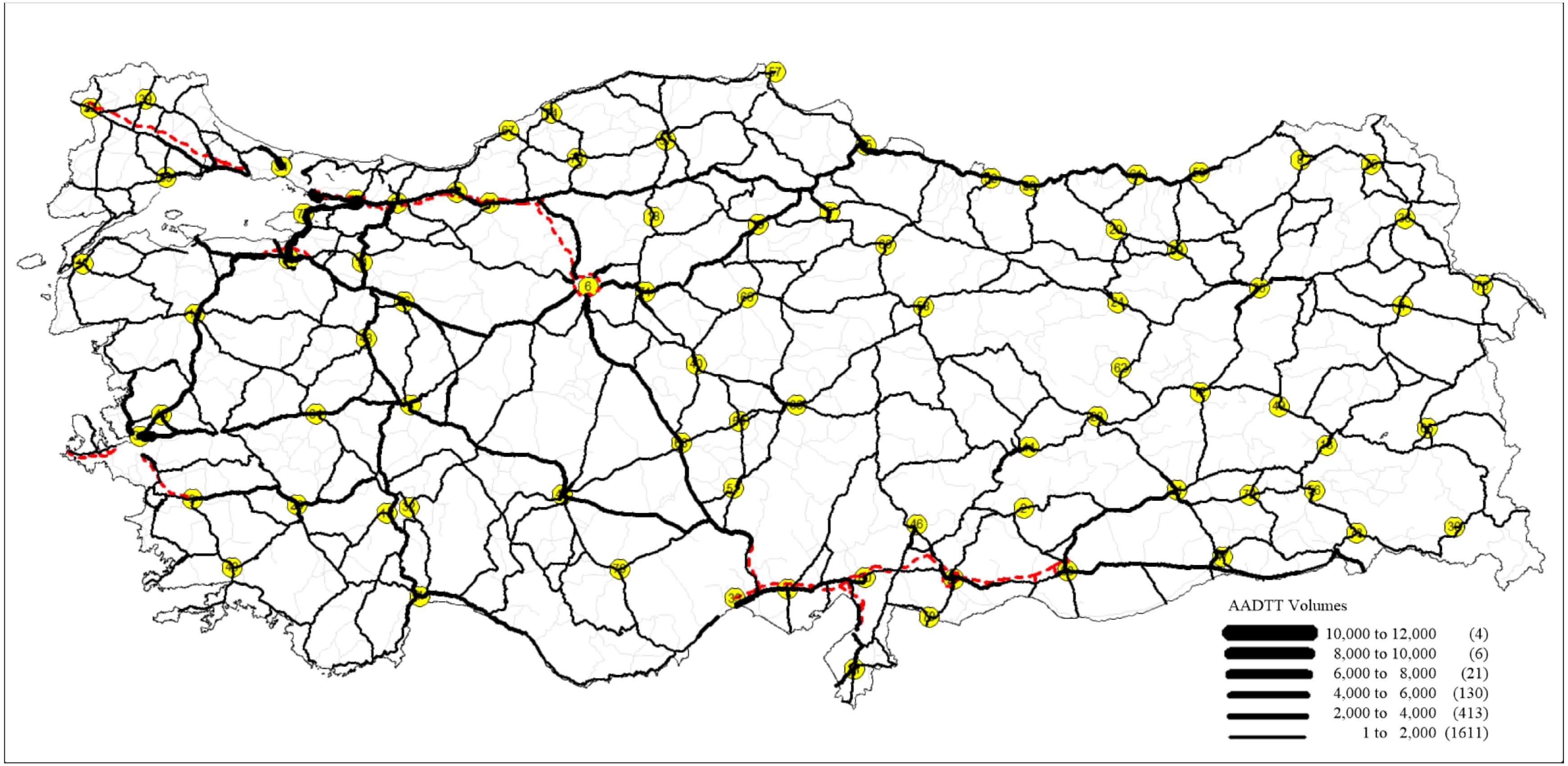


Figure 5.14 Publsıshed AADTT volumes on state road sections for 2011 (Source: TGDH, 2012b)

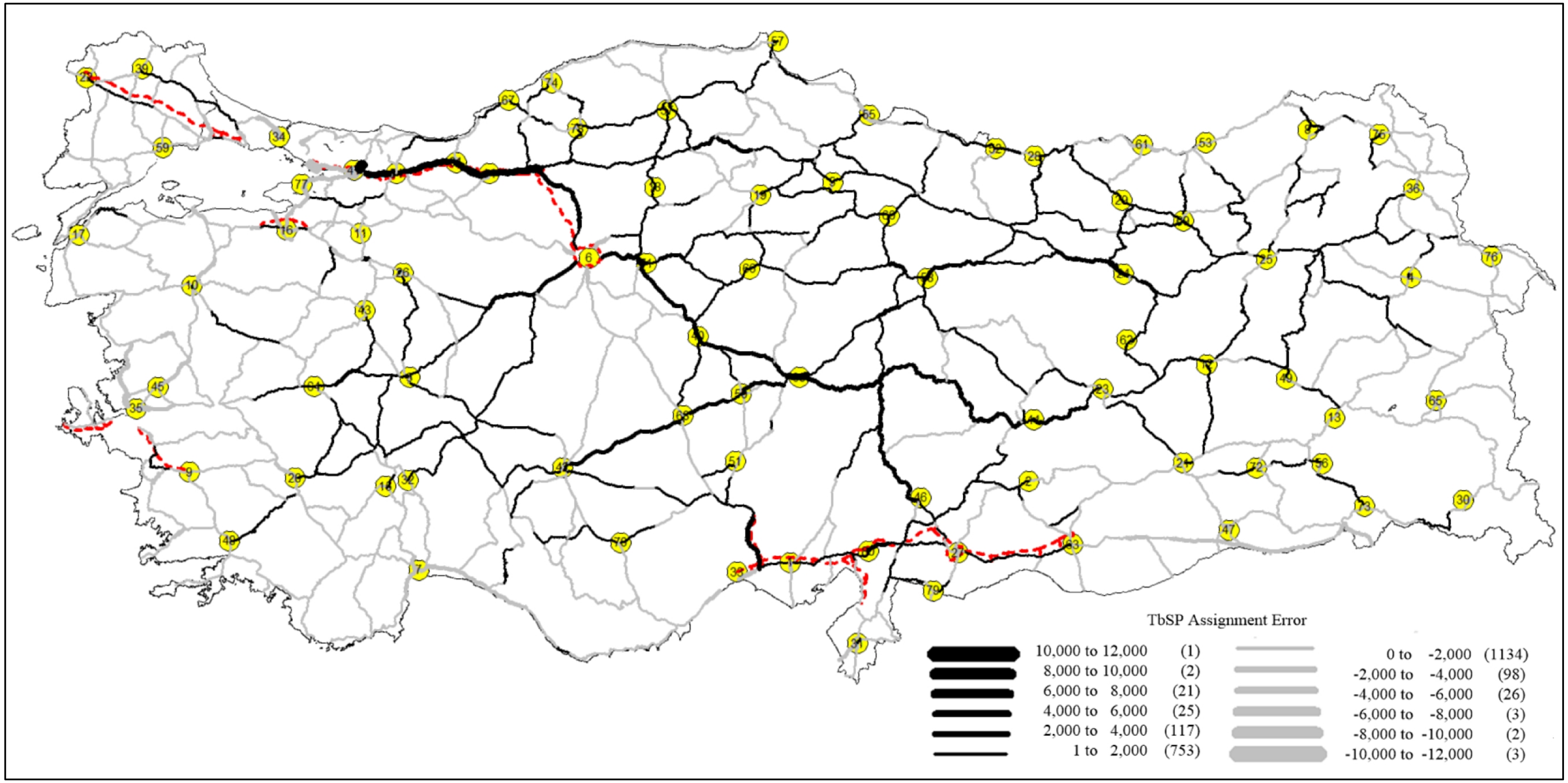


Figure 5.15 Daily TbSP assignment errors on state road sections for 2011

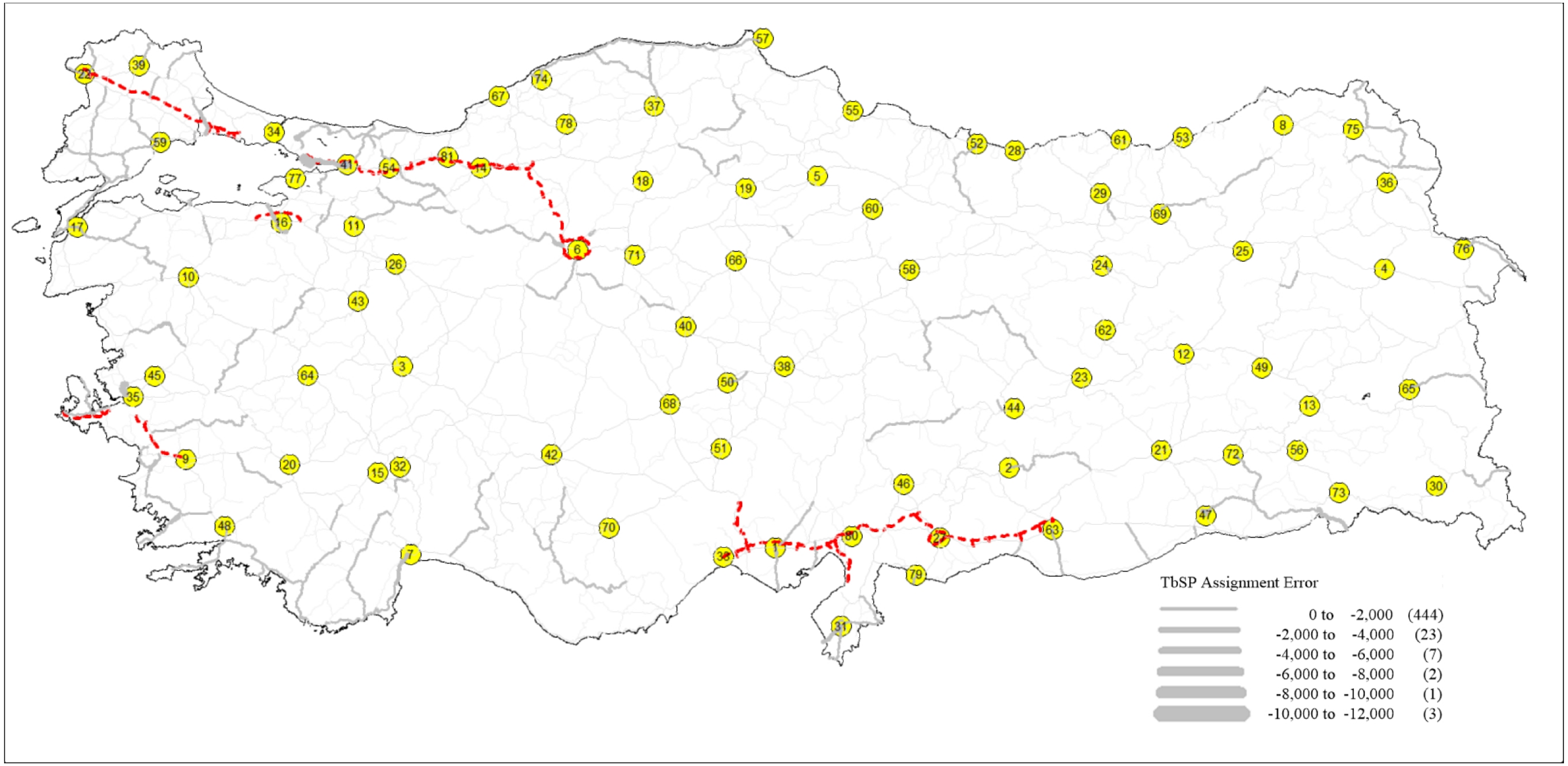


Figure 5.16 Daily TbSP assigment errors on not-assigned state road sections for 2011

5.4.3 Major Truck Assignment Error Sources

Errors along Motorways: As mentioned earlier, truck volumes were not assigned to motorway sections. Therefore, all truck traffic was naturally assigned to closest state road sections along the existing motorways, so that truck volumes on state roads along the motorway sections were overestimated (see Figure 5.15). A state road section of “750-04,2” is an example of motorway error around Bolu (see Table 5.4). Figure 5.17 and Figure 5.18 shows two different examples of motorway errors in Turkey. The first example is along the corridor of Kocaeli (41), Sakarya (54), Duzce (84), Bolu (14) and Ankara (6). Average assignment error in this region was around 6,000 trucks, and it increased to 10,500 trucks around Bolu (14) (see Figure 5.17). The second example is along the corridor of Mersin (33), Adana (1), Osmaniye (80), Gaziantep (27) and Sanliurfa (56). As similar, all truck traffic was again assigned to parallel state road sections in this corridor. Average assignment error was around 1,500 trucks in this corridor, and it increased to 5,000 trucks around Mersin (33) (see Figure 5.18).

Errors around ports: As mentioned before, there is a significant imbalance between produced and attracted trips for port provinces. Locations of these ports can be seen in Figure 5.8. Number of produced and attracted trips of these provinces are presented in Table E.2 and Table E.3 (see Appendix E). Even though, there is a port impact in trip generation equation, these trips couldn’t be assigned from exact location of ports, due to the province level assignment methodology. As a result, all trips were assigned between city centers and state road link volumes around port locations were underestimated. A state road section of “010-15,6” is an example of port error around Samsun Port (see Table 5.4).

Errors around border gates: Although, border gates have high potential for truck traffic, there isn’t any border gate impact in trip generation and attraction equations. Therefore, the existing variables in trip generation and attraction equations cannot reflect the actual truck trip potentials of the provinces of border gates. As a result, truck volumes around border gates were underestimated. A state road section of “400-30,1” is an example of border gate error around Nusaybin Border Gate (see Table 5.4). Figure 5.19 shows border gate related errors along Nusaybin Border Gate (in Mardin (47)) and Habur Border Gate (in Sirnak (73)). Average assignment error was around 3,250 trucks in this region. As it is seen, all of the state road truck volumes around these border gates were underestimated. Similar errors can be observed around the other border gates with Greece, Bulgaria, Georgia and Iran (see Figure 5.15).

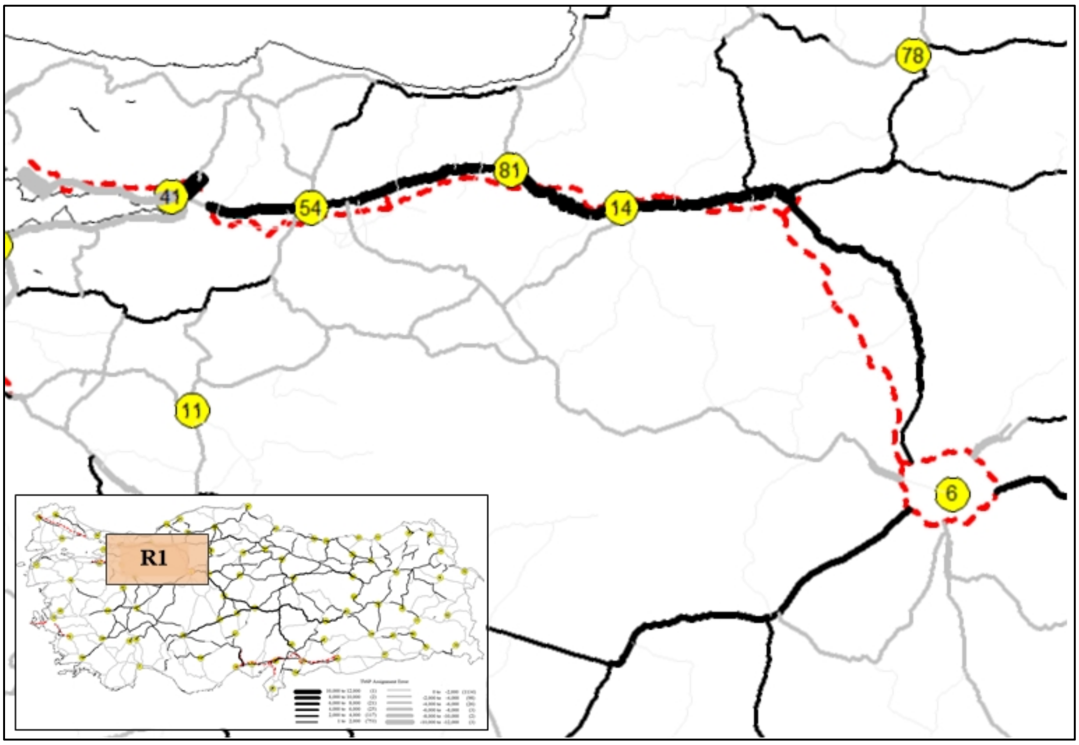


Figure 5.17 Motorway errors along Kocaeli and Ankara

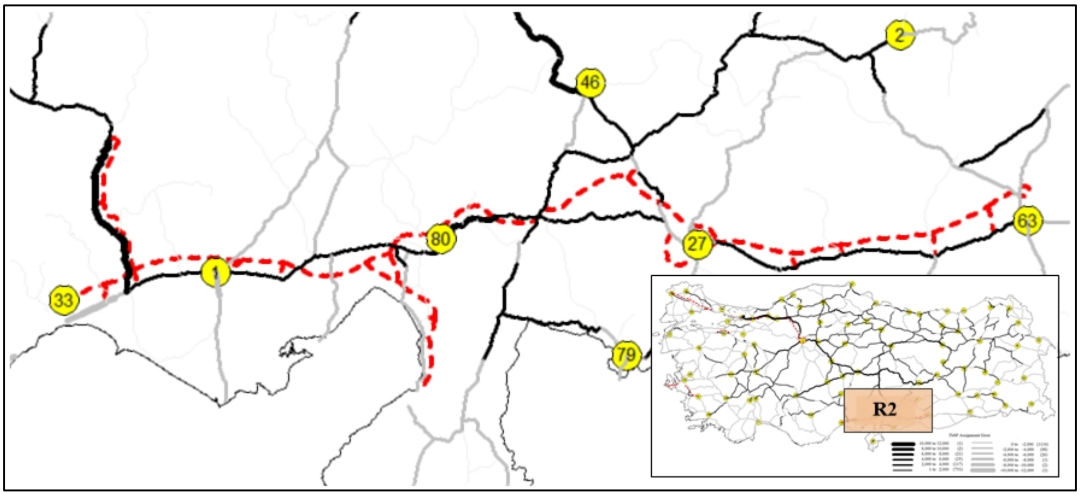


Figure 5.18 Motorway errors along Mersin and Sanliurfa

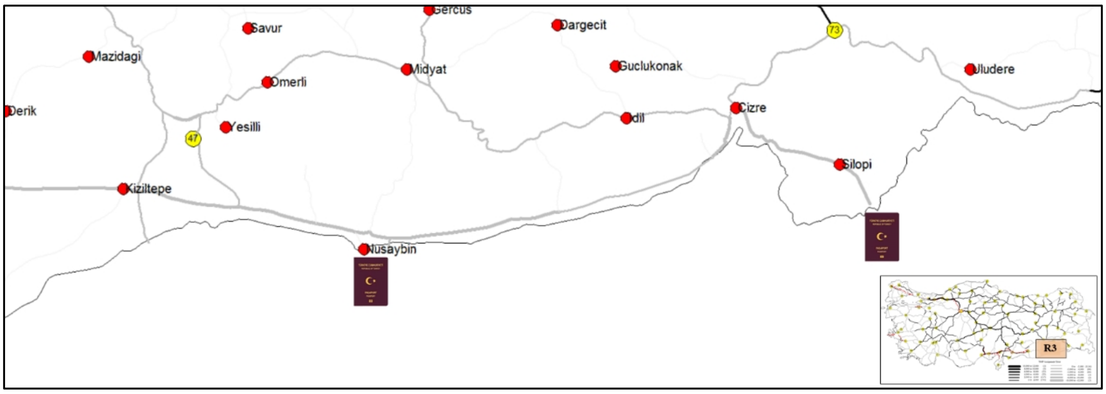


Figure 5.19 Assignment errors along Nusaybin and Habur border gates

Province level assignment errors: As discussed in Section 5.2, county level assignment is necessary to capture actual travel behavior of the truck flows. However, the existing trip generation and trip distribution steps were developed at province level due to unavailability of required socioeconomic and commodity flows data at county level. As a result, province level assignment introduce some errors. For example, truck volumes on the state road sections between Center of Izmir and Aliaga County (in Izmir) were underestimated (see Figure 5.20). In fact, there is a high truck demand on the state road sections of this corridor. However, TbSP assignment principle or combination of the TbSP and DbSP assignment principles couldn't capture actual truck volume on these sections. An average assignment error on this corridor was around 5,000 trucks. A state road section of "550-09,3" is an example of the state road sections in this corridor (see Table 5.4).

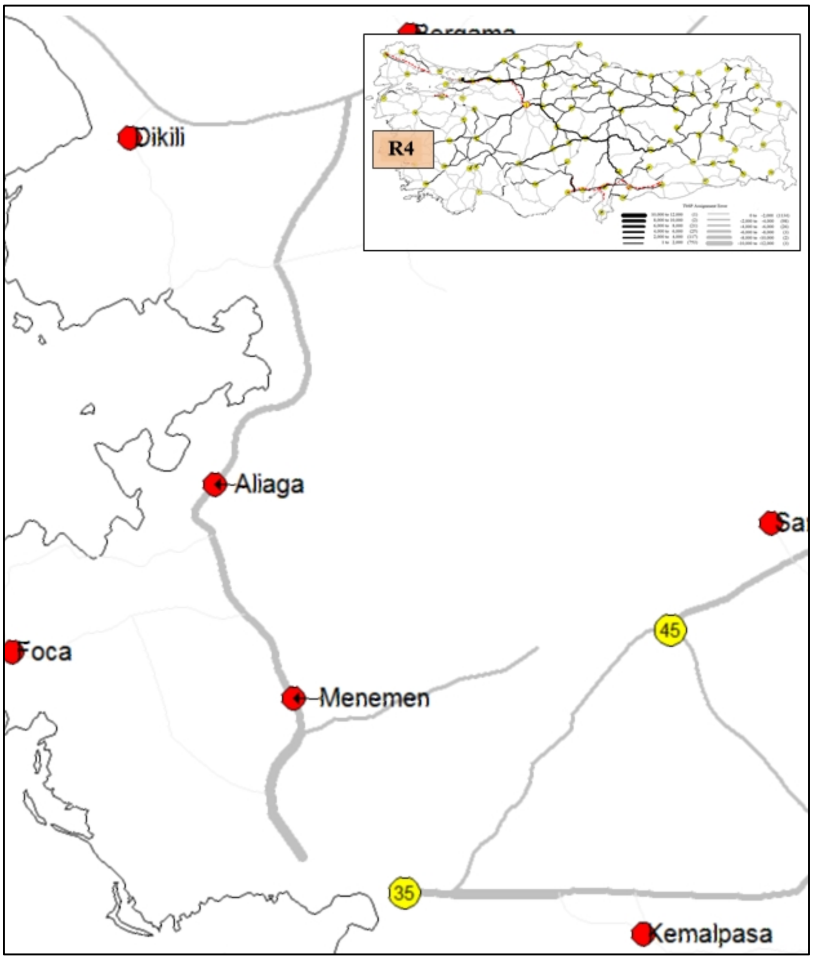


Figure 5.20 Assignment errors between Izmir and Aliaga

5.5 Evaluation of the Truck Network Assignment Principles

These analyses showed that the existing truck demand models for trip generation and distribution in Turkey have major shortcomings. Even though the published national truck vehicle-km value is forced in the calibration of the trip distribution step, state road link volumes estimated from network assignment have significant errors when compares with the published AADTT values. Neither TbSP assignment principle alone nor any combination of TbSP and DbSP principles reduced these assignment errors, which suggests that existing trip generation and distribution models cannot be safely used to validate a national truck network assignment principle.

The extreme cases that are mainly the large errors due to modeling problems discussed above, were excluded by omitting errors beyond three standard deviations of the mean error. The second round of analysis was performed with the cleaned-up data to evaluate the assignment errors under different network assignment schemes as follows: a) 100% TbSP, b) 75% TbSP and 25% DbSP, and c) b) 50% TbSP and 50% DbSP. The distribution of the errors did not provide any significant difference between different principles, either (see Figure 5.21). As a result, there is no scientific support for to use or not to use the proposed assignment principles that can be reached going through a traditional four-step model using province level trip generation, distribution and network assignment.

County level assignment is required to improve assignment errors. Even so, any combination of the TbSP and DbSP would always inherent some level of error, which was also observed in the county level SP analysis of the surveyed trucks. Actually, it is necessary to validate a county level network assignment principle using county level trip generation and distribution steps. However, it is rather challenging to develop these functions at county level due to unavailability of the required socioeconomic or commodity flow data.

In the light of all the determination and validation attempts for a truck network assignment principle, it is clear that the TbSP obtained from the analysis of the route choices of the surveyed trucks remain as the unchallenged most appropriate assignment principle for truck freight studies in Turkey with the currently existing data.

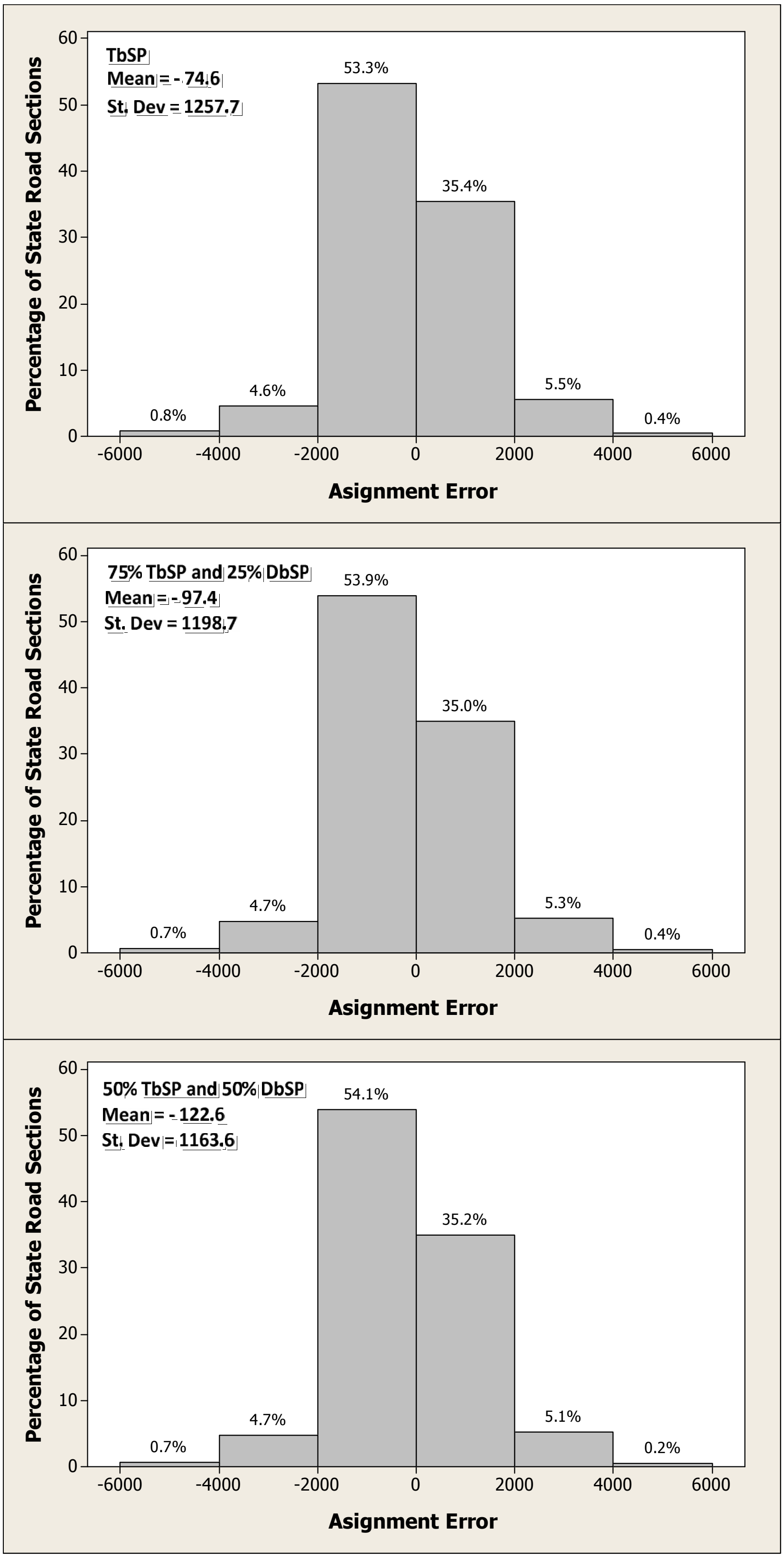


Figure 5.21 Histogram of the assignment errors with the cleaned-up data

CHAPTER 6

CONCLUSIONS AND FURTHER RECOMMENDATIONS

In Turkey, road transportation dominates the freight transportation with a 90% share. These movements are mostly performed by trucks. In addition, trucks accounts almost 25% of the average daily traffic on Turkish highway network. The dominance of trucks in freight transportation tends to create essential problems such emissions, noise, accidents and congestion. Also, environmental impacts of road freight have been lately taken more into consideration in different regions in the world due to the rapid growth in trucking activity in the last decade. To develop better policies for reductions of truck freight emissions in Turkey, it is necessary to estimate current level of these emissions, which is chosen as the main goal of this study.

However, in the absence of disaggregate commodity flow data, which is the case in Turkey, the next best solution was to develop a model that integrates disaggregate level roadside axle survey data with aggregate level national freight flow statistics. In this research, as for the disaggregate data of roadside axle surveys by Turkish General Directorate of Highways (TGDH) were used. Annually almost 10,000 have being captured in these surveys, and they provide valuable information for each surveyed truck, such as origin and destination of the truck trips, truck types, commodity types, payloads, loading conditions, etc. On the other hand, there are some limitations in these surveys. They are performed in spring, summer and fall seasons. Surveys are not conducted in the winter due to heavy weather conditions. In addition, there might be some bias in the sampling of the roadside axle surveys against overloaded and very heavy trucks. It is mentioned that such trucks are not stopped during these surveys, as it is not safe to stop and weight them. Furthermore, as roadside axle surveys are performed only on state roads, they are not capable of capturing most of the intracity movements. Therefore, intracity movements were excluded from the scope of this study.

For emission calculations COPERT 4 software was selected due to its common usage in European Union and moderate level of data requirements. The model was run for the annual road freight emissions calculations from 2000 to 2009, for which the roadside axle survey data were available.

In the following sections, general overview and conclusions of this research is summarized accompanied with further recommendations for improvement.

6.1 Road Freight Characteristics for Turkey

In Turkey, compared to other modes, highway network is well-developed and provides higher level of accessibility. In 2009, average truck trip distance in Turkey was around 493 km. In addition, 60% of the surveyed trucks had trip distances shorter than 500 km. This fact suggests that even for the intercity truck freight, intermodal freight alternative may not very desirable, as the latter is attractive for distances more 500 km with high volumes.

It was observed that rigid and articulated trucks have not been equally used in road freight movements. In national statistics published for 2009, rigid trucks captured 69.1% of the vehicle-km and 60.3% of the ton-km in truck transportation. The remaining demand was served by articulated trucks. On the other hand, the share of articulated trucks in these movements significantly increased during last decade. Survey results showed furthermore that articulated trucks serve in longer distances than rigid trucks. Average payload was also higher for articulated trucks (17.7 tons) as they have higher load carrying capacity than rigid trucks, which had an average payload of 10.6 tons. Analysis of the empty trucks in the survey data showed that 28.2% of the surveyed trucks between 2007 and 2009 were empty. These trucks corresponded to 22.3% of the vehicle-km in roadside axle surveys, and it was close to 25% average empty running in EU (European Union) countries. Average trip distance of these movements was 371 km, which was smaller than average trip distance of the laden trips.

Analysis of the commodity type information encoded in the axle load surveys using NST-2000 system showed that payload of the trucks changed by significantly by commodity type. Payload was heaviest for coal and lignite; peat; crude petroleum (Type 2) with 21.1 tons.

However, the lightest ones were the equipment utilized in the transport of goods (Type 16) and goods moved in the course of household (Type 17) with 7.8 tons. Average trip distance was the highest for transport equipment (Type 12) with 943 km, whereas it was the lowest for metal ores and other mining products (Type 3) with 376 km. According to vehicle-km share of the different commodity types, food products (Type 4) accounted for the highest share with 15.9%. On the other hand, it was only 0.8% for mails and parcels (Type 15) and unidentifiable goods (Type 19). Food products (Type 4) captured highest ton-km share in road side axle surveys with 16.6%. The lowest ton-km share was for equipment and materials utilized in the transport of goods (Type 16) with only 0.5%.

In the literature, there is not a single definition for inefficiency, so that different inefficiency definitions can be used based on different levels of vehicle utilization. In this study, as the average loading condition of the laden trucks was 75% for 2009, loading conditions under 70% were considered inefficient.

6.2 Evalution of the Road Freight Emission Estimations for Turkey

The results of the proposed methodology showed that CO_2 emissions remained almost constant between 2000 and 2009, with a value of 12,076 kilotons of CO_2 for the year of 2009. Rigid trucks were responsible for 68.1% of these emissions. This share was not unexpected considering market share of rigid and articulated trucks in freight transportation. Between 2000 and 2009, 25% decrease in the share of rigid truck emissions was observed, while emissions from articulated trucks were tripled. CO_2 estimations were validated with the published values in the literature, and it was found that CO_2 estimations for intercity trucking in Turkey were within the range of published values. But, it should be noted here that this study included emissions from only intercity truck movements. Intracity truck movements are generally subjected to the congestion and performed at lower speeds; therefore they have higher emission rates per vehicle-km. This suggests that if intracity movements are included, the truck CO_2 emissions would be higher.

In 2009, empty movements accounted for 17.2% of the CO_2 emissions. Furthermore, inefficiently loaded trucks accounted for 25.7% of the CO_2 emissions. Share of inefficiently loaded movements varied from 25.6% for NO_X to 30.4% for CH_4. Euro I trucks constituted the largest CO_2 emission share with 57.5% in 2009. The share of Conventional and Euro I trucks was 30.4% and 12.1%, respectively.

Furthermore, a sensitivity of the proposed methodology to the level of disaggregate data availability was tested by creating two additional scenarios with different data aggregation for loading and vehicle circulation parameters. The results showed that if the vehicle-km distribution is known among the different vehicle types and emission legislations, an average loading factor can be a good estimator; therefore, close values of emission estimations can be achieved. Otherwise, if the vehicle-km is equally distributed among the different vehicle types and emission legislations, significant differences in emission calculations can be expected. This also reminds us again the problem of reliability due to input variable assumptions. In this study, instead of actual disaggregate truck vehicle-km values, published aggregate statics were used with estimating the national circulation profile by the circulation profile of the survey data. Any biasedness in the survey sampling would definitely reflect errors in the estimation of the national emissions. Ideally, commodity flow data should be used to find national circulation profiles. Existence of such data would also enable estimation of emissions for different commodity types.

6.3 Evaluation of Emission Reduction Strategies for Road Freight Transportation

Even though limited, disaggregate nature of the roadside axle survey data enabled estimation of emissions by truck type, loading conditions and emission legislations. Therefore, disaggregate level emission results provided opportunity to calculate the level of inefficiency and the emission cost of this inefficiency.

There were only 3 strategies that can be evaluated by the results of the estimations:

a) Elimination of the empty movement in the long haul
b) Consolidation of the inefficient movements
c) Replacement of the old Conventional truck with new Euro IV trucks

a) Although empty movements can be seen as a strategy tool but it should be noted that they cannot be totally eliminated by the nature of freight transportation. As mentioned above, even in the EU countries, empty movements corresponded to 25% of the truck kilometers. Assuming a reduction in the long haul even is only theoretically meaningful, as free trade and economy conditions challenge any application of such strategy. However, this is still an acceptable area for reduction area. Better management of freight movements, such as logistics management, development of load matching agencies, back loading initiatives might decrease the share of empty movements. Furthermore, different freight companies might also coordinate to find backloading and reduce empty movements. Concordantly, Climate Change Action Plan (CCAP) prepared by Ministry of Environment and Urbanization, aimed to set a platform where all stakeholder in the transportation sector can collaborate and work together to increase transportation efficiency and reduce emissions in Turkey.

b) Only 2.5% of the CO_2 emissions can be reduced, if all inefficient movements are replaced by equivalent 70% loaded trucks. Even lower emission savings is expected, if inefficient movements are defined as those less than half loaded. Therefore, any policy regarding elimination of inefficiently loaded movements without targeting reduction of empty runs does not have significant emission reduction potential. Furthermore, consolidation of inefficiently loaded trucks is almost inapplicable in free economy conditions. It is also not meaningful without considering different commodity types and their weight and/or volume restrictions. As mentioned before, for some sectors, vehicle utilization is constrained by volume and weight based measure may underestimate the actual utilization of the vehicles.

c) A scenario that assumes the replacement of old Conventional trucks with new Euro IV trucks could significantly reduce regulated emissions, such as NO_X by 25.4%, CO by 14.5% and PM by 40.8%. CO_2 emissions can be reduced 4.4%, as the CO_2 emissions are directly related with fuel consumption. According to the Turkish Highway Transportation Regulation, trucks over 20 years old cannot be used for national and international freight transportation. CCPA also aimed to increase share of energy efficient vehicle in transportation in Turkey. Currently, Euro I and Euro IV trucks are more frequently used in freight transportation. But, it not easy to replace all Conventional truck with Euro IV without subsidies and financial incentives as they are private property. Carbon taxation for emission production can be considered to speed up the renewal process, but it should also be noted that fuel taxation is already high in Turkey. Any further increase may damage economy and mobility in negative ways.

6.4 Challenges of the Modeling Road Freight Demand and Emissions for Turkey

With or without disaggregate level data, truck network assignment principle is needed. Applicability of Time-based SP (TbSP) and Distance-based SP (DbSP) assignment principles were analyzed using roadside axle survey data. As discussed before, province level assignment is not acceptable. Therefore, county level assignment should be performed. However, county level assignment requires county level trip generation and distribution steps, which are not available for Turkey. Possible solution is to find hybrid use of regional trip productions with county level assignment calibrated by the published link volumes. Even if commodity flow data is not going to be collected, a national level truck freight survey can be conducted to estimate assignment principle better as it may vary for different commodity types. For instance, hazardous materials have different transportation and route choice objectives than agricultural and mining products. In addition, motorways must be included in to surveys to consider effects of value of time for different commodity types. Furthermore, trip chaining behavior must be studied, as it significantly effects the route choice decision of the truck movements. GPS based data can be utilized to study such measures that is already collected for fleet management by the companies.

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APPENDIX A

BACKGROUND OF ROAD FREIGHT EMISSIONS

The aim of this chapter is to provide the literature review on key variables and factors influencing road freight transportation emissions. In addition, the type of emissions and their environmental and health effects will be discussed. Finally, regulations to control road transportation emissions will be presented.

A.1 Introduction

Transport activity is one of the key components of economic growth, and it is expected to increase, to meet growing transportation needs of people in both developed and developing countries (EEA, 2010).It is also the single largest source of environmental impacts in the logistics systems (Wu and Dunn, 1995). As presented in Figure A.1, electricity production, road transport and industrial activity dominate global energy-related CO_2 emissions, and the former two sectors, along with international shipping and aviation, have experienced higher global growth rates than any other source sector over the past decades (OECD/ITF, 2010). This growth is likely to continue in the future. In 2004, transportation sector produced 6.5 Gt. CO_2 emissions per year, which accounted for the 22% of the global CO_2 emissions from fuel combustion, suggesting that freight transportation was responsible for 8% of the emissions. Specifically, freight transportation was responsible for almost one-quarter of all energy consumed by transportation sector at the global level (OECD/ITF, 2008b). Freight transportation energy consumption has been increasing, because of the growing importance of the road freight, even with the decreased energy intensity. Consequently, freight transportation's energy consumption share and the associated emissions have been increasing (Perez-Martínez, 2010). Besides, freight transportation is growing even more rapidly than passenger transportation and this trend is expected to continue in the future (Kahn Ribeiro et al., 2007 and Eom et al., 2012). Freight transportation ton-km is expected to increase 2.5% per year between 2000 and 2030 by comparison with 1.6% expected annual increase in passenger-km within the transportation sector. Consequently, it is one of the sectors where the level of CO_2 emissions is higher than in the base year of the Kyoto agreement (WBCSD, 2004).

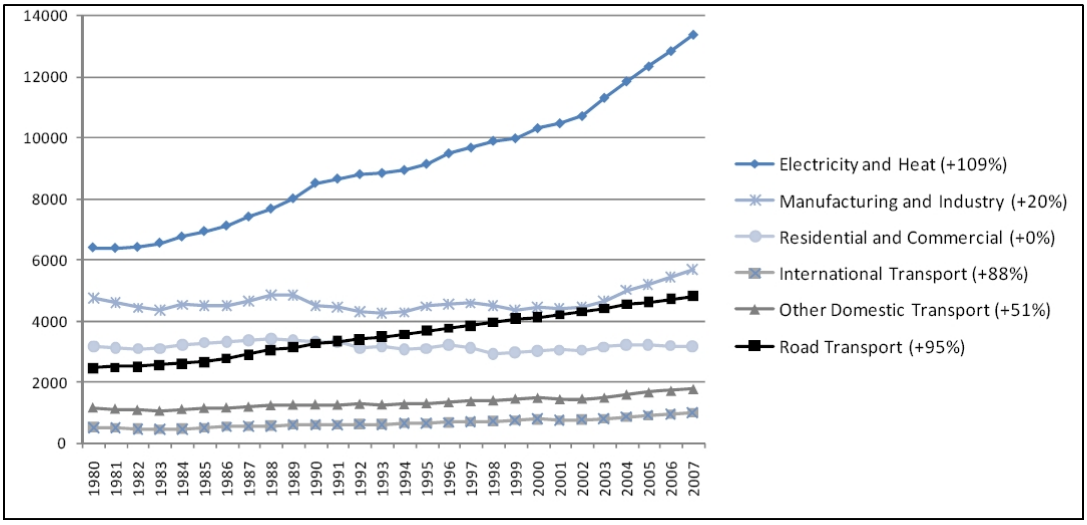


Figure A.1 Sources of global CO_2 emissions, 1980-2004 (Mt CO_2) (Source: OECD/ITF, 2010)

TurkStat (2011b) published findings that reported that the total greenhouse gas emissions were 369.6 Mt CO_2 in Turkey in 2009. CO_2 emissions accounted for 299.1 Mt. of these emissions and the share of transportation sector in direct CO_2 emissions was 15.6% (i.e. 46.7 Mt) (TurkStat, 2011b). Figure A.2 presents the trends in transportation sector CO_2 emissions in Turkey between 1990 and 2007 by European Commission (EC, 2010). Transportation sector CO_2 emissions increased by 96% and reached to 51.0 Mt. Road transportation accounted for the 84% of transportation sector CO_2 emissions in 2007. The share of civil aviation in CO_2 emissions was 12%. Railways and waterborne railways accounted for negligible shares in the total transportation CO_2 emissions in Turkey.

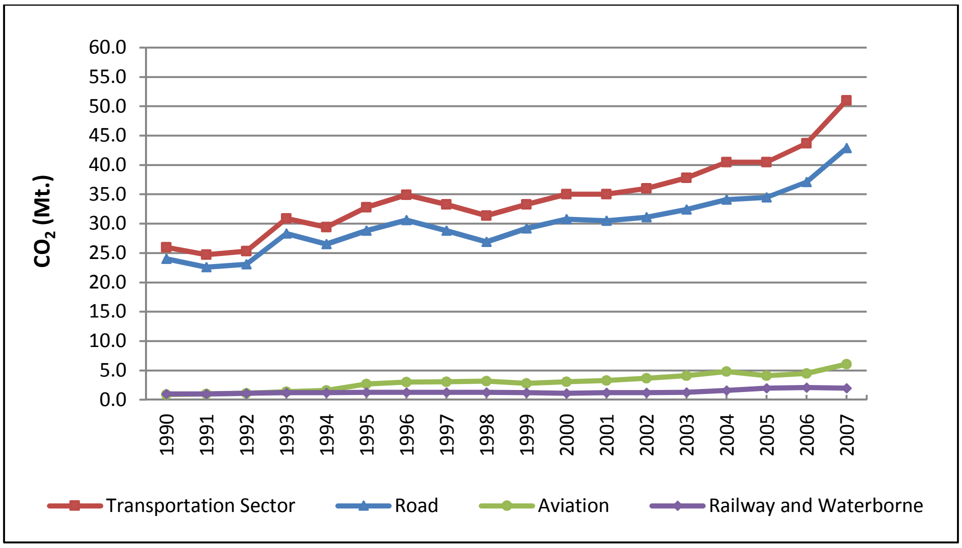


Figure A.2 Trends in transportation sector CO_2 emissions in Turkey (Source: EC, 2010)

McKinnon (2008) argued that this increase in freight transportation demand is mainly the function of the expansion of production and consumption, as well as extinction of the average hauling distance that each unit of freight is moved. Kahn Ribeiro et al. (2007) presented that, CO_2 emissions for each ton-km of freight transportation has been rising, because increasing share of high carbon-intensive modes, particularly air-freight and trucking. Figure A.3 displays estimates of freight and passenger transportation CO_2 emissions from road transportation for a selected number of countries. Heavy duty trucks accounts for 18% to 29% of total transportation sector emissions with the exception of China (OECD/ITF, 2010). OECD/IEA (2008) published detailed information on freight transport energy use and activity for a group of IEA-18 countries. Freight transportation ton-km increased by 34% between 1990 and 2005 in IEA-18 (see Figure A.4). Furthermore, trucking activity increased in all IEA-18 countries and trucking was the fastest growing freight mode in most of them, which puts upward pressure on freight demand and carbon emissions (Eom et al., 2012). Trucking increased substantially in large countries with low population densities such as Canada, New Zealand and Norway.

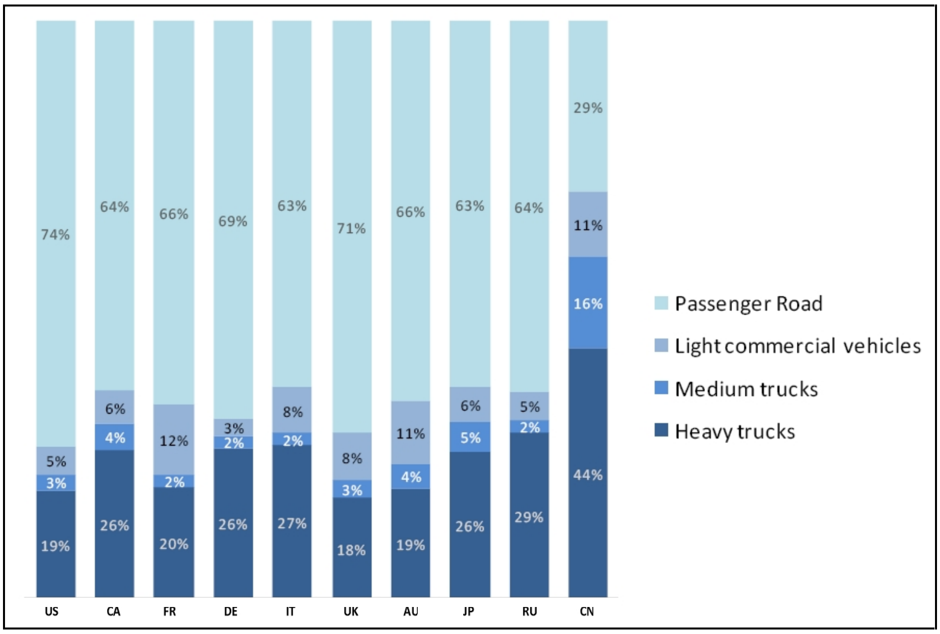


Figure A.3 Estimated breakdown of road transportation CO_2 emissions in 2005 (Source: OECD/ITF, 2010)

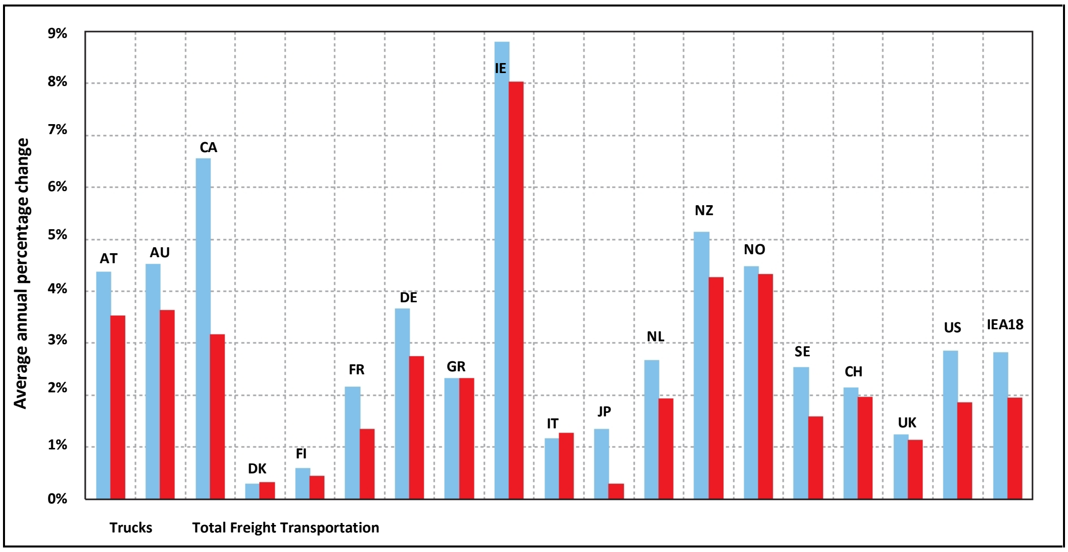


Figure A.4 Average annual percent change of freight ton-km by mode, 1990-2005 (Source: OECD/IEA, 2008)

For the IEA-18, freight transport accounted for 30% of total transportation energy use in 2005. Energy use in freight transport increased by 27% to 13 EJ, and associated direct and indirect CO_2 emissions increased by 26% to 1.0 Gt. CO_2 between 1990 and 2005. The growth in the energy consumption of the freight sector was almost due to higher consumption of trucking, which increased by 35% (see Figure A.5). Trucks increased their total freight transport energy consumption to 82% in 2005. On the other hand, energy consumption for rail freight increased by 16%, but its share of energy use declined to 6%. Conversely, both the energy consumption and the share of energy use for water freight declined, and it accounted for 12% of freight energy use in 2005. Oil dominates the freight transport sector, accounting for 99% of the total final energy consumption, most of which is diesel. Diesel (87%) was the dominant fuel for trucks. On the other hand, ships used mainly diesel (40%), and heavy fuel oil (59%). Rail transport energy use is split between diesel (88%) and electricity (12%). The energy intensity of truck movements has remained almost stable during the period of 1990 to 2005 showing only a slight decrease of 0.4% per year. This consequence is actually balance of the following contradictory two trends: one, the increasing share of freight movements increases the energy intensity and two, a steady decline of energy intensity of freight movements over time due to the advancement of technology. A decomposition of changes in truck energy per ton-km, truck-km per ton-km (inverse of the payload) and truck energy per truck-km is presented in Figure A.6. This reveals that the overall energy intensity of trucking was most strongly influenced by the evolution of load factors. For half of the countries analyzed, an increase in load factors (i.e. a decrease in truck-kilometers per ton-kilometer) led to a decline in truck energy intensity (measured as truck energy per ton-kilometer). In Finland, France and the United States, changes in vehicle energy intensity had a greater impact on trucking energy intensity, than did the evolution of load factors (OECD/IEA, 2008).

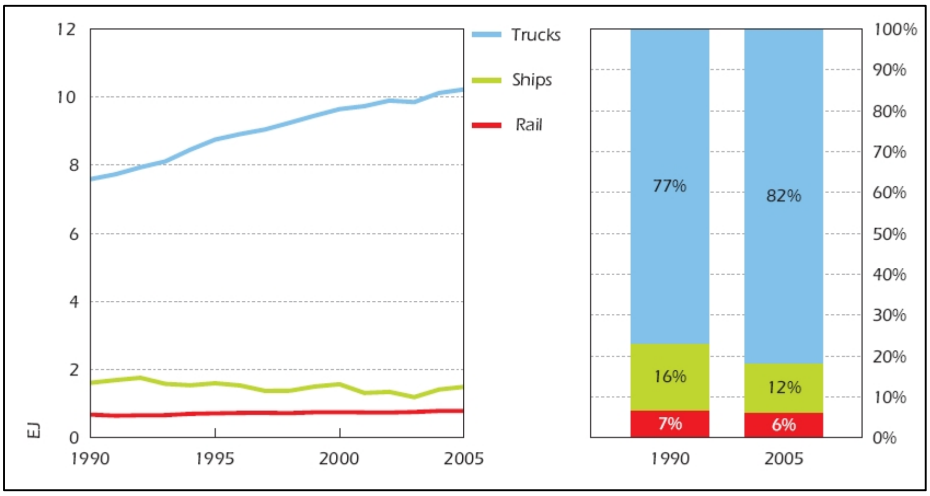


Figure A.5 Freight transport energy use by mode, IEA-18 (Source: OECD/IEA, 2008)

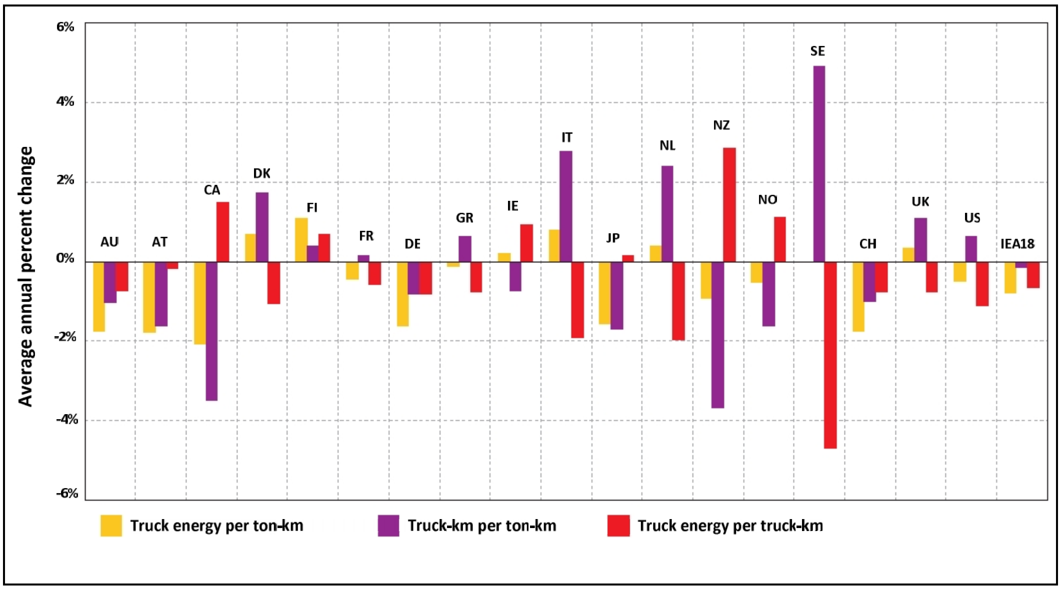


Figure A.6 Decomposition of changes in truck energy intensity, 1990-2005 (Source: OECD/IEA, 2008)

A.2 Emissions and Regulations

The movement of freight causes the most serious environmental impacts in most countries, even though improvements in vehicle technology play a significant role in reducing emissions (OECD/ITF, 2008a; Cooper et al. 1994). Road freight transportation contributes to air pollution at a local, regional and global level. Environmental impacts of road freight transportation are primarily local. But, some pollutants may cause diffusion of the pollution at a regional scale, if they are transported from their original sources and transformed into secondary pollutants as acid aerosols and ozone (see Table A.1). On the other hand, transportation emissions may contribute to climate change and cause global environmental problems (Cullinane and Edwards, 2010). Road transport pollutants may affect human health in a variety of ways. The cost of these health effects is one of the largest environmental costs of road transport (Delucchi, 2000). A summary of environmental and health effects of road transportation air emissions is presented in Table A.2.

Table A.1 Effects of transport related emissions (Source: Hickman et al., 1999)

Effect	Pollutant								
	PM	**HM**	**SO_2**	**NOX**	**NMVOC**	**CO**	**CH_4**	**CO_2**	**N_2O**
Local	■	■	■	■	■	■			
Regional			■	■	■	■			
Acidification			■	■					
Photochemical				■	■	■			
Global				■	■	■	■	■	■
Greenhouse-indirect				■	■	■	■		
Greenhouse-direct							■	■	■

PM- particulates, HM- heavy metals, SO_2- sulphur dioxide, NOx- oxides of nitrogen, NMVOC- non-methane volatile organic compounds, CO- carbon monoxide, CO_2- carbon dioxide, N_2O-nitrous oxide.

Table A.2 Environmental and health effects of road transportation emissions (Source: Johnstone and Kareausakis, 1999)

Air pollutant	**Health and environmental effects**
Carbon monoxide (CO)	Combines with hemoglobin in the blood to form carboxyhaemoglobin, reducing the blood's oxygen carrying capacity. Exposure to high concentrations results in loss of consciousness and death. At lower concentrations, CO affects the functioning of the central nervous system, causing impairment of vision, and slowing reflexes and mental functions. Can also cause headaches and drowsiness.
Nitrogen oxides (NO_X)	Involved in the formation of nitrous and nitric acid, and contributes to eutrophication or acidification. Also involved in the formation of tropospheric ozone and contributes to global warming. Exposure is linked to increased susceptibility to respiratory infection, increased airway resistance in asthmatics, and decreased pulmonary function.
Hydrocarbons (HC)	Both hydrocarbons and aldehydes can cause irritation of skin and mucous membranes and may lead to breathing difficulties; long-term exposure to hydrocarbons has been shown to lead to impairment of lung function. Hydrocarbons are also involved in the formation of tropospheric ozone (O_3) and photochemical smog, which in turn may cause respiratory problems
Particulate matter (PM)	Can irritate mucous membranes lining the respiratory tract and may give rise to breathing difficulties.
Sulphur dioxide (SO_2)	Associated with respiratory disease, chest discomfort, and possible risk of mortality.
Lead (PB)	Can be absorbed by gut or deposited in lungs. It is accumulated in the liver, kidney, brain, bone and nervous tissue, and can cause gastro-intestinal colic, fatigue, headaches and other ailments related to circulatory, reproductive, nervous and kidney systems.

Relative contribution of the different vehicle categories to the European road transport emissions are presented in the Table A.3. The results imply that trucks are the major source of road transportation nitrogen oxides emissions. Trucks are also responsible for the considerable part of the total particulate matter and methane emissions. According to Doll and Wietschel (2008), non-CO_2 road transportation emissions can be reduced and controlled by technical solutions, such as alternative fuels, filter technologies, internal engine optimization systems and other solutions. Trucks are also second largest source of CO_2 emissions from road transportation.

Table A.3 Emissions of different vehicle categories from road transportation in 2005 (Source: EEA, 2007)

Air Pollutant	**Cars**	**HDVs**	**LDVs**	**Buses**	**2-wheelers**
Nitrogen oxides (NO_X)	39%	47%	7%	6%	1%
Particulate matter (PM)	34%	32%	19%	6%	9%
Methane (CH_4)	67%	12%	2%	2%	17%
Carbon dioxide (CO_2)	65%	22%	8%	3%	2%
Non-methane volatile organic compounds (NMVOC)	51%	3%	3%	1%	42%
Carbon monoxide (CO)	74%	3%	5%	1%	17%

Emissions from road freight vehicles have been strictly regulated by European legislation since the early 1990s. During this period, vehicle manufactures have improved their engine technologies and have introduced various emission control systems to meet the requirements of the legislation. Today, regulated pollutants levels (carbon monoxide, nitrogen oxides, hydrocarbons and particulate matter) of modern vehicles are a lot lower than the vehicles manufactured two decades ago (see Table A.4). Emissions from diesel engines were first regulated in 1988 with the introduction of ECE 49 regulation. Vehicles meet the terms of ECE 49 are all classified as “conventional”. Directive 91/542/EEC were implemented at two stages, Stage I (Euro I) valid from 1992 to 1995 and Stage II (Euro II) from 1996-2000. Directive 1999/99/EC Stage I (Euro III) introduced a 30% reduction of all pollutants relative to Euro II and became valid from 2000. Finally, Euro IV and Euro V were implemented 2005 and 2008, respectively.

Euro V legislations are very stringent and require a reduction of more than 70% of NO_X emissions and 85% PM relative to Euro II legislation. The current discussions on Euro VI emission regulation, which will be implemented in 2014, are planning a further reduction of 80% of NO_X emissions and 50% PM over Euro V legislation. Nitrogen oxide and particulate matter emissions are particularly targeted and will be almost negligible after implementation of Euro VI legislation in 2013 (Cullinane and Edwards, 2010; Ntziachristos and Samaras, 2010). The more stringent Euro VI legislations will most likely lead a small increase in fuel consumption, because of the relationship between NO_X emissions and fuel consumption. Reducing NOx emissions often leads to an increase in fuel consumption (Visser et al., 2008). European Commission (EC, 2007) assumes that the fuel consumption of Euro VI vehicles will be 2% to 3% higher than Euro V vehicles, which is equivalent to an increase in CO_2 emissions of diesel truck engines by 0.1% in 2015 and 0.3% in 2020. The consumption of a fully laden 40ton truck meeting Euro V emission legislation is around 30 l/100 km. A slightly higher consumption of 30.6 l/100 km is expected for a truck meeting Euro VI emission legislation (Speilmann, 2010). Visser et al. (2008) argued that implementation of Euro VI legislation will lead to a reduction of total NO_X emissions from road traffic by almost 5% in 2015 and 21% to 23% in 2020 in the Netherlands. Besides, implementation of this proposal will lead to a reduction of 2% to 3% combustion-related PM-2.5 emissions of all road traffic in 2015 and 11% to 13% in 2020.

Table A.4 Euro emission regulations for diesel truck engines, g/kWh (smoke in m^{-1})
(Source: Cullinane and Edwards, 2010; Ntziachristos and Samaras, 2010)

Technology	Legislation	Date	CO	HC	NO_x	PM
Euro I	91/542/EEC Stage I	1992	4.5	1.1	8.0	0.36
Euro II	91/542/EEC Stage II	Oct. 1996	4.5	1.1	8.0	0.15
Euro III	1999/96/EC Stage I	Oct. 2000	2.1	0.66	5.0	0.10
Euro IV	1999/96/EC Stage II	Oct. 2005	1.5	0.46	3.5	0.02
Euro V	1999/96/EC Stage III	Oct. 2008	1.5	0.46	2.0	0.02
Euro VI	—	2013	1.5	0.13	0.4	0.01

APPENDIX B

MODELING ROAD FREIGHT EMISSIONS

The following sections describe briefly the different approaches used in modeling hot, cold and evaporative emissions.

B.1 Modeling Hot Emissions

There are number of models to estimate hot emissions on a variety of spatial and temporal scales. These emission models can be divided into three main groups of increasing level of complexity (Esteves-Booth et al., 2002):

- Emission factor models
- Average speed models
- Modal models

B.1.1 Emission Factor Models

The emission factor models use a simple method. The estimation of emissions is expressed by the use of an emission factor related to specific type of vehicle and driving circle. An emission factor is a representative value that relates the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant (EPA, 2007). Emission factors are derived from the average values of number of repeated measurements under particular driving circle (Cloke et al., 1998). This type of estimations is mainly used on a macro scale, when information on traffic flows and modes are insufficient. The emission factors are usually expressed per vehicle and per unit distance (activity-based approach) or per unit of fuel consumed (fuel-based approach). Aggregated emission factors for regulated pollutants (CO, HC, NO_X and PM) and CO_2 are not generally used in detailed air pollution studies, as more sophisticated approaches are available. However, they are available to estimate levels of unregulated pollutants, where there is insufficient information to define a more detailed relationship with vehicle operation. A number of aggregated emission factors are given in the European Environment Agency's COPERT model. COPERT provides emission factors for the unregulated pollutants methane (CH_4), nitrous oxide (N_2O) and ammonia (NH_3) for urban, rural and motorway driving segments. The aggregated emission factors used in COPERT are used in many regional and national inventory models (Barlow and Boulter, 2009).

Fuel based approach: As the CO_2 emissions from road freight transportation sector are directly related to the type and amount of fuel used, the energy consumption and related carbon emissions equates to the type and density of diesel used. Standard diesel engines emit 2.82 kg CO_2/litre and ultra low sulphur diesel emits 2.57 kg CO_2/litre. DEFRA (2010) suggested that 2.64 kilograms of CO_2 emissions are emitted for every litre of diesel fuel burnt. This value is very comparable with 2.7 kg of CO_2 per litre of diesel fuel specified by Australian Greenhouse Office (2003).

Activity based approach: This approach calculates emissions using activity based conversion factors. This requires freight transportation activity data by vehicle type. Table C.1 summarizes the CO_2 emission factors for rigid and articulated trucks considering their loading conditions in the UK. The higher the gross vehicle weight the higher emissions per vehicle-km, however it leads the lower emissions per ton-km (DEFRA, 2008).

Table B.1 Road freight transportation CO_2 conversion factors (Source: DEFRA, 2008 and 2010)

Type	Gross Vehicle Weight (ton)	Loading	Kg CO_2 per Vehicle-km	Kg CO_2 per Ton-km
Rigid	3.5 – 7.5 t	0%	0.528	0.591
		50%	0.576	
		100%	0.619	
	7.5 – 17.0 t	0%	0.671	0.336
		50%	0.767	
		100%	0.863	
	>17.0 t	0%	0.798	0.187
		50%	0.973	
		100%	1.149	
Articulated	3.5 – 33.0 t	0%	0.692	0.163
		50%	0.865	
		100%	1.038	
	>33.0 t	0%	0.698	0.082
		50%	0.930	
		100%	1.163	

B.1.2 Average Speed Models

Average speed models are based on speed related emission function generated by the measurement of the emission rates over a variety of trips at different emission levels. Examples of this type model are COPERT, NAEI and ARTEMIS. They are based on the principle that the average emission factor for a specific pollutant and a given type of vehicle varies according to the average speed during a trip. The emission factor is generally expressed in grams per vehicle-km. Figure B.1 shows how a average speed emission function varies over a range of driving cycles with each cycle representing a specific type of driving, including stops, starts, accelerations and decelerations.

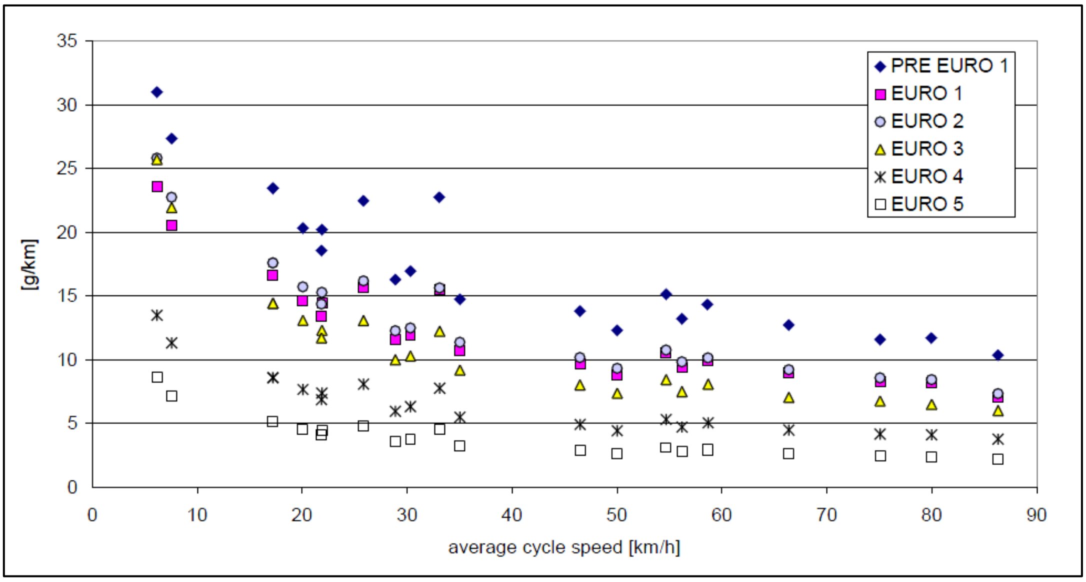


Figure B.1 Simulated NO_X emission factors for articulated trucks, 34 – 40 tons, 50% loaded, 0% road gradient (Source: Sturm, 2009)

Specific examples of average speed models include the following:

COPERT: COPERT is a free program that can be used to calculate emissions of air pollutants from road transport, and contains some of the most widely used average-speed functions. The development of COPERT has been financed by the European Energy Agency as part of activities of European Topic Centre on Air and Climate Change. The initial version of the program, COPERT 85 (Eggleston et al., 1989), was followed by COPERT 90 (Eggleston et al., 1993), COPERT II (Ahlvik et al., 1997) and COPERT III (Ntziachristos and Samaras, 2000). COPERT 4 (Gkatzoflias et al., 2007) is the latest version of the methodology. COPERT 4 estimates emissions of all regulated air pollutants (CO, NO_X. VOC, PM) for different vehicle categories as a function of average speed. Functions are also available for fuel consumption and unregulated pollutants. The COPERT methodology is one of the most widely used models in Europe for estimating national level exhaust emissions and preferred method in the European Environment Agency's Emission Inventory Guidebook (EEA, 2007).

ARTEMIS: The ARTEMIS project commenced in 2000. Its main objective was to understand causes of the differences in model estimations and address the uncertainties in emission modeling. The other objective of ARTEMIS was to develop a methodology for estimating emissions from all transport modes at the national and international level. The software for the road transport model in ARTEMIS has been produced by INFRANS. It contains both average speed emission factors and traffic situation emission factors (Barlow and Boulter, 2009). Table B.2 presents average CO hot emission functions for articulated trucks of 34-40 t gross vehicle weight and 50% loaded at 0% gradient. Aggregated emission functions for other pollutants and trucks classes are provided by Boulter and T Barlow (2009). The more detailed discussion of COPERT model is presented in Chapter 2.

Table B.2 ARTEMIS CO average speed functions for articulated trucks, 34 – 40 tons, 50% loaded and 0% road gradient (Source: Boulter and Barlow, 2009)

Legislation	Form of function (E:g/km; V:km/h)	Coefficients				
		a	b	c	d	e
Pre-Euro I	$E = e + a * e^{-b*V} + c * e^{-d*V}$	9.7284	0.0568	20.3582	0.3169	1.8837
Euro I	$E = e + a * e^{-b*V} + c * e^{-d*V}$	6.7252	0.0511	18.1552	0.3058	1.6043
Euro II	$E = \frac{1}{c * V^2} + b * V + a$	0.0729	0.0138	-0.0001	---	---
Euro III	$E = a + \frac{b}{1 + e^{-c}} + d * \ln(V) + e * V$	1.5025	161.6538	-1.9091	0.4412	0.0443
Euro IV	$E = a + \frac{b}{1 + e^{-c}} + d * \ln(V) + e * V$	0.0500	0.8637	3.4871	1.5534	-0.0068
Euro V	$E = a + \frac{b}{1 + e^{-c}} + d * \ln(V) + e * V$	0.0551	0.8881	3.4079	1.5290	-0.0049

B.1.3 Modal Emission Models

Modal emission models use higher level of complexity to provide precise estimation of emissions as a function of different levels of speed as well as of the various operational modes during a series of short steps often one second, such as acceleration, deceleration, steady speed cruise, and idle (Barlow and Boulter, 2009 and Esteves-Booth et al., 2002). These models mainly used at micro level and emission rate for a given vehicle category and pollutant is assumed to be fixed, and total emission during a trip or in a section of road is calculated by weighting each modal emission rate by the time speed in the model (Hung et al. 2005). The most complex modal models employ a matrix of combinations of instantaneous (second-by-second) speed/acceleration and emission rates. Therefore, such models can be used to calculate second-by-seconds emissions and fuel consumption for a particular vehicle type from a given driving circle. Demir et al. (2011) reviewed several instantaneous emissions models for road freight transportation.

Instantaneous fuel consumption model: An instantaneous fuel consumption model was developed by Bowyer et al. (1985). It uses vehicle characteristics, such as mass, energy, efficiency parameters, drags force and fuel consumption components associated with aerodynamic drag and rolling resistance, and estimates the fuel consumption per second. It assumes that the changes in acceleration and deceleration levels occur within 1 second time interval and takes the form:

$$f_t = \begin{cases} \alpha + \beta_1 R_t v + (\beta_2 + M a^2 v/1000) & \text{for } R_t > 0 \\ \alpha & \text{for } R_t \leq 0 \end{cases} \tag{B.1}$$

where, f_t is the fuel consumption per unit time (mL/s), R_t is the tractive force (kN) required to move the vehicle and calculated as the sum of drag force, inertia force and grade force as $R_t = b_1 + b_2 v^2 + Ma/1000 + gM\omega/100000$. Furthermore, α is the constant idle fuel rate (in mL/s, typically between 0.375 and 0.556), β_1 is the fuel consumption per unit of energy (in mL/kJ, typically between 0.09 and 0.08), β_2 is the fuel consumption per unit of energy acceleration (in mL/(kJ m/s^2), typically between 0.03 and 0.02), b_1 is the rolling drag force (in kN, typically between 0.1 and 0.7), and b_2 is the rolling aerodynamic force (in kN/(m/s^2), typically between 0.00003 and 0.0015). In addition, ω is the percent grade, a is the instantaneous acceleration (m/s^2), M is the weight (kg), and v is the speed (m/s). The authors suggested that the model is able to estimate fuel consumption of individual vehicles within 5% error, and later dynamometer tests suggested that its accuracy is within 10% (Esteves-Booth et al., 2002).

A four mode elemental model of fuel consumption: A four mode elemental model presented by Bowyer (1985) consists of sets of functions to estimate fuel consumption for idle, cruise, acceleration and deceleration driving modes. The model includes the same parameters as instantaneous fuel consumption model developed by Bowyer et al. (1985), and introduces additional initial speed, final speed and energy related parameters. Therefore, more accurate estimations can be made, if the initial and final speeds of the acceleration and deceleration cycles are known (Demir et al., 2011).

Acceleration fuel consumption: The following equation can be used to estimate fuel consumption during acceleration phase from an initial speed of v_i to final speed of v_f ($v_f>v_i$):

$$F_a = \max\{\alpha t_a + (A + k_1 B(v_i^2 + v_f^2) + \beta_1 M E_k + k_2 \beta_2 M E_k^2 + 0.0981\beta_1 M\omega)x_a,\ \alpha t_a\} \qquad (B.2)$$

where, E_k denotes the change in kinetic energy per unit distance during acceleration and is calculated as $E_k = 0.385810^{-4}(v_f{}^{2} - v_f^{2})/x_a$. The integration coefficients are $k_1 = 0.616 + 0.000544v_f - 0.0171\sqrt{vi}$ and $k_2 = 1.376 + 0.00205v_f - 0.0053v_i$. If the travel distance x_a and the travel time t_a are not known, they can be estimated as $x_a = ma(v_i + v_f)t_a/3600$ where, $ma = 0.467 + 0.00200v_f - 0.00210v_i$ and $t_a = (v_f - v_i)/(2.08 + 0.127\sqrt{(v_f - v_i)} - 0.0182v_i)$. A is the function parameter (in mL/km, typically between 21 and 100), and B is the function parameter in $((mL/km)/(km/h)^2$, typically between 0.0055 and 0.018).

Deceleration fuel consumption: The following equation can be used to estimate fuel consumption during deceleration phase from an initial speed of v_i to final speed of v_f ($v_f<v_i$):

$$F_d = \max\{\alpha t_d + (k_x A + k_y k_1 B(v_i^2 + v_f^2) + k_a \beta_1 M E_k + 0.0981 k_x \beta_1 M\omega)x_d,\ \alpha t_d\} \qquad (B.3)$$

where, k_x, k_y, k_a are energy related parameters. $k_x = 0.046 + 100/M + 0.00421v_i + 0.00260v_f + 0.05444\omega$; $k_y = k_x^{0.75}$; $k_a = k_x^{3.81}(2- k_x^{3.81})$ and $k_1=0.621 + 0.000777v_i - 0.0179\sqrt{v_f}$. If travel distance x_a and the travel time t_a are not known, they are estimated as for Eq. (3.4), although the coefficients change slightly.

Cruise fuel consumption: The following equation can be used to estimate fuel consumption by a vehicle during cruise phase allowing for speed fluctuations.

$$F_c = \max\ \{f_i/v_c + A + B v_c^2 + k_{E1}\beta_1 M E_k + k_{E2}\beta_2 M E_{k+}^2 + 0.0981 k_G \beta_1 M\omega,\ f_i/v_c\} \qquad (B.4)$$

where, f_i denotes the idle fuel rate (mL/h), v_c is the average cruise speed (km/h). The change in positive kinetic energy per unit distance during the cruise mode is calculated as $Ek_+ = \max\{0.258 – 0.0018v_c, 0.10\}$. k_{E1}, k_{E2} and k_G are the calibration parameters estimated from

k_{E1} = max{12.5/v_c + 0.000013 v_c^2; 0:63}, k_{E2} = 3.17, and k_G = 1 - 2.1Ek_+ for $\omega < 0$, and 1 - 0.3Ek_+ for $\omega > 0$.

Fuel consumption while idle: Total fuel consumption while vehicle idle can be calculated from: F_i=αt_i, where, t_i is the idle time (s), and α is the idle fuel rate (mL/s). The total fuel consumption Ft (mL) using a four mode elemental modal can be calculated as:

$$F_t = \int_0^{t_a} F_a dt + \int_0^{t_d} F_d dt + \int_0^{t_c} F_c dt \int_0^{t_i} F_i dt \qquad \text{(B.5)}$$

The authors suggested that the model is able to estimate fuel consumption within 1% error, and later dynamometer tests suggested that its accuracy is within 10%. If the initial and final speeds are known, the model yields more accurate estimates for fuel consumption, and provides results very similar to those of the instantaneous model (Demir et al., 2012).

A running speed model fuel consumption: Bowyer et al. (1985) introduced a running speed model to estimate fuel consumption when a vehicle is running and an idle mode. This model can be considered as more aggregated from of the elemental model introduced by Bowyer et al. (1985). Since acceleration, deceleration and cruise phases are considered together in a single function.

$$F_s = \max\{\alpha t_i + (f_i/v_c + \Upsilon + B\,v_r^2 + k_{E1}\beta_1 ME_k + k_{E2}\beta_2 ME_{k+}^2 + 0.0981 k_G \beta_1 M\omega) x_s, \alpha t_s\} \qquad \text{(B.6)}$$

where, F_S denotes the fuel consumption (mL/h), x_s is the total distance, v_r is the average running speed (km/h). t_s and t_i the travel time and idle time. Average speed is calculated as v_f=3600x_s/(t_s - t_i). Furthermore, E_{k+} = max{0.35 – 0.0025v_r, 0.15}. k_1 = max{0.675–1.22/v_r, 0.5}, k_2 = 2.78 + 0.0178v_r.

A comprehensive modal emission model: A comprehensive modal emission model for heavy duty vehicles was developed by Barth et al. (2000, 2005) and Barth and Boriboonsomsin (2008). It follows, the model of Ross (1994), and includes three modules: engine power, engine speed and fuel rate.

Engine power module: The power demand function for a vehicle is obtained from the tractive power requirements P_{tract}(kW) placed on the vehicle at the wheels:

$$P_{tract} = (Ma + MgSin\theta + 0.5C_d pAv + MgC_r Cos\theta)v/1000 \quad (B.7)$$

where, v is the speed (m/s)' and M is the weight (kg), with p is the air density in kg/m^3 (typically 1.2041), A is the frontal surface area in m^2 (typically between 2.1 and 5.6), and g is the gravitational constant in m/s^2 (typically 9.81). C_d is the coefficient of aerodynamic drag (typically 0.7), and C_r the coefficient of rolling resistance (typically 0.01). The following equation is used to translate the tractive requirement into engine power requirement.

$$P = P_{tract} / \eta_{tf} + P_{acc} \quad (B.8)$$

where, P is the second-by-second engine power output (kW), η_{tf} is the vehicle drive train efficiency (typically 0.4), and P_{acc} the engine power demand associated with running losses of the engine and the operation of vehicle accessories and typically 0.

Engine speed module: Engine speed is approximated by:

$$N = S(R(L)/R(L_g))v \quad (B.9)$$

where, N is the engine speed (in rpm, typically between 16 and 48), S is the engine-speed/vehicle-speed ratio in top gear L_g, R(L) is the gear ratio in gear L = 1, . . . , L_g, and v is the vehicle speed (m/s),

Fuel rate module: The fuel rate (g/s) is expressed by:

$$FR \approx \left(KNV + \frac{P}{\eta}\right)\frac{1}{43.2}[1 + b_1(N - N_0)^2] \quad (B.10)$$

$$K = [K_0[1 + C(N - 30\sqrt{3.0}/V)]\ \ ) \tag{B.11}$$

where, FR is the fuel use rate in g/s, P is the engine power output (KW), K is the engine fraction factor (typically 0.2), N is the engine speed (revolutions per s), V is the engine displacement (in liters, typically between 2 and 8), η is the measure of indicated efficiency for diesel engines (typically 0.45). b_1 and C are coefficients.

MEET Methodology: Hickman et al. (1999) described a methodology called MEET (Methodologies for Estimating air pollutant Emissions from Transport), to calculate energy consumption and emissions from heavy duty vehicles. This methodology includes number of functions which are dependent on speed and number of predefined parameters for heavy duty vehicles of weights ranging from 3.5 to 32 tons. The following speed dependent function is used to estimate fuel consumption:

$$\varepsilon = K + av + bv^2 + cv^3 + \frac{d}{v} + \frac{e}{v^2} + \frac{f}{v^3} \tag{B.12}$$

where, ε is the rate of emission in g/km for an unloaded goods vehicle, or for a bus or coach carrying a mean load, on a road with a gradient of 0%, K is a constant, and a to f are coefficients. Coefficients were derived different classes of heavy duty vehicles for carbon monoxide, carbon dioxide, hydrocarbons, oxides of nitrogen and particulates. Table B.3 presents coefficients of emission functions for heavy goods vehicles with gross vehicle weights from 16 to 32 tons.

Table B.3 Coefficients of emission functions for heavy goods vehicles of 16 - 32 tons
(Source: Hickman et al., 1999)

Pollutant	K	a	b	c	d	e	f
CO	1.53	0	0	0	60.6	117	0
CO_2	765	-7.04	0	6.32E-04	8334	0	0
VOC	0.207	0	0	0	58.3	0	0
NO_X	9.45	-0.107	0	7.55E-06	132	0	0
PM	0.184	0	0	1.72E-07	15.2	0	0

Coefficients in Eq. B.12 correspond to standard testing conditions (i.e. empty vehicles and zero gradients). Depending on the vehicle type a number of corrections might be required to include effects of road gradient and vehicle loading condition. Hickman et al. (1999) suggested the following equation to take the effect of road gradient into account:

$$\mathrm{G} = \mathrm{A}_6\mathrm{v}^6 + \mathrm{A}_5\mathrm{v}^5 + \mathrm{A}_4\mathrm{v}^4 + \mathrm{A}_3\mathrm{v}^3 + \mathrm{A}_2\mathrm{v}^2 + \mathrm{A}_1\mathrm{v} + \mathrm{A}_0 \qquad \text{(B.13)}$$

where, G is gradient correction, v is the mean speed and A_0 to A_6 are constants for each pollutant, vehicle and gradient class. A_6 is 0 for all heavy duty vehicle classes. The gradient factor coefficients for heavy duty vehicles of 16-32 t are presented in Table B.4, where speed is the range for which the correction is applicable.

The following is used to take the loading factor into consideration:

$$\mathrm{L} = \mathrm{k} + \mathrm{n}\mathrm{ɤ} + \mathrm{p}\mathrm{ɤ}^2 + \mathrm{q}\mathrm{ɤ}^3 + \mathrm{rv} + \frac{\mathrm{s}}{\mathrm{v}^2} + \frac{\mathrm{t}}{\mathrm{v}^3} + \frac{\mathrm{u}}{\mathrm{v}} \qquad \text{(B.14)}$$

where, ɤ is the gradient in percent and v is the mean velocity of the vehicle in km/h. k is a constant and n to u are coefficients. Then, MEET suggests the following equation for estimating CO_2 emissions (g/km) depending on the vehicle type, a number of corrections may be made to allow for the effects of road gradient, vehicle load:

$$\mathrm{E} = \varepsilon(\mathrm{v})\ \mathrm{GL} \qquad \text{(B.15)}$$

where, E is the corrected hot emissions, ε(v) is the average speed (v) dependent emission rate for standard conditions G and L are correction factors for gradient and loading, respectively.

Table B.4 Coefficients of gradient factor functions for heavy duty vehicles 16 - 32 tons (Source: Hickman et al., 1999)

Pollutant	**A_5**	**A_4**	**A_3**	**A_2**	**A_1**	**A_0**	**Slope (%)**	**V (km/h)**
CO	0.00E+00	-1.50E-05	1.43E-03	-4.92E-02	7.32E-01	-2.31	(4) – (6)	12.5 – 36.5
	-7.70E-08	1.30E-05	-8.51E-04	2.62E-02	-3.80E-01	3.15	(-6) – (-4)	13.5 – 49.9
	-2.46E-08	4.79E-06	-3.44E-04	1.13E-02	-1.66E-01	2.12	(0) – (4)	14.9 – 69.7
	1.44E-09	-3.32E-07	3.06E-05	-1.45E-03	2.91E-02	0.88	(-4) – (0)	15.1 – 86.1
CO_2	0.00E+00	-6.69E-06	6.55E-04	-2.31E-02	3.69E-01	0.11	(4) – (6)	12.5 – 36.5
	-1.22E-07	2.03E-05	-1.30E-03	3.94E-02	-5.70E-01	3.75	(-6) – (-4)	13.5 – 49.9
	-5.25E-09	9.93E-07	-6.74E-05	2.06E-03	-1.96E-02	1.45	(0) – (4)	14.9 – 69.7
	-8.24E-11	2.91E-08	-2.58E-06	5.76E-05	-4.74E-03	0.86	(-4) – (0)	15.1 – 86.1
VOC	0.00E+00	6.18E-06	-6.51E-04	2.39E-02	-3.66E-01	3.24	(4) – (6)	12.5 – 36.5
	-4.96E-08	9.03E-06	-6.37E-04	2.11E-02	-3.22E-01	3.08	(-6) – (-4)	13.5 – 49.9
	-2.11E-08	4.32E-06	-3.30E-04	1.17E-02	-1.91E-01	2.25	(0) – (4)	14.9 – 69.7
	3.21E-09	-7.41E-07	6.58E-05	-2.82E-03	5.69E-02	0.76	(-4) – (0)	15.1 – 86.1
NO_X	0.00E+00	2.30E-06	-2.49E-04	9.39E-03	-1.26E-01	2.51	(4) – (6)	12.5 – 36.5
	-1.09E-07	1.84E-05	-1.20E-03	3.70E-02	-5.49E-01	3.83	(-6) – (-4)	13.5 – 49.9
	-2.00E-08	3.87E-06	-2.81E-04	9.57E-03	-1.43E-01	2.08	(0) – (4)	14.9 – 69.7
	5.72E-11	1.59E-08	-4.09E-06	2.73E-04	-1.18E-02	0.98	(-4) – (0)	15.1 – 86.1
PM	0.00E+00	-1.05E-05	9.88E-04	-3.35E-02	5.10E-01	-1.09	(4) – (6)	12.5 – 36.5
	-6.72E-08	1.16E-05	-7.82E-04	2.50E-02	-3.79E-01	3.23	(-6) – (-4)	13.5 – 49.9
	-3.60E-08	7.00E-06	-5.07E-04	1.69E-02	-2.49E-01	2.59	(0) – (4)	14.9 – 69.7
	2.40E-11	3.95E-08	-6.78E-06	3.25E-04	-9.46E-03	1.12	(-4) – (0)	15.1 – 86.1

B.2 Modeling Cold and Evaporative Emissions

Cold start emissions are usually incorporated into models based on trip length and average speeds. In many models, cold start emissions have been introduced as a penalty factor over the hot emissions assuming the cold start period of the vehicle. Therefore, the accuracy of cold start emission estimations starts to decrease, if they are used in modal models since approximations are being used. Besides, these conversion factors are usually developed from secondary testing on vehicles that have not been used to develop the modal models (Cloke et al. 1998). Boulter (1997) reviewed factors affecting cold start emissions for various pollutants and vehicle types. Some fundamental factors that affect cold start emissions include (Boulter and Latham, 2009):

- The pollutant
- The vehicle type (car, light goods vehicle, heavy goods vehicle), The fuel type (e.g. petrol, diesel)
- Emission legislation technology (e.g. Euro I, Euro II)
- The engine and catalyst temperatures at the start and end of each trip

All trips do not start with the engine and catalyst temperatures at the ambient temperature and end with their full operational temperature. Thus, engine and catalyst temperatures are dependent on the factors such as (Boulter and Latham, 2009):

- The ambient temperature
- The wind speed
- The parking duration
- The driving cycle during the cold start period

However, little research has been conducted to study effect of these factors on cold start emissions from heavy vehicles (Boulter and Latham, 2009). Furthermore, Boulter (1997) noted that cold start emissions from heavy vehicles are minimal level compared to hot emissions. On the other hand, their contributions to local emissions could be significant. Measurements on Euro II vehicles on urban driving conditions conducted by Engler (2001) showed that fuel consumption is about 18% and particle mass emissions were around 30-50% higher during cold start period. The studies also showed that only for CO_2 and NO_X, there is a correlation between heavy vehicle engine or vehicle size and the cold start emissions. Table B.5 presents cold start emissions for four classes of heavy vehicles used in MEET classification system (Hickman, 1999).

Table B.5 Cold excess emissions from HGVs (Source: Hickman, 1999)

Class	CO	CO_2	HC	NO_X	PM
3.5 - 7.5 ton	6	200	2	-1	0.6
7.5 - 16 ton	6	300	2	-2	0.6
16 - 32 ton	6	500	2	-5	0.6
32 - 40 ton	6	750	2	-7	0.6

APPENDIX C

ROAD FREIGHT EMISSION REDUCTION STRATEGIES

As the road transport is the dominant mode of the freight transportation in most of the developed countries, the efficiency of the freight movements is the main determinant of the environmental impacts of the freight transportation. At the international level, predominance of the road freight transportation is expected to continue to grow, and this suggests the needs for implementation of technological, operational and modal policy precautions taking into account environmental criteria (Vanek and Morlok, 2000). According to McKinnon (2003), improvements in the logistic supply chains and transportation process such as more backloading or shared user distribution have the potential to reduce environmental impacts of freight transportation while maintaining the economic growth. Copper et al. (1998) linked the economic growth and road freight transportation demand including environmental effects of freight vehicles. Similarly, Ahman (2004) pointed out the following measures to achieve the decoupling of economic growth and road freight transportation CO_2 emissions.

- Shifting to non-carbon fuels
- Promoting modal shift to less carbon-intense modes
- Use of more energy efficient vehicles
- More efficient logistic systems
- Shifting to less transport intensive economic growth

CO_2 emissions from road freight transportation sector are closely related to the type and amount of fuel used. As almost all freight transportation trucks are diesel powered, the energy consumption and related carbon emissions equates directly to the amount of diesel fuel consumption (Léonardi et al., 2006). Fuel consumption of the road freight transportation is measured in different ways. The first measure relates fuel consumption to the distance travelled, which is often called as energy efficiency or fuel efficiency (e.g. km per litre); and the other measure expresses it in relation to amount of freight movement and is known as energy intensity (e.g. ton-km per litre) (McKinnon, 2010; Ruzzenenti and Basosi, 2009). Ang-Olson and Schroeer (2002) suggested that, "in a typical modern diesel truck engine, 53% of the fuel energy is lost as heat through the exhaust system and cooling system, and another 5% is dissipated through engine friction and pumping losses, leaving 42% available as engine output." This energy is used to overcome the following factors:

- Aerodynamic drag
- Rolling resistance
- Drive train friction
- Operation of ancillary equipment
- Inertial forces during acceleration or climbing

The contribution of each of these factors to energy losses depends on operating speed, vehicle weight, terrain, driver behaviour, weather and pavement conditions, etc. Ang-Olson and Schroeer (2002) explored the potential of technological and operational strategies to improve environmental performance road freight transportation in the US. As presented in Figure C.1, potential savings vary from under 1% for automatic tyre inflation systems to almost 8% for reduction in maximum speed from 105 km/h to 95 km/h.

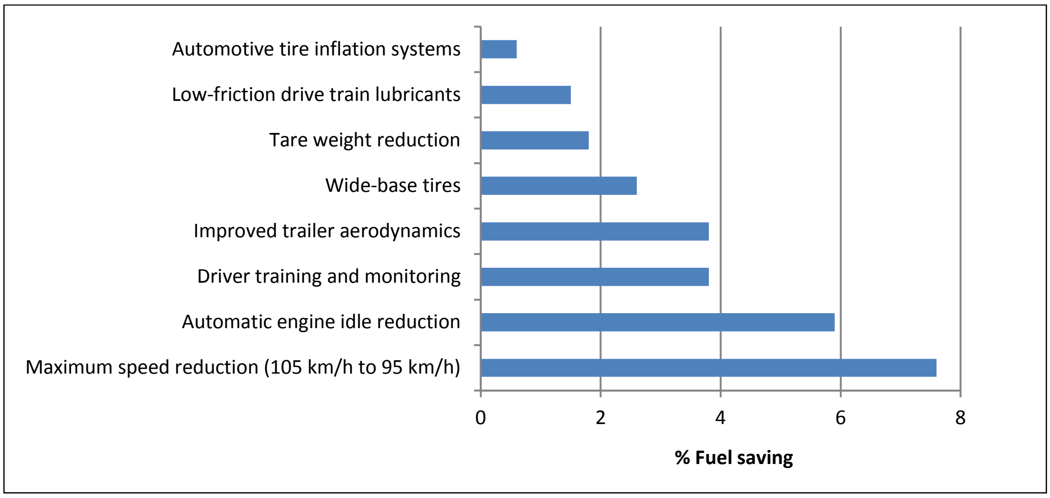


Figure C.1 Estimated fuel savings from US road freight transportation (Source: Ang-Olson and Schroeer, 2002)

In theory, if a freight operator implements these measures; they may cut their fuel consumption up to 30%. However, this is unrealistic in practice, as some measures are counteracting. For instance, cutting maximum speed reduces the effectiveness of improved trailer aerodynamics (McKinnon, 2008). Léonardi and Baumgartner (2004) suggested that fuel efficiency is a product of the following interacting factors, of which the vehicle usage efficiency is the most important:

- **Vehicle efficiency**: Focuses on improvements in vehicle technology and design.
- **Driver efficiency:** Focuses on training and on-board units to measure components of driving behaviour that influence fuel consumption.
- **Route efficiency:** Focuses on the selection of optimum routing based on road and traffic conditions.
- **Logistic efficiency:** Focuses on determining optimum loading factor of vehicles, selecting the most suitable vehicle category and optimizing the entire transport chain from the point of origin to the final destination.

These measures to improve fuel efficiency of the freight transportation vehicles will be discussed in the following sections.

C.1 Vehicle Efficiency

Over the past decades, technical improvements have significantly enhanced the fuel performance of the freight vehicles (McKinnon, 1999). It has been estimated that average fuel efficiency of the trucks has been improving at an annual rate of 0.8 to 1.0%. The main improvements have been achieved until 1990, and then the rate of fuel efficiency improvements has been relatively small; because truck manufacturers have had to meet the more stringent NOx and PM emission legislations (McKinnon, 2008). It is estimated that average truck fuel efficiency would be 7% to 10% higher, if these emission control regulations had not been introduced (see Table B.3). Further improvements in local air quality conflicts with attempts to reduce fuel consumption and CO_2 emissions; because the control regulated emissions require the usage of some instruments which are likely to lead to fuel consumption increase. The Euro VI which will be implemented in 2013 in the EU requires modifications in engine technologies that would have negative impacts on fuel economy (IEA/OECD, 2009).

There are also further attempts on technological improvements to improve fuel economy of the freight trucks. For instance, fuel economy regulation introduced in 2005 in Japan proposed almost 12% improvement in fuel economy compared to 2002 (IEA, 2007, Piecyk, 2010b). These improvements not only based on technological advances in diesel engines, but also number of modifications in vehicle design. For instance, improving aerodynamic resistance of the vehicles can dramatically improve fuel consumption at high speeds. Utilization of the lower resistance tires, maintaining of the proper tire pressure, reducing tare weight of the vehicle, reducing idle truck engine operations and speed reduction can also lead to significant improvements in fuel efficiency and carbon emission per unit of cargo transported (Gaines et al., 1998; Woodrooffe et al., 2010; Léonardi and Baumgartner, 2004). Modifications in vehicle design can also improve efficiency in fuel consumption by reducing air resistance (McKinnon, 2010a). Banister and Hickman (2006) suggested that improvements in the carbon efficiency of freight vehicles have potential to reduce emissions from 25% to 50% as compared to 2000 in 2030 in the UK. Nealer et al. (2012) showed that 10% increase in fuel efficiency of diesel powered truck engines would decrease energy consumption and emissions by approximately 6% in the US. IEA (2008) estimated that there exists 40% reduction potential in fuel use per ton-km, through the implementation of available technologies.

Figure C.2 shows available data on trends in truck efficiency for rigid (single unit) and articulated trucks (trailer or combination trucks) in the US and UK since 1993. It notes that average fuel efficiency of rigid trucks has been increasing in the UK and US, that the fuel efficiency of articulated trucks in the US has been decreasing, and the fuel efficiency of articulated trucks in the UK has remained almost stable since 1993. Average fuel efficiency of similar sized trucks may show variations, even for trucks used for very similar purposes. Besides, Nylund and Erkkila (2007) found that fuel efficiency of different brands of the same types of the new truck may show 5% to 15% variations in Finland.

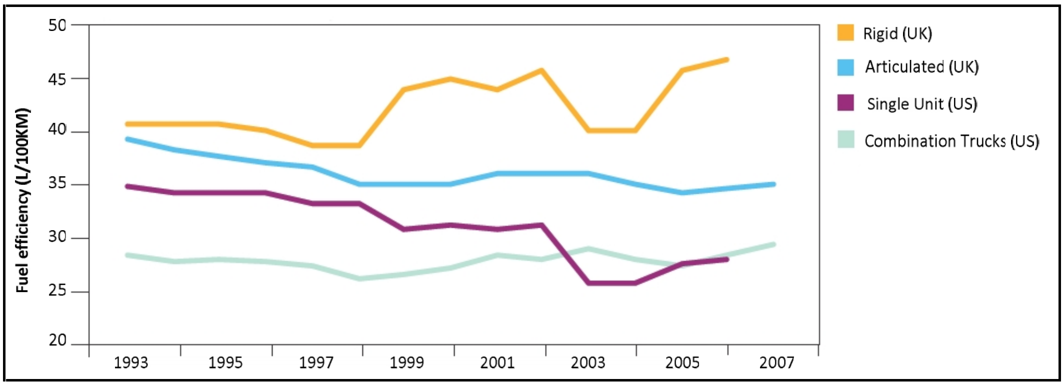


Figure C.2 Fuel efficiency of trucks in the UK and US, 1993-2007 (Source: IEA/OECD, 2009)

On the other hand, trucks have a relatively long life span, which slows down the technology penetration. Many old trucks are still used in developing countries. The data published by Transport Canada (2005) showed that the average fuel efficiency of trucks reduces as they get older (see Figure C.3). Therefore, public funds can be used to scrap older vehicles with more fuel efficient models. Recently, Spanish government initiated an early scrappage policy. However, research conducted in UK fount that significant public funds are necessary to reduce average age of the truck fleet as a cost effective approach to save fuel consumption and decrease level of CO_2 emissions (IEA/OECD, 2009). Cloke et al. (1998) also implied the importance of vehicular maintenance to control emissions.

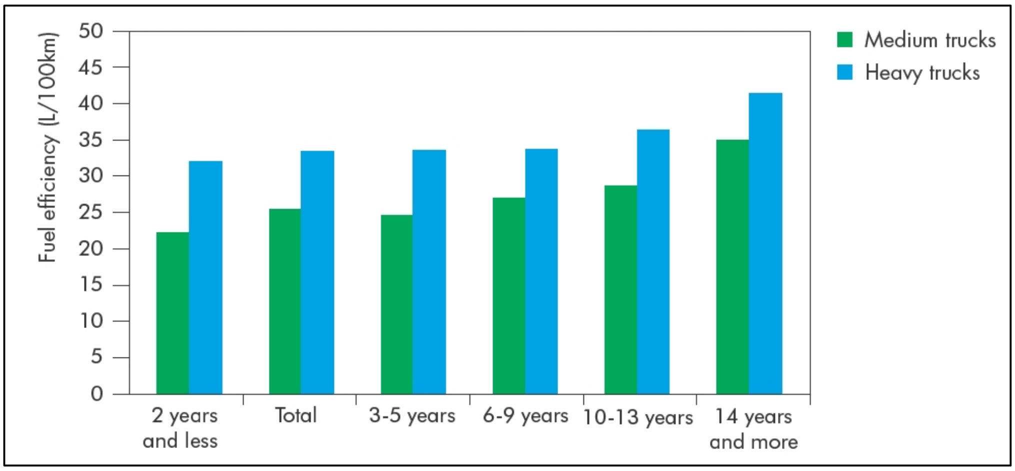


Figure C.3 Decline in average fuel efficiency as truck ages increases (Source: Transport Canada, 2005)

Maximum gross vehicle weights and dimensions of the vehicles have changed over the period. As the vehicles are more heavily loaded, their energy consumption per km rises, even though their energy consumption per ton-km may decline. Figure C.4 shows that energy consumption per ton-km dramatically decreases as the truck pay load increases for a 40 ton maximum gross vehicle weight of 5 axle truck. As noted in the figure, although the benefits starts to slow down after 10 ton, it still improves, for instance, almost half of the energy used per ton-km for a 25 ton loaded truck as compared to a 10 ton loaded one.

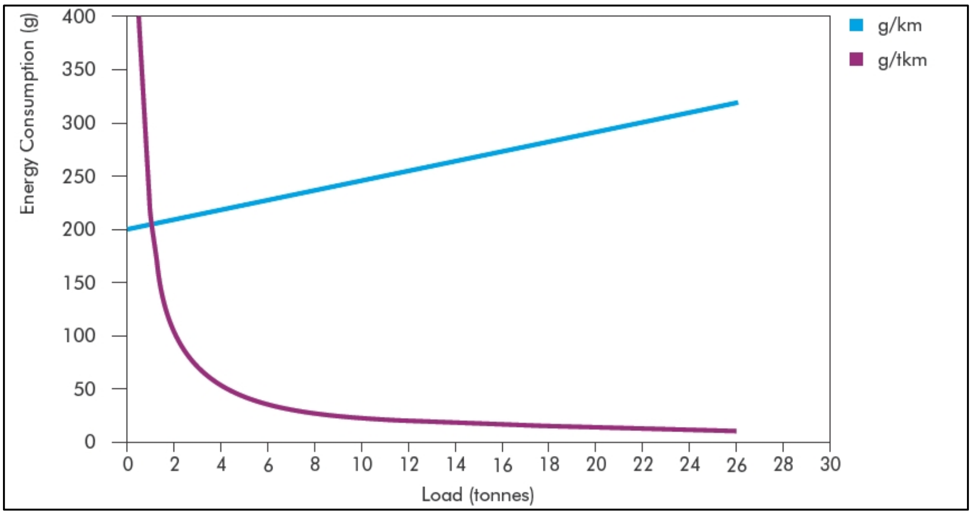


Figure C.4 Relationship between fuel efficiency/energy intensity and payload in a 40 ton, 5 axle truck (Source: IFEU, 2008)

On the other hand, a truck with a 10 ton load used almost 250 g of fuel per km, and this increases to 320 g per km for a truck with 25 ton load. If 20 ton was moved in two times of 10 ton each, the total energy requirement would be 500 g of fuel per time, which is almost double that needed by a large truck. Consequently, the increasing maximum truck weight can yield improvements per ton-kilometer, though these benefits decline for each extra ton of increase (IEA/OECD, 2009). The benefits of increasing maximum truck weight have been recommended in several studies as an effective way of increasing loading efficiency, and in this manner achieving reductions in cost, energy and emissions. McKinnon (2005) estimated that the increase in maximum truck weight in the UK from 41 to 44 tons has cut CO_2 by around 170,000 tons per year. Longer and heavier vehicles (e.g. 25.5 meters long and capable of operating gross weights of 50 tons), more frequently operated in Sweden, Finland

and the Netherlands, have seen significant reductions in emissions per ton-km.(Arcadis, 2006; Vierth et al., 2008; Backman and Nordstrom, 2002).

C.2 Driver Efficiency

As stated by Zanni and Bristow (2010), the improvement of the driving skills is the one of the most important factors that can be employed to reduce both fuel consumption and emissions. Driving style is the main influence on fuel consumption apart from the vehicle itself and starts with selection of the driver and continues through training, motivation and involvement (EEBPP, 2001). As it is documented in the literature, the efficient training of the freight vehicle drivers can achieve reduction in carbon emissions (McKinnon, 2007). It is estimated that well-designed fuel management program can decrease the fuel efficiency of road freight operations by 15% to 20% (Holman, 1996). The UK government initiated the Safe and Fuel Efficient Driving (SAFED) training program in 2003 and 12,000 truck drivers were trained between until 2008. Following the training, fuel consumption data showed that companies experienced an average 4-5% improvement with some companies noting upwards of 12% improvement in fuel consumption, as a consequence of the fuel efficient driving techniques, reduced waiting times and selection of the uncongested routes (Freight Best Practice, 2008). Similarly, a fuel monitoring programme resulted in 11.7% improvement in the period 1999-2005 in the UK (DfT, 2007b). In the US, it is estimated that average truck speed is within the range of 95 km/h to 105 km/h, and every 2 km/h, reduction in average speed gains fuel efficiency of 1% (Southwest Research Institute, 2008).

C.3 Route Efficiency

Improving driver skills should consider use of information and communication systems, such as optimized vehicle routing and vehicle communication, positioning and navigation. It is clear that road type and traffic conditions can influence fuel efficiency. Driving with frequent gear changes, accelerating and braking sharply increases the fuel consumption. A truck that would use 28 l/100 km at 50 km/h without stopping would use 52 l/100 km if it stops one per kilometer, and 84 l/100 km if it stops twice per kilometer (IEA/OECD, 2009). The Japanese Automotive Manufacturers Association (JAMA, 2008) published a result of a study on fuel consumption and carbon emissions with different speeds (see Figure C.5).

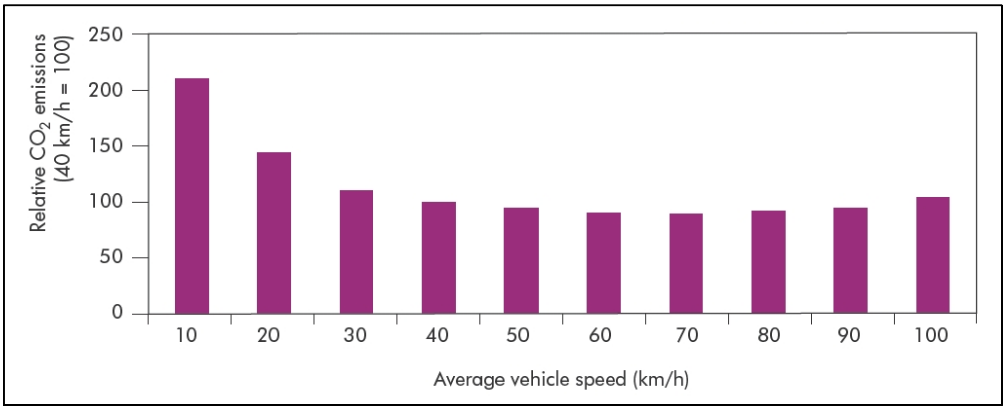


Figure C.5 CO_2 emissions at different average speeds (Source: JAMA, 2008)

It is seen that increasing rate of CO_2 emissions below an average speed of 40 km/h and above an average speed of 90km/h. Consequently, road freight operations can be avoided from congestion to minimize environmental effects. For instance, the share of road truck vehicle-km between 8 p.m. and 6 a.m. increased from 8.5% in 1985 to 19% in 2005 in the UK (Black et al., 1995 and DfT, 2006). Léonardi and Baumgartner (2004) argued that the implementation of information technology based scheduling systems with telematics application for data communication and positioning and navigation systems showed positive effects on the environmental impacts of freight transportation, by minimizing the distance travelled. It has been studied that computerized vehicle routing and scheduling techniques could reduce the distance travelled up to 10% (Eibl, 1996), though examples of 20% distance savings are quoted in the literature (Eibil et al., 1994; Ball and Bliss, 1993). Ando and Taniguchi (2005) mentioned cost reduction and carbon emission savings of 10% by the implementation of information and communication technologies. On the other hand, minimizing the distance travelled between origin and destination points do not need to minimize fuel consumption, as the shortest route may include hilly terrain, urban areas and the congested sections of the road network (McKinnon, 1999). In the literature, a few studies investigated the impacts of traffic restriction and regulations on emissions. Anderson et al. (2005) presented that vehicle weight access restrictions in urban areas generate increase in total distance travelled from 7 to 23% by freight vehicles and a consequent increase in tailpipe emissions up to 7%. Finnegan et al. (2007) and Hsing-Chung and Meyer (2009) studied implementation of dedicated freight routes on emissions in urban areas. Hsing-Chung and Meyer (2009) found that the CO_2 emissions can be decreased by 60% reducing congestion and improving truck flows. Similarly, Melo et al. (2007) concluded that the usage of bus lanes by freight vehicles may reduce carbon emissions up to 50% at non-peak time in the City of Porto in Portuguese.

C.4 Logistic Efficiency

Optimization of the logistic structure of the freight flows can reduce both cost and carbon emissions efficiently (Vilkelis, 2011). McKinnon (2007) presented a logistic framework to reduce CO_2 emissions from road freight transportation by incorporating all the factors that influence freight traffic activity and related energy consumption. It is also important that this framework illustrates the links between freight transportation and economic activity (see Figure C.6).

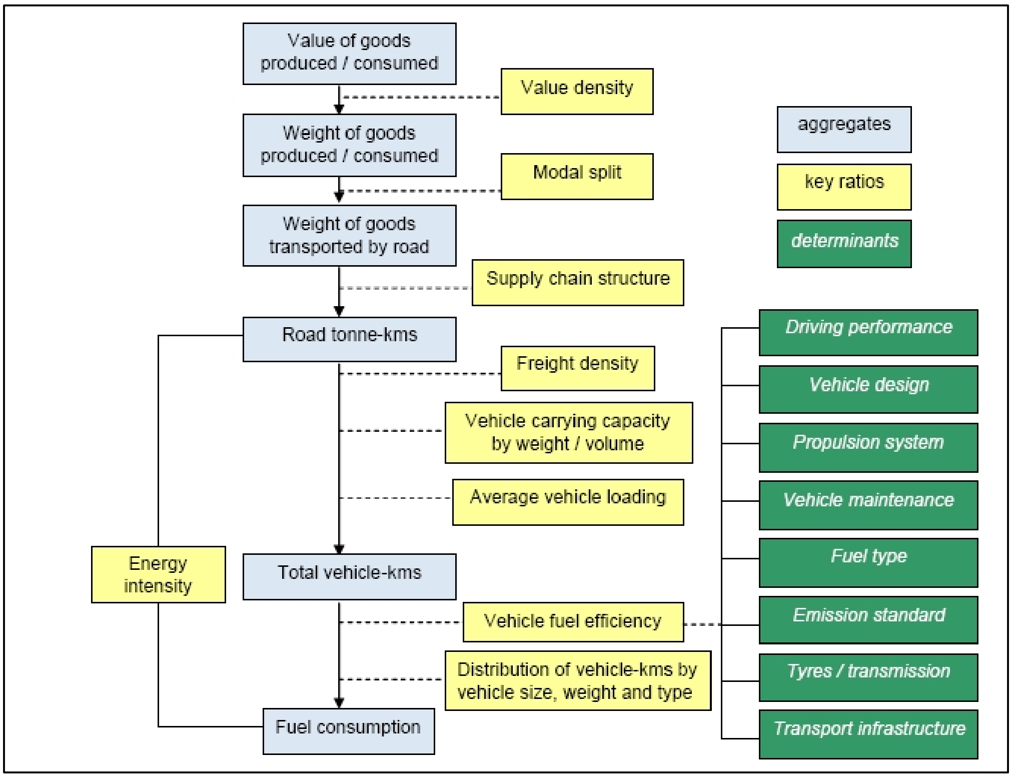


Figure C.6 Framework for analysing opportunities for CO_2 reduction (Source: McKinnon, 2008)

Liimatainen and Pöllänen (2010) developed a more detailed framework based on the framework developed by McKinnon (2007) which focuses only on road freight transport

(See Figure C.7). The energy efficiency of road freight transport, which is the energy consumption per ton-km, is also in the framework. However, important key variables remained almost same in these two frameworks, which can be defined as follows:

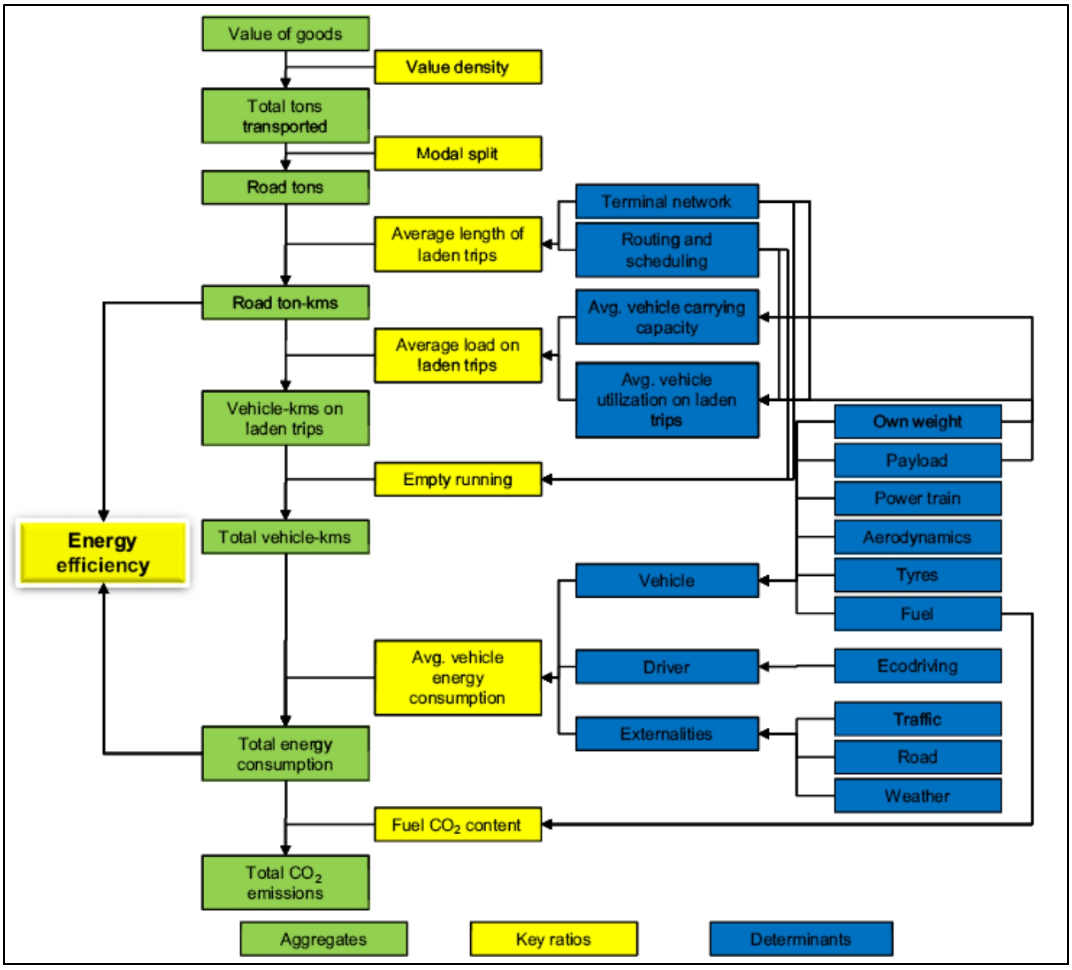


Figure C.7 Framework for analysing energy efficiency and CO_2 emissions in road freight transportation (Source: Liimatainen and Pöllänen, 2010)

- **Modal split**: Represents the proportion of tons or ton-km transported by different transport modes, e.g. road freight transportation share can be expressed as the tons/ton-km transported by road against the total tons/ton-km transported.
- **Handling factor**: It can be considered a crude measure of how many times goods are being handled as they move along the supply chains, i.e. number of links in the chain.

- **Average length of haul**: The mean length of each link in the supply chain. It can be estimated by dividing ton-km by tons lifted. The handling factor and average length of haul together determine the "transport intensity" of economy. This can be defined as the amount of freight movement generated for every ton of product produced or consumed.
- **Loading factor**: It is the ratio of the actual load carried by truck to the maximum that could be carried if it was loaded to the maximum carrying capacity.
- **Empty running:** The proportion of the total vehicle km runs empty.
- **Fuel efficiency:** It can be expressed by measuring distance travelled per unit of fuel consumed.
- **Carbon intensity of energy source:** It is the amount of carbon emitted per unit of fuel consumed.

As the measures to improve fuel efficiency of the freight transportation are discussed previously, the focus of this will be on the other key variables.

Modal split

The proportion of truck and rail transportation modes in freight varies greatly among countries. Even countries of similar sizes and levels of economic development can have different market shares (see Figure C.8).

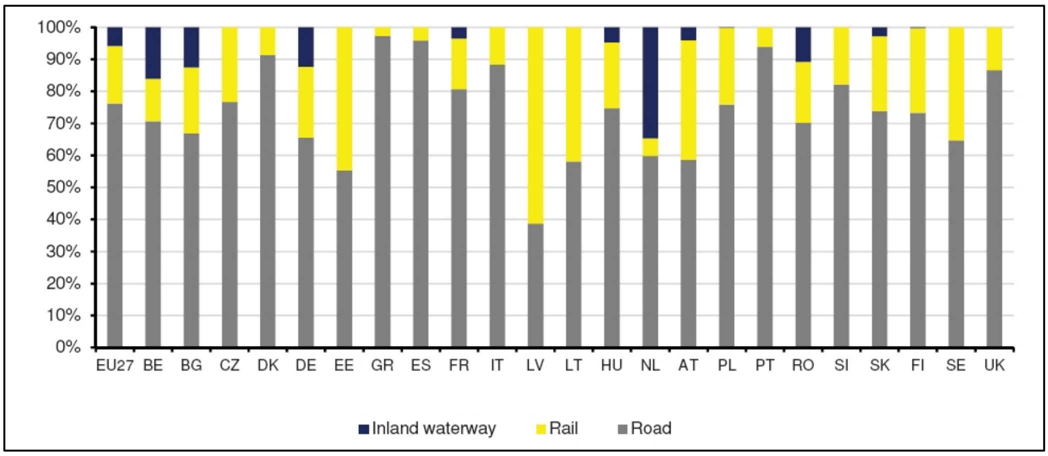
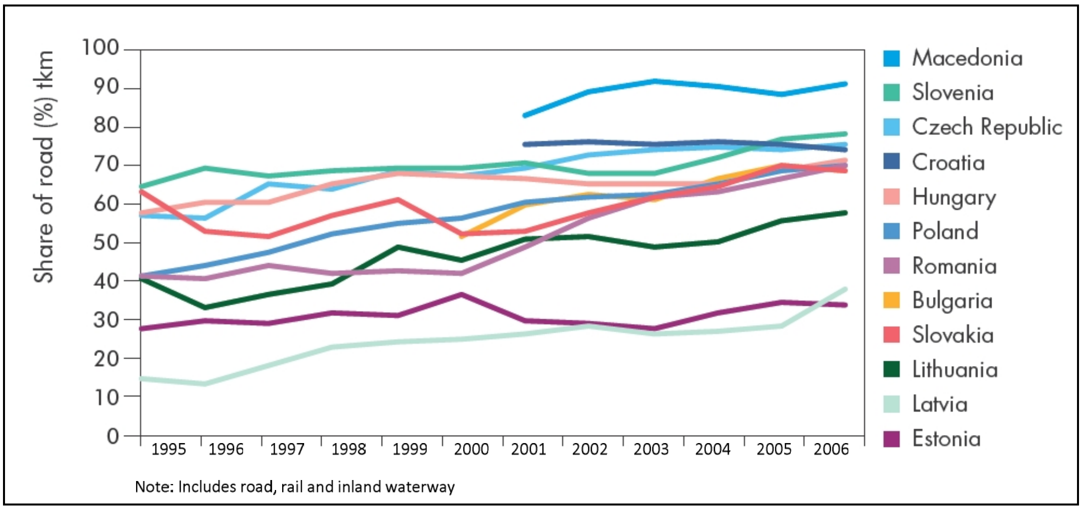


Figure C.8 Modal split of freight transport in EU countries in 2008 (Source: Eurostat, 2011)

The variations in the modal share of freight transportation reflects differences in industrial structure, the geographic distribution of population and economic activity, and the quality and capacity of relevant infrastructure, etc. Trucking is increasing in the worldwide surface freight market at different rates in different countries (see Figure C.9). The trend to shift road freight can be explained mainly by the following attributes (IEA/OECD, 2009):

- More investment in road infrastructure than rail infrastructure in many countries.
- Increases in the maximum allowed size and weight of the trucks.
- The liberalization of the road freight markets and removal of the regularity protections afforded to rail.
- Changes in the industrial supply chain structure, such as the shift from primary production to manufacturing in many developed countries, therefore, rail captures the smaller share of the manufactures goods.
- The increasing demands towards flexible and just-in-time manufacturing. Inflexible and slow speed trains services are not capable of that demand.



Note: Includes road, rail and inland waterway

Figure C.9 Road share of inland freight transportation in Central/Eastern Europe, 1995-2006 (Source: IEA/OECD, 2009)

Several organizations publish datasets introducing environmental impacts of freight transportation modes based on kilometers travelled, ton-km of commodities moved, quantity of energy consumed (e.g. INFRAS, 2004; IFEU, 2008; TREMOVE, 2008). However, the datasets vary greatly, even if calibrated in the same units. Nevertheless, they give a general sense of the importance of the air pollution produced by trucks. They also give a good sense of the relative environmental impacts of truck and rail (OECD, 1997). Table C.1 summarizes energy consumption and emission estimates for most of the atmospheric pollutants. It is clear that there is a wide variation in the levels of atmospheric emissions per ton-km. The average CO_2 emission factors from freight transport by road are about three times higher than from transport by rail and waterborne. Therefore, shifting freight transportation from road to rail, waterborne provides significant opportunities to reduce level of CO_2 emissions in many countries (Eom et al., 2012; Cullinane and Edwards, 2010; Vanek and Morlok, 2000). Nealer et al. (2012) estimated that shifting of all truck to rail enables up to 5% decrease in total emission in the US. McKinnon (2000) showed that 4% reduction in truck empty running would have significantly higher savings in energy consumption than the doubling of rail freight traffic. On the other hand, Speilmann (2005) questioned this view and argued that no mode of transportation can be considered the most environmental friendly.

Table C.1 Average emission factors from freight transport modes in the EU (Source: IFEU, 2008)

Mode	Type	EC* (kj/tkm)	CO_2 (g/tkm)	NO_X (mg/tkm)	SO_2 (mg/tkm)	NMHC (mg/tkm)	PM (mg/tkm)
Aircraft	—	9,876	656	3,253	864	389	46
Truck (34-40t)	Euro I	1,086	72	683	—	75	21
	Euro II	1,044	69	755	—	55	10
	Euro III	1,082	72	553	90	54	12
	Euro IV	1,050	70	353	—	59	2
	Euro V	996	66	205	—	58	2
Train	Diesel	530	35	549	44	62	17
	Electric	456	18	32	64	4	4.6
Waterborne	Upstream	727	49	839	82	84	26
	Downstream	438	29	506	49	51	16

* EC= Energy consumption, NMHC= Non-methane hydrocarbons.

OECD/IEA (2008) published energy intensities of the freight transportation modes among 18 IEA countries (see Figure C.10). Though energy intensities of truck, rail and ship vary significantly, truck transportation is the most energy intensive mode. On average, trucks are 2 to 17 times more energy intensive than rail per ton-km. The variation energy intensive of freight transportation can be explained by the size and geography of the country, the type of freight load, haulage, fuel prices and type, the vehicle size and utilization of vehicle capacity (Eom et al., 2012). For instance, in regions where electrified rail is used and electricity generation produces less greenhouse emissions such as in the EU, rail freight can offer significant emission reductions over trucking (IEA/OECD, 2009).

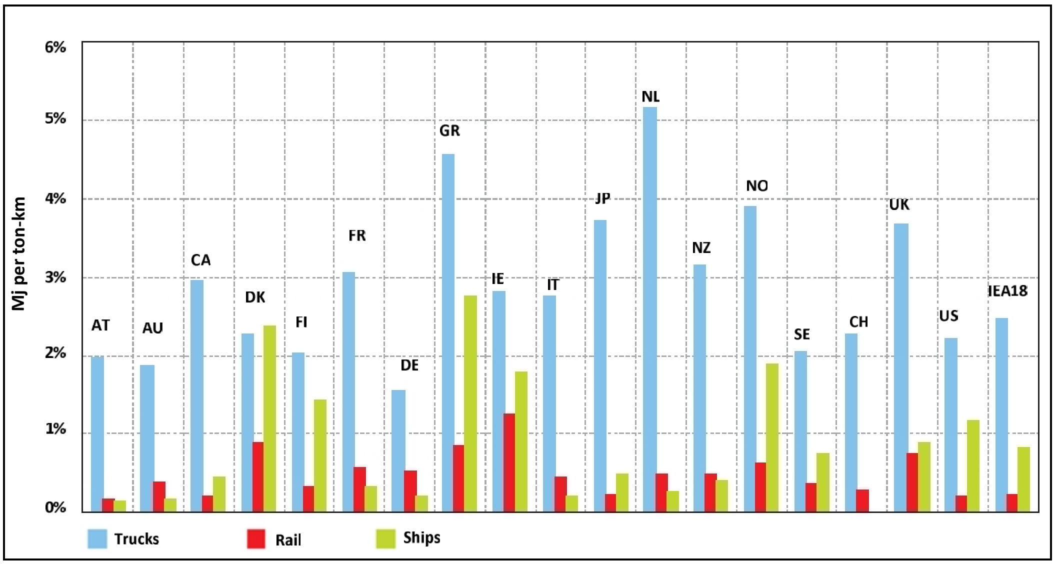


Figure C.10 Freight transportation energy consumption per ton-km by mode in 2005 (Source: OECD/IEA, 2008)

The modal shift from road to rail can be realized by increasing the share of intermodal freight transportation (Piecyk, 2010b). Intermodal freight transportation is defined as “the movement of goods in one and the same loading unit (e.g. a container) or vehicle which uses successively several modes of transport without handling the goods while changing modes” (OECD, 2002). On the other hand, according to Van Klink and Van den Berg (1998), intermodal can be competitive only if high volumes are transported over the long distances. In general, intermodal transportation is said to have become attractive at a distance of at least 500 km. Buhler and Jochem (2008) empirically tested impact of the increase of road truck user charge and acceleration of speed of rail services to 80 km/h on modal shift from road transport to intermodal transportation (rail-truck-rail) and associated CO_2 emissions in Germany. The results showed that CO_2 emissions would decline by 1% to 4% by changing mode choice. The authors claimed that the weak impact of mode choice on CO_2 emissions were due to one, inelasticity of mode choice to changes in service quality and prices and two, longer trip distances required to perform intermodal transportation cause loss of some of its advantage of being environmentally efficiently expressed in CO_2 emissions per tom-km. A literature review on the freight transportation mode choice showed that environmental and energy issues are not sufficiently studied in the freight transportation mode choice studies (Meixell and Norbis, 2008).

Handling factor

Handling factor is the ratio of tons lifted statistics to the weight of products consumed or exported (McKinnon, 1989). Cool (1997) defines handling factor as the frequency of lifts of the tonnes moved along the supply chain. It is possible to reduce CO_2 emissions by reducing the number of spate journeys from origin and final destination of the freight movements, (e.g., reduction in the number of links and nodes). This involves elimination of the intermediate locations for processing, storage and handling and achieves higher degree of vertical integration between production and consumption sites. Conversely, some nodes are used as Urban Consolidation Centers where goods are collected and assembled into larger loads for more efficient delivery. Urban Distribution Centers, Construction Consolidation Center and Vehicles Reception Points are the most common applications of Urban Consolidation Centers. Urban Consolidation Centers are normally publicly owned logistic infrastructures in which deliveries to both home and business are consolidated (Zanni and Bristow, 2010). Urban Distribution Centers operating in France led significant traffic, noise and emission reductions (Patier, 2005). Construction Consolidation Centers have been widely used recently to minimize freight traffic and CO_2 emissions (Browne et al., 2005b). Vehicles Reception Points have been used to reduce emissions from freight sector. These locations generally serve a specific area of town or city center where drivers are assisted for parking and unloading, and deliveries are transported to final destination by using handling equipment. Small retail organizations and shops are generally using Vehicle Reception Points, for which deliveries are smaller and can be transported with smaller equipment (Zanni and Bristow, 2010). These centers are used in various cities in France and achieved up to 80% reduction of CO_2 emissions (Patier, 2005).

Loading factor

Improving truck utilization by encouraging higher payload weights could provide important reductions in emissions (Taniguchi and van der Haiden, 2000). Baumgartner et al. (2008) argued that in addition to minimizing the travelled distance, computerized routing scheduling and vehicle telematics offer a great potential to improve average vehicle loading and, therefore, environmental performance of freight transportation. European Union official freight statistics indicated that average loading factor has been increasing. The average truck payload weight varies from 7 ton to 16 ton in the European Union, with an overall average of 10 ton (see Figure C.11). This wide variation may reflect differences in the industrial structure, vehicle size and weight regulations, and the nature and level of transport outscoring, etc.

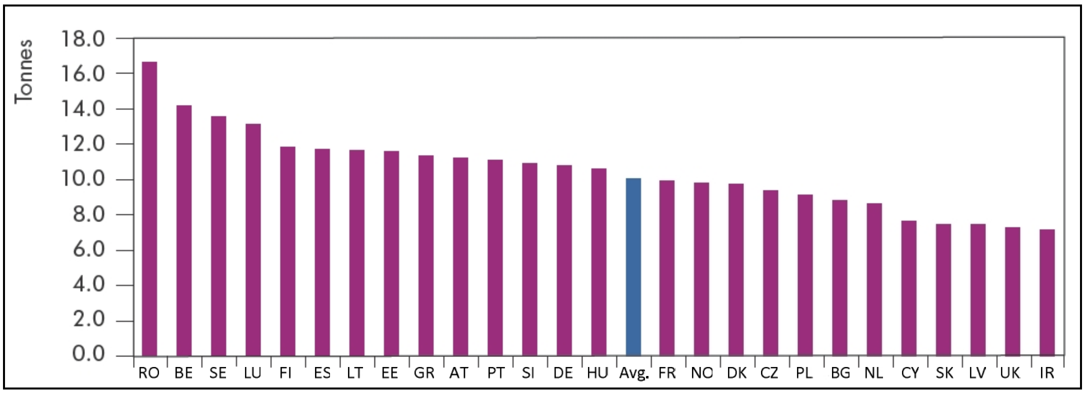


Figure C.11 Trend in the average payload weight on laden trips in Europe in 2006 (Source: IEA/OECD, 2009)

Average payload increased in14 of the 26 member countries, for which historical data is available, by 5% between 2004 and 2007. The recent survey performed in UK revealed that truck payload would increase by 10% by 2020 (IEA/OECD, 2009). This trend lead reduction in empty movements and caused slower growth rate for vehicle-km statistics than ton-km statistics (McKinnon, 1999). Loading factor can be improved by more efficient choice of loading methods, the modification of the size of pallets, the utilization of the vehicle inner height, the utilization of modular loads, and changes in the shape of packaging (Zanni and Bristow, 2010).

McKinnon (2006) presented that the following factors influence levels of vehicle loading:

- **Demand fluctuations** – when a company faces variable demand, the vehicles developed with sufficient capacity to accommodate peak orders will unavoidably be running with excess capacity during low-season periods.
- **Just-in-time (JIT) delivery** – companies sometimes prefer to sacrifice transport efficiency to achieve other productivity benefits.
- **Unreliability of delivery schedules** – if schedules are unreliable, backloading and high degrees of load consolidation might be difficult to achieve.
- **Vehicle size and weight restrictions** – load factor is a weight based measure and may underestimate actual vehicle utilization of the vehicles in many sectors, such as food, non-food retailing, parcels and automotive because of the low density of goods transported. Conversely, some high density loads reach the maximum weight limit before all the space in the vehicle is occupied (IEA/OECD, 2009 and McKinnon, 2009). McKinnon (2005) estimated that the increase in maximum truck weight in the UK from 41 to 44 tons has cut CO_2 by around 170,000 tons per year. The study in Australia showed that higher load factors for freight vehicles achieved 17% reduction in CO_2 emissions (DTRS, 2004). Longer and heavier vehicles (e.g. 25.5 meters long and capable of operating gross weights of 50 tons) more frequently operate in Sweden, Finland and the Netherlands where significant reductions in emissions per ton-km have been shown (Arcadis, 2006; Vierth et al., 2008).
- **Health and safety regulations** – may also constrain weight and dimensions of loads.
- **Capacity constraints at company premises** – limited storage capacity at either end points of a truck trip might restrict the vehicle capacity utilization.

Empty running and Average length of haul

As the highway most dominant mode of freight transportation for most of the countries, the efficiency of road freight transportation is the major determinant of the environmental impacts of freight transportation. According to McKinnon and Ge (2006), the fundamental difference between freight and passenger transportation is that, people generally return to their origin point of survey, however freight movements are mostly performed from point of production to point of consumption, in one direction. It is clear that it is important to minimize the distances transported in order to maximize efficiency of freight transportation. Roughly, one quarter of the truck emissions out of 1.62 billion tons of truck emission in Europe are caused by empty running trucks (Vilkelis, 2011). McKinnon and Edwards (2010) classified reasons for inefficient loaded freight movements as follows (see Figure C.12):

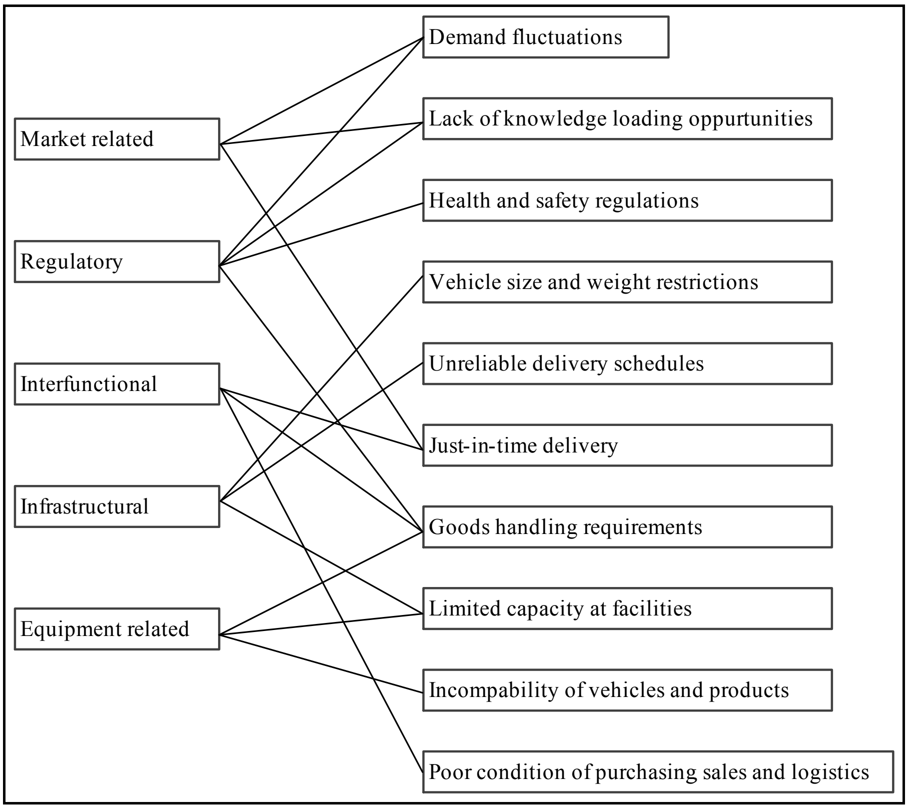


Figure C.12 Five-fold classification of the constrains on vehicle utilization (Source: McKinnon and Edwards, 2010)

- Market related constraints associated with the spatial pattern of trade and fluctuations on the volume of freight flow.
- Regularity constrains governing the size and weight of vehicles, the timing of deliverables, and health and safety aspects of vehicle loading and unloading.
- Inter-functional constrains imposed on transport management by other departments within the business.
- Infrastructure constrains related to physical capacity of transportation networks and storage capacity at both ends of a freight movements.
- Equipment related constraints resulting from the incompatibility of vehicles, handling equipment and loads

Piecyk (2010b) argued that, even though, backloading is a key point to improve the overall vehicle utilization and minimization of the empty vehicle-km, there is still a significant proportion of vehicle-km returning base empty. A survey conducted by Davies et al. (2007) over 46 companies in the UK showed that, 4.4% of respondents did not backload their vehicles, 20.9% of the respondents sometimes backload and 74.4% always tried to backload their vehicles. The reasons for not backloading vehicles include:

- High base demand
- Too few available backhaul rates
- Limited trust to unknown companies
- Available loads take too long to load and deliver
- Short backload distances (the distance where specified is from 125 km to 200 km)
- No time to search for backloads
- No loads available

Similarly, a study by McKinnon (1996) based on interview of 73 manufactures and 23 retailers identified the following factors influencing backloading:

- Requirements of the outbound delivery service
- Internal management structure
- Incompatibility of vehicles and products
- Need to recover handling equipment/ packaging
- Unreliability of backloading operation
- Inadequate transport capacity
- Poor matching of locations and schedules
- Limitations of the route scheduling system

Empty movements are likely to decrease over to time for several reasons, including the development of load matching agencies and online freight exchanges, backloading initiatives by retailers and manufacturers, strengthening flow of products going back along the supply chain for recycling and remanufacture and increase in the average length of haul (IEA, 2009; McKinnon and Ge, 2006). Similarly, IEA/OECD (2009) argued that it is more likely to find financial incentive for backloading in longer hauls. Therefore, the level of empty running tends to be lower in larger countries. In the UK, truck companies had an average length of around 100 km and on average an empty run of 27% of their kilometers (DfT, 2009).

Conversely, J. B. Hunt, as one of the largest carriers in the US, had an average hauling distance of 832 km and an average empty running of only 12% (IEA/OECD, 2009). The proportion of empty truck kilometres in the EU ranges from 15% to 35% depending on the country with an average of around 25% (see Figure C.13). Piecyk and McKinnon (2009) showed that empty running is declining in most of the European countries over time. The average level of empty running in the 18 European countries decreased from 27.6% in 2004 to 27.1% in 2007. On the other hand, empty running may vary greatly across different sectors in the economy. Léonardi and Baumgartner (2004) found that 48% of the truck kilometres run empty in the container transportation business compared to 17% overall average of 50 companies included in the sample in Germany. Another study conducted by Liimatainen and Pöllänen (2011) showed that 20% of the road freight movements run empty in food sector compared to more than 35% in the construction sector in Finland in 2009.

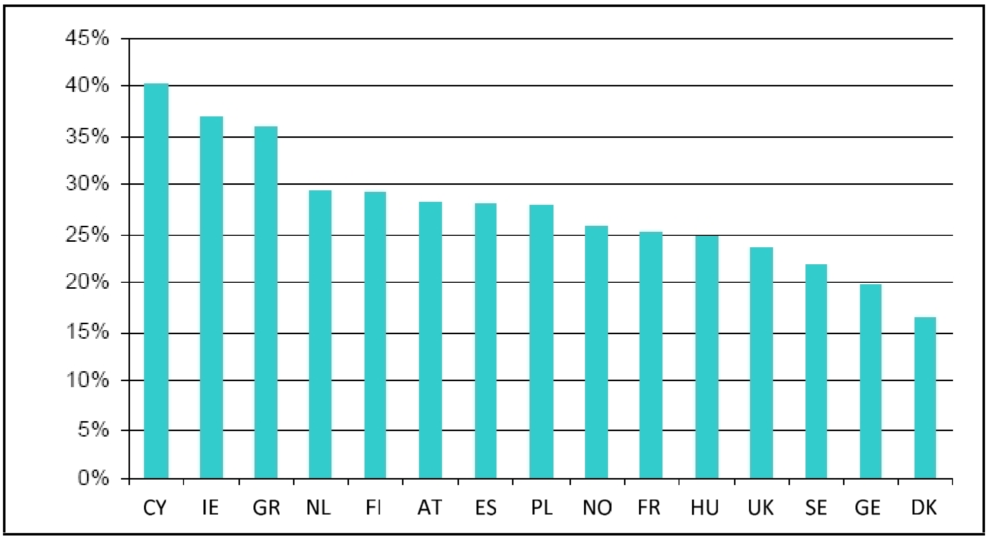


Figure C.13 International variations and trends in truck empty running (Source: Piecyk and McKinnon, 2009)

Carbon intensity of energy source

One of the solutions to reduce CO_2 emissions from road transportation is to shift less carbon intensive fuels. These fuels are generally considered as alternative fuels, e.g. biofuels, natural gas, electricity or hydrogen. Compressed Natural Gas (CNG) powered vehicles achieved reductions in CO_2 emissions (DfT, 2007c). McKinnon (2008) argued that the use of biodiesel has been promoted in freight transportation by means of environmental effects. Piecyk

(2010b) stated that CO_2 emission reduction by biodiesel can only be assessed through life cycle analysis. Some researchers have estimated life cycle savings of greenhouse gas emissions of around 52%-53% from the substitution of biodiesel for conventional low sulphur diesel (Mortimer et al. 2002, Concawe et al. 2006). On the other hand, a report prepared by Department by Transport (DfT, 2007d) suggested that there is a 10% increase in exhaust CO_2 emissions due to biodiesel.

Table C.2 summarized literature review of the other studies exploring the potential of emission reduction policies (Zanni and Bristow, 2010).

Table C.2 Summary of road freight emission reduction literature (Source: Zanni and Bristow, 2010)

Implementation of Consolidation Centers (CC) - Distribution Centers (DC)	
(TfL, 2007) London, UK	A CC generated 75% decrease in CO_2 emissions, a reduction in the number of construction vehicles entering the City of London of 68%.
(Song et al., 2009) West Sussex, UK	The usage of Collection/Delivery Points could achieve savings in CO_2 from home delivery operations of up to 40%.
Cooperative and Collaborative Freight Transportation Systems	
(Taniguchi and van der Heiden, 2000) Kobe, Japan	These cooperative solutions were simulated to be likely to achieve up to 51.8% reduction in CO_2 emissions from urban collection and delivery operation when the demand for freight services was doubled.
(Melo and Costa, 2007) Porto, Portugal	For lorries, collaborative system resulted, in 11% reduction in traffic It generated a 3% increase in average speed and a 13% reduction in CO_2 emissions.
Automatic Vehicle Location Systems (AVLS)	
(DfT, 2007c) Birmingham, UK	Optimised vehicle routing generated a saving of 360 journeys per year from 2002 for a total annual saving of 24,000 miles.
(Taniguchi and van der Heiden, 2000) Kobe, Japan	Advance routing and scheduling systems generated a reduction of 8.3% in CO_2 emissions.
(DfT, 2007e) Marshalls, UK	The use of AVLS and GRPS, and an improved fuel management generated an annual reduction 4000 journeys, 330,000 Vehicle/km, 515 tonnes of CO_2.
Congestion Charging Scheme (CCS) and Low Emission Zones (LEZ)	
(TfL, 2008) London, UK	The London CCS generated between 2002 and 2007 a 13% reduction of van traffic within the charging zone. In the case of lorries, the reduction was 5%.
(Buhler and Jochem, 2009) Germany	A study on the impact of road user charging on freight modal choice quantified in 1% the reduction of CO_2 emissions from freight vehicles on German motorways.
(Browne et al., 2005c) London, UK	Negligible effects on traffic as freight companies' are not likely to change their operational routes because of the scheme.

APPENDIX D

SUPPLEMENTARY INFORMATION FOR FREIGHT TRANSPORTATION

D.1 Introduction

Figure D.1 presents highway freight transportation share in European Union (EU) countries in 2010. It is seen that highways are also one of the predominant modes in most of the countries. The share of highway freight transportation in EU-27 was 76.4% in 2010. The share of railway was 17.1%. Inland water captured only 6.5% of the freight transportation volume in EU-27 countries.

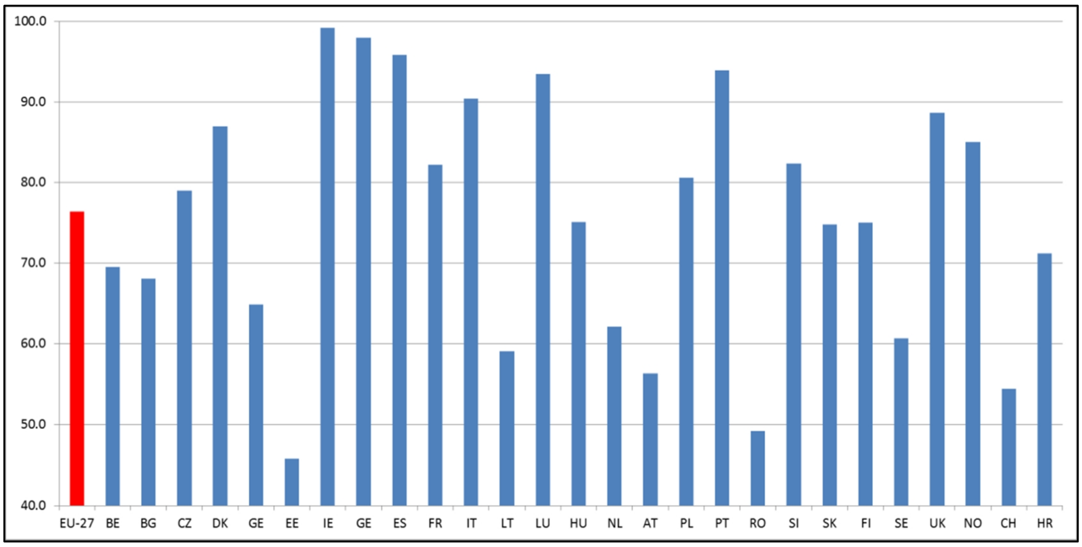


Figure D.1 Road freight transportation shares in the EU countries in 2010 (EC, 2010)

Table D.1 presents a qualitative rating of the modes for major industry groups based on national averages in the US. Road transportation is the most important transportation option in almost all of the sectors (OTPA, 2004). There hasn’t been any study to show the economic values of the goods on different freight modes in Turkey. The study conducted in France showed that although road freight accounted for 74.5% of the freight transportation demand for the period 1990-1995, but it accounted for 95.0% in terms of added value of transported goods (Quinet and Vickerman, 2004).

Table D.1 Average national modal intensity ratings for major industry groups in the US (Source: OTPA, 2004)

Sectors	Airway	Maritime	Railway	Highways
Agriculture/Forestry	C	B	B	A
Manufacturing	C	A	A	A
Distribution	B	B	A	A
High-Tech	A	B	C	A
Construction	C	B	C	A
Health Care	B	C	C	B
Tourism	A	A	B	A
Military	A	B	B	A

* Less Important **C** → **B** → **A** More Important

D.2 Road Freight Transportation in Turkey

Table D.2 presents number of vehicles in national vehicle fleet in 2009. The number of all registered vehicles was 14,316,700 in 2009. The share of different vehicle types in national vehicle fleet were automobile (49.6%), motorcycle (16.1%), agricultural tractor (9.6%), medium commercial vehicle (MCV) (15.4%), truck (5.1%), minibus (2.7%), bus (1.4%) and the others (2.3%). The number of registered trucks was 727,302 in 2009. Istanbul (17.7%), Ankara (8.3%), Izmir (4.9%) and Konya (4.5%) were the main cities in terms of number of registered trucks (TGDH, 2011).

Table D.2 Number of registered vehicles in national vehicle fleet (Source: TGDH, 2011)

Year	Total	Automobile	Tractor	Truck (1)	Minibus	Bus	Others(2)
1985	2,391,357	983,444	502,590	205,496	87,951	47,119	564,757
1986	2,641,353	1,087,234	565,945	217,111	97,917	50,798	622,348
1987	2,887,287	1,193,021	628,787	225,872	106,314	53,554	679,739
1988	3,140,265	1,310,257	683,577	234,166	112,885	56,172	743,208
1989	3,388,259	1,434,830	728,481	241,392	118,026	58,859	806,671
1990	3,750,678	1,649,879	769,456	257,353	125,399	63,700	884,891
1991	4,101,975	1,864,344	794,651	273,409	133,632	68,973	966,966
1992	4,584,717	2,181,388	828,580	287,160	145,312	75,592	1,066,685
1993	5,250,622	2,619,852	870,559	305,511	159,900	84,254	1,210,546
1994	5,606,712	2,861,640	895,506	313,771	166,424	87,545	1,281,826
1995	5,922,859	3,058,511	937,528	321,421	173,051	90,197	1,342,151
1996	6,305,707	3,274,156	988,142	333,269	182,694	94,978	1,432,468
1997	6,863,462	3,570,105	1,053,381	353,586	197,057	101,896	1,587,437
1998	7,371,541	3,838,288	1,107,457	371,163	211,495	108,361	1,734,777
1999	7,758,511	4,072,326	1,131,626	378,967	221,683	112,186	1,841,723
2000	8,320,449	4,422,180	1,159,070	394,283	235,885	118,454	1,990,577
2001	8,521,956	4,534,803	1,179,068	396,493	239,381	119,306	2,052,905
2002	8,655,170	4,600,140	1,180,127	399,025	241,700	120,097	2,114,081
2003	8,903,843	4,700,343	1,184,256	405,034	245,394	123,500	2,245,316
2004	10,236,357	5,400,440	1,210,283	647,420	318,954	152,712	2,506,548
2005	11,145,826	5,772,745	1,247,767	676,929	338,539	163,390	2,946,456
2006	12,227,393	6,140,992	1,290,679	709,535	357,523	175,949	3,552,715
2007	13,022,945	6,472,156	1,327,334	729,202	372,601	189,128	3,932,524
2008	13,765,395	6,796,629	1,358,577	744,217	383,548	199,934	4,282,490
2009	14,316,700	7,093,964	1,368,032	727,302	384,053	201,033	4,542,316

(1) Includes all heavy duty vehicles, (2) Includes Motorcycles, Medium Commercial Vehicles, Private Purpose Vehicles, and Earth Movers

Figure D.2 displays the trends in the number of registered vehicles in the national vehicle fleet. In 2004, number of trucks in national vehicle fleet increased almost 60% from 405,034 to 647,402. Similarly, share of trucks in national vehicle fleet increased from 4.5% to 6.3%. Then, it started to continuously decrease due to increase of other vehicles in national vehicle fleet. In 2009, trucks represent 5.1% of the vehicles in national vehicle fleet.

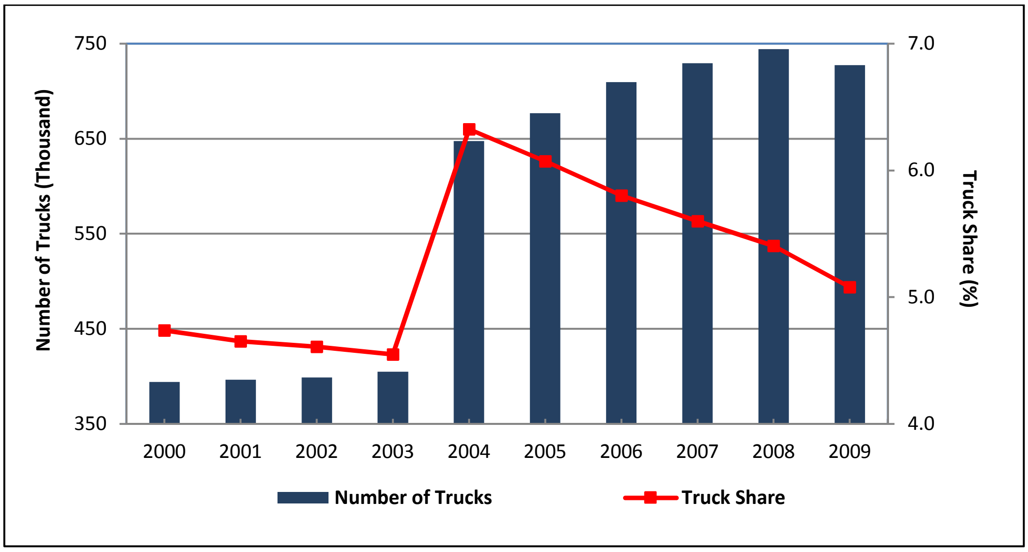


Figure D.2 Trends in number of trucks in Turkey (Source: TGDH, 2011)

D.3 Economic Activity and Road Freight Transportation

There is a close link between economic growth (typically measured as Gross Domestic Product (GDP)) and freight transportation growth (Banister and Stead, 2002; Tapio, 2005). GDP is the measure of the total value of the final output of goods and services produced in the economy in a specific period and it is a sum of consumption, investment, government purchases and net exports. Freight transportation volume is generally expressed in terms of ton-km which takes into account both weight of the moved goods and distance over which they are transported. A study of a sample of thirty-three countries at different development conditions undertaken by World Bank found that differences in GDP explained 89% of the variation in road freight ton-km demand. Therefore, trade and freight transportation are inseparable concepts that complement each other. Efficient transportation systems accelerate economic development creating economic and social opportunities. On the other hand, the lack of effective and efficient transportation system leads to non-economic movements and lost opportunities (TGDH, 2011). Besides, movement of freight is also important in terms of regional development strategies (Celik, 2001). Figure D.3 illustrates how investments in transportation infrastructure can lead to growth in the national economy. Investments that reduce the cost of transportation by improvements in reliability, transit times, and service levels can also help increase and sustain economic growth. The efficiency and reliability of the freight transportation system affects economic productivity, and it is the most important determinant of economic performance (ICF and HLB, 2002).

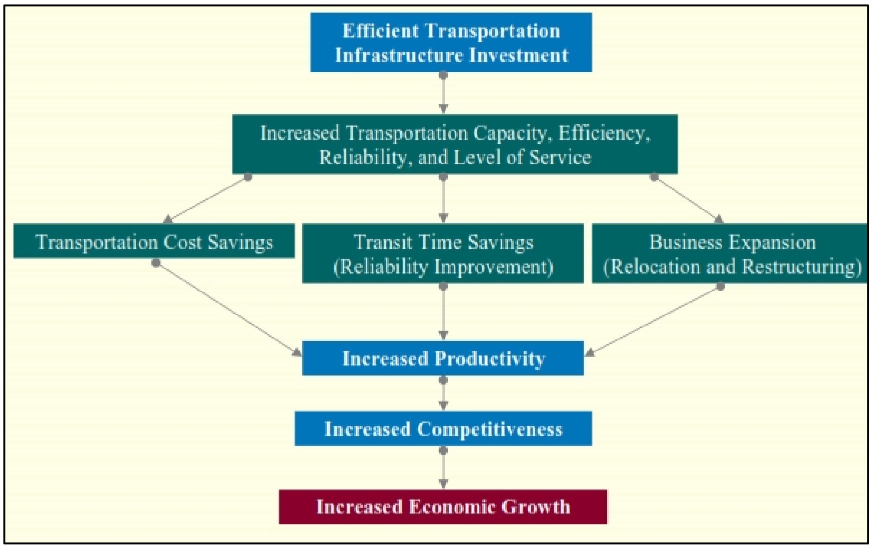


Figure D.3 Transportation and economy (Source: ICF and HLB, 2002)

Figure D.4 shows the relationship between GDP and road freight movements in the period of 2000-2011 in Turkey. As it is seen, road freight transportation sector closely mirrors economic conditions in Turkey. During the national recession period in 2001 and global financial crisis in 2008, the freight transportation activity decreased. Freight transport intensity is a measure that the volume of freight transport (measured in ton-km) and the economic output (GDP). Peake (1994) defined transport intensity to evaluate how efficiently transport is used in production and consumption, i.e. what volume of transport is required per unit of economic output (ton-km/GDP). Road freight transport intensity dropped from 0.61 ton-km per dollar of GDP in 2000 to 0.26 ton-km per dollar of GDP in 2011. According to the OECD (2006), this kind of relationship is expressed as relative (weak) decoupling where the transport rate is positive but less than the GDP growth rate. A number of studies have investigated the degree of decoupling of GDP and transport growth in Europe (Tapio, 2005; Leonardi et al., 2006; Verny, 2007) and in the US (Banister and Stead, 2002). According to Banister and Stead (2002), there are significant signs of decoupling in the US, while road freight traffic is continuing to grow at much faster rate than GDP in the EU (McKinnon, 2007).

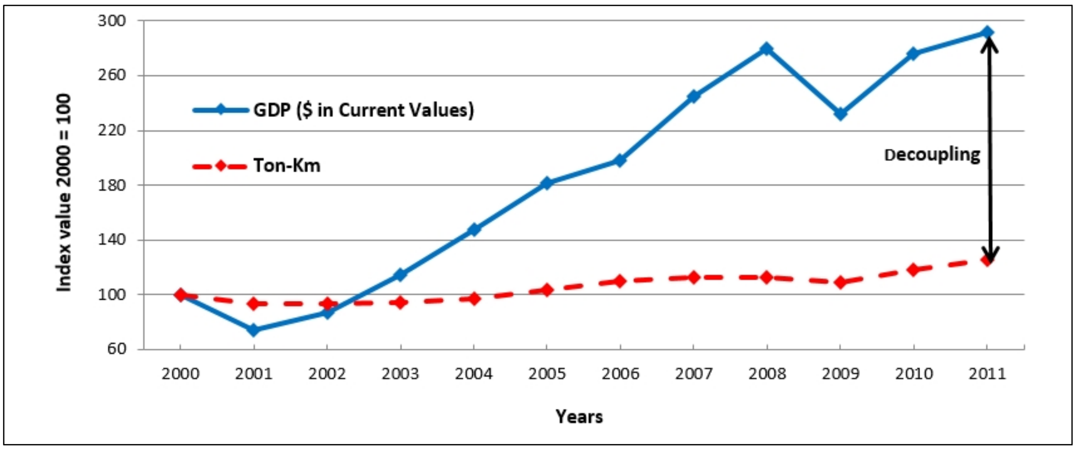


Figure D.4 Decoupling of economic growth and road freight transportation (Source: TGDH, 2011)

Tapio (2005) presented a more comprehensive framework to explain different aspects of decoupling. According to Tapio (2005), the growth of GDP and transportation volume can be coupled, decoupled or negatively decoupled (see Figure D.5). Elasticity values (i.e. the percentage change in the transportation volumes divided by the percentage change in GDP) of 0.8-1.2 are accepted as coupling. Decoupling is divided into three subcategories: a) weak decoupling: GDP and transport volume increases where 0<elasticity<0.8; b) strong decoupling: GDP grows and transportation volume decreases where elasticity<0; and c) recessive decoupling: GDP and transport volume decrease where elasticity >1.2. Similarly, negative decoupling include three subcategories: a) expansive negative decoupling: GDP and transportation volume increases where elasticity >1.2; b) strong negative decoupling: GDP decreases and traffic volume increases where elasticity <0; and c) weak negative decoupling: GDP and transportation volume decrease where 0<elasticity<0.8.

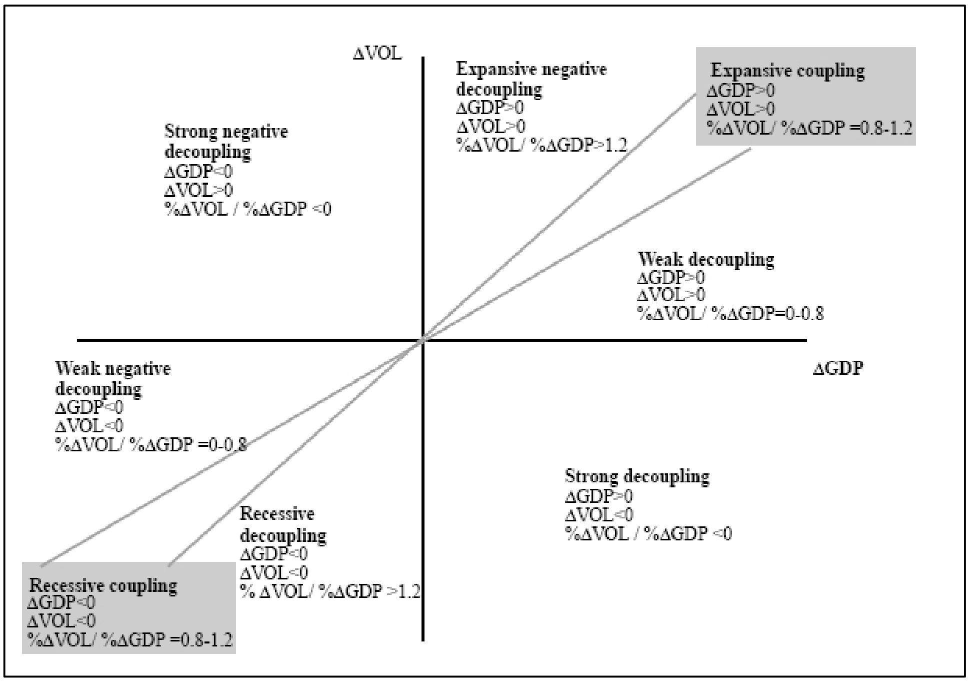


Figure D.5 The degrees of coupling and decoupling of GDP and transportation growth (Source: Tapio, 2005)

D.4 Road Freight Data Collection in Turkey

TGDH is the responsible authority to collect freight traffic data on intercity roads. On the other hand, local authorities are responsible to collect data on provincial roads. However, there are some by passes and peripheral roads on which TGDH is responsible to collect traffic data. TGDH regularly performs “short duration counts,” “continuous counts” and “axle load surveys” to observe variations in traffic counts (e.g. time of day, day of week, seasonal, monthly and directional), trucks loads and freight types on arterial roads. In the following sections, brief information about each type of the survey is given (Unal, 2009).

D.4.1 Short Duration Counts

These counts are collected on specific road segments to ensure the validity of truck counts on arterial and major collector roads and give segment specific count information. Short duration counts are realized over a 7-day period by mobile pneumatic tubes. Short duration counts do not account for temporal variations in traffic flow, such as seasonal variations. In addition, these counts need to be factored to adjust overall traffic data, to estimate the annual traffic data. On average, 1,000 locations are covered each year with a cycle period of three years.

D.4.2 Continuous Counts

Continuous data is collected to understand temporal changes in traffic volume based on 5 or 15 minutes time intervals, 24 hours a day, all year round. They also provide the controls for adjusting short term counts to average daily traffic. TGDH realizes continuous counts by inductive loop devices. The data collected by the inductive loop devices is periodically sent to central system to calculate the various statistics such as AADTT (Annual Average Daily Truck Traffic), AAWDRTT (Annual Average Weekday Truck Traffic) and seasonal adjustment factors. The data collected by continuous traffic counts and classification points will be presented at different levels in the remaining part of this section. Figure D.6 to Figure D.8 presents hourly distribution of truck and all traffic collected by continuous count devices between 2007 and 2009. Trucks and total traffic showed almost similar hourly behavior. Volumes increased in day hours until peak value at 4-6 pm and then, started to decrease least daily volumes until 3-5 am (TGDH, 2001).

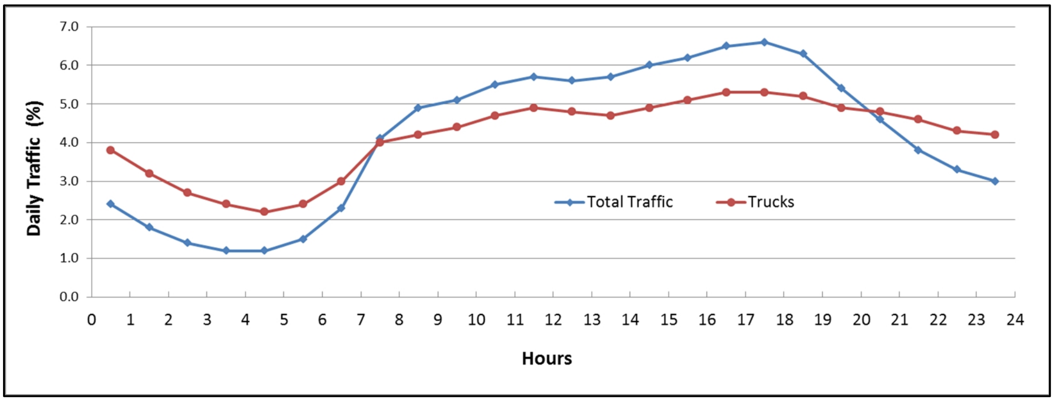


Figure D.6 Hourly traffic volumes in 2007 (Source: TGDH, 2011)

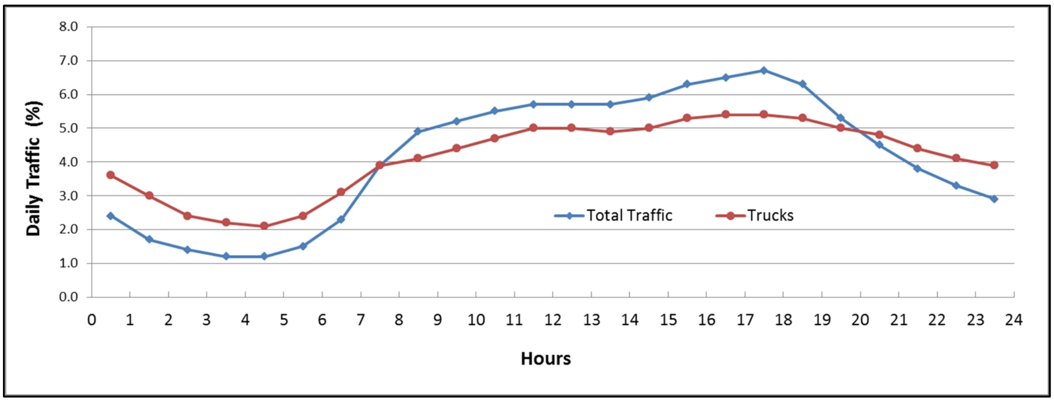


Figure D.7 Hourly traffic volumes in 2008 (Source: TGDH, 2011)

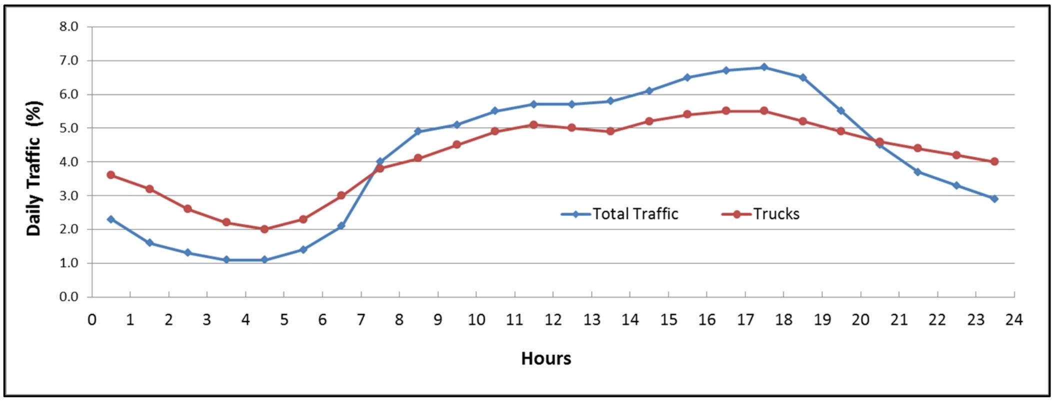


Figure D.8 Hourly traffic volumes in 2009 (Source: TGDH, 2011)

Figure D.9 to Figure D.11 shows daily distribution of traffic between 2007 and 2009. Generally, daily traffic volume started to increase from Monday to Friday and reached peak value on Friday and slightly decreased on weekend. It is seen that, truck traffic showed variations and their volume significantly decreased on weekends. Furthermore, truck volumes on Monday were significantly lower than the other weekdays even lower than the volume on Saturday. Continuous traffic counts also enable study of monthly and seasonal variations in traffic.

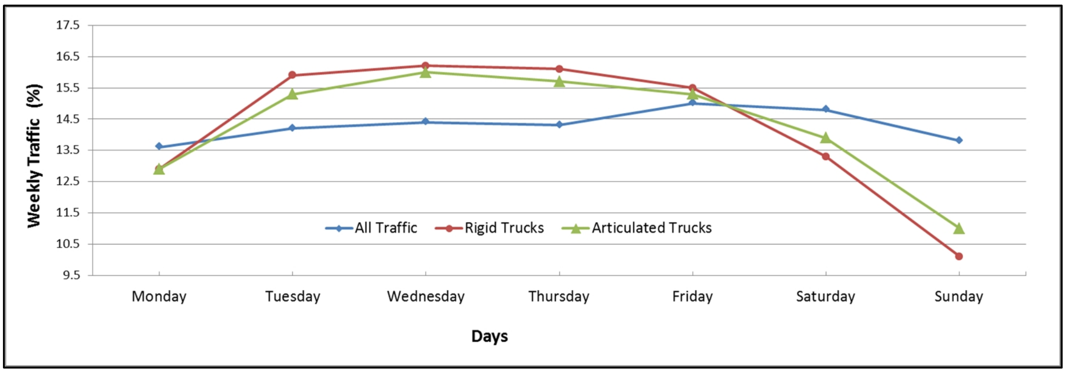


Figure D.9 Daily traffic volumes in 2007 (Source: TGDH, 2011)

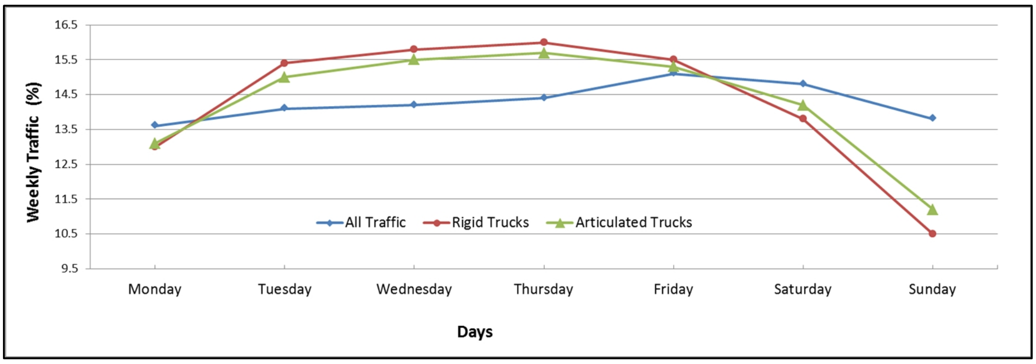


Figure D.10 Daily traffic volumes in 2008 (Source: TGDH, 2011)

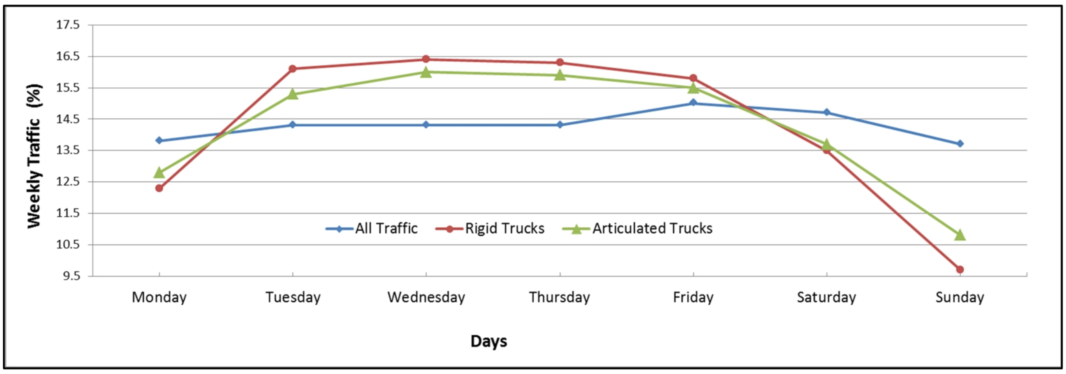


Figure D.11 Daily traffic volumes in 2009 (Source: TGDH, 2011)

Figure D.12 to Figure D.14 shows monthly distributions of truck traffic between 2007 and 2009. Generally, traffic volumes increased in summer and decreased in winter months.

Trucks volumes showed small seasonal variations. In addition, all traffic volumes showed significant changes affected by seasonal variations.

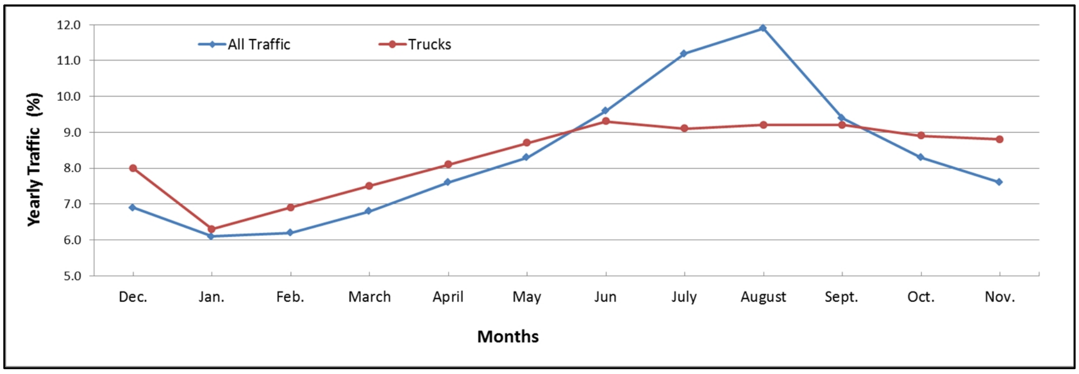


Figure D.12 Monthly traffic volumes in 2007 (Source: TGDH, 2011)

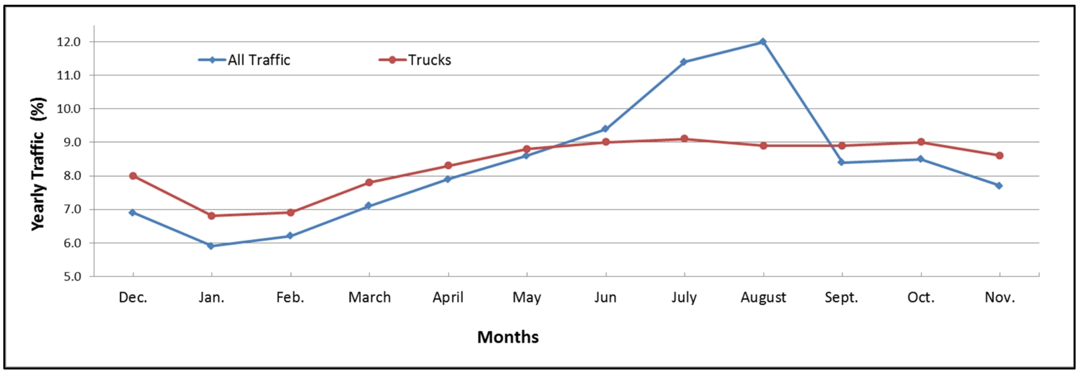


Figure D.13 Monthly traffic volumes in 2008 (Source: TGDH, 2011)

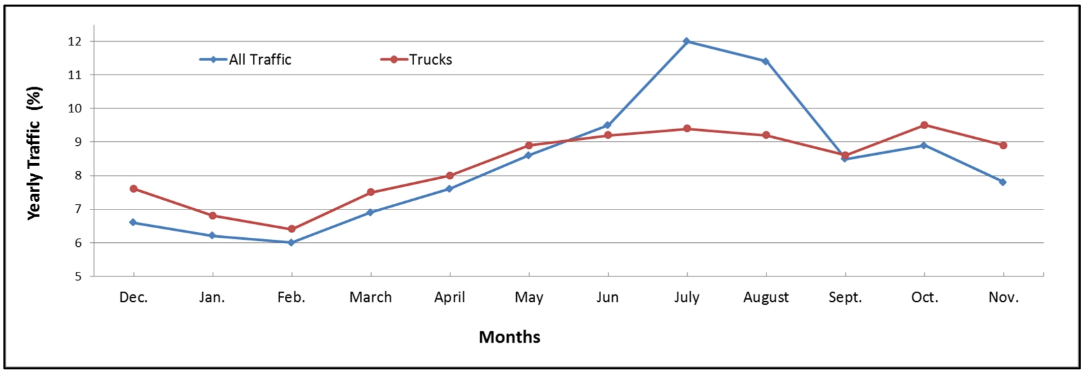


Figure D.14 Monthly traffic volumes in 2009 (Source: TGDH, 2011)

Figure D.15 to Figure D.17 presents monthly shares of different vehicle types in the national traffic. As the automobiles constitute the largest share in the traffic, the variations in the automobile traffic greatly affects the share of other vehicles in the traffic. The share of automobiles starts to increase after June due to the beginning of summer season and reaches its peak value in July and August. Monthly shares of truck traffic increases in winter due to decrease in automobile traffic. On the other hand, bus, medium commercial vehicle, and light commercial vehicle volumes do not show significant variations. It should be noted that light commercial vehicles included automobiles in 2007 (see Figure D15).

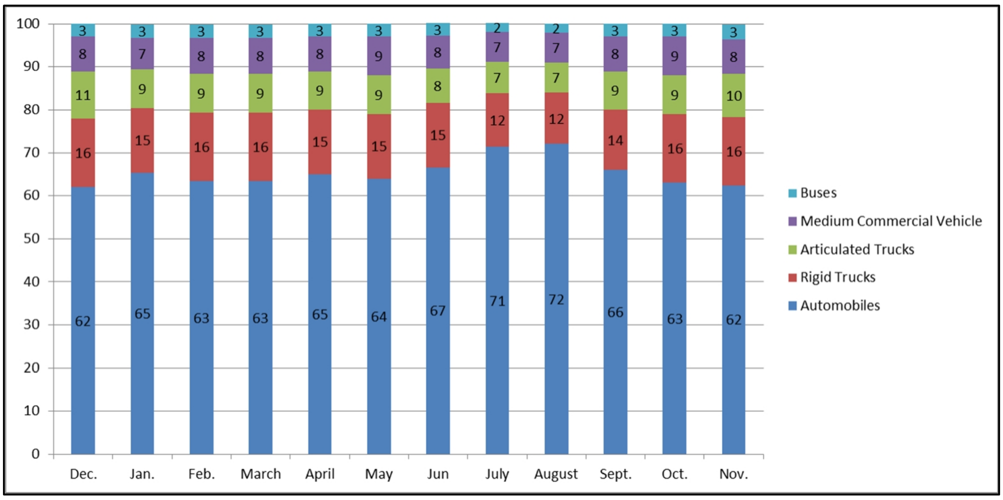


Figure D.15 Monthly traffic compositions in 2007 (Source: TGDH, 2011)

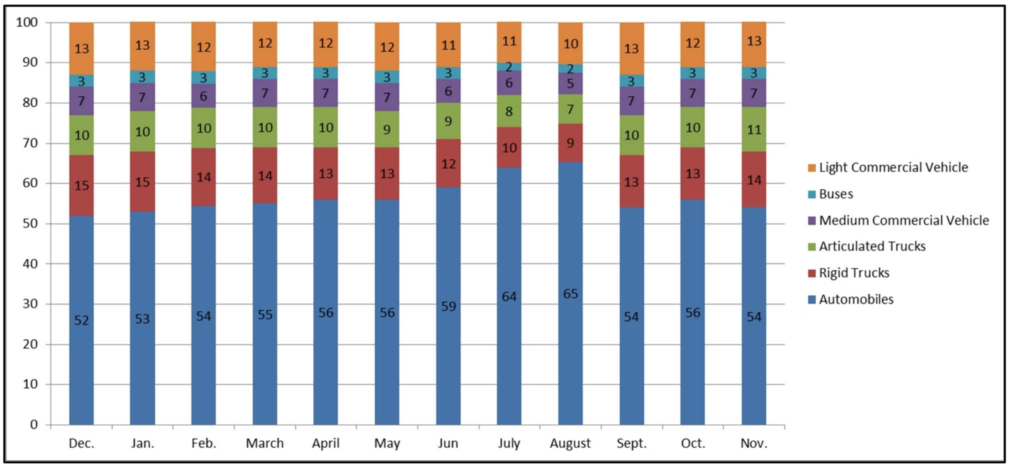


Figure D.16 Monthly traffic compositions in 2008 (Source: TGDH, 2011)

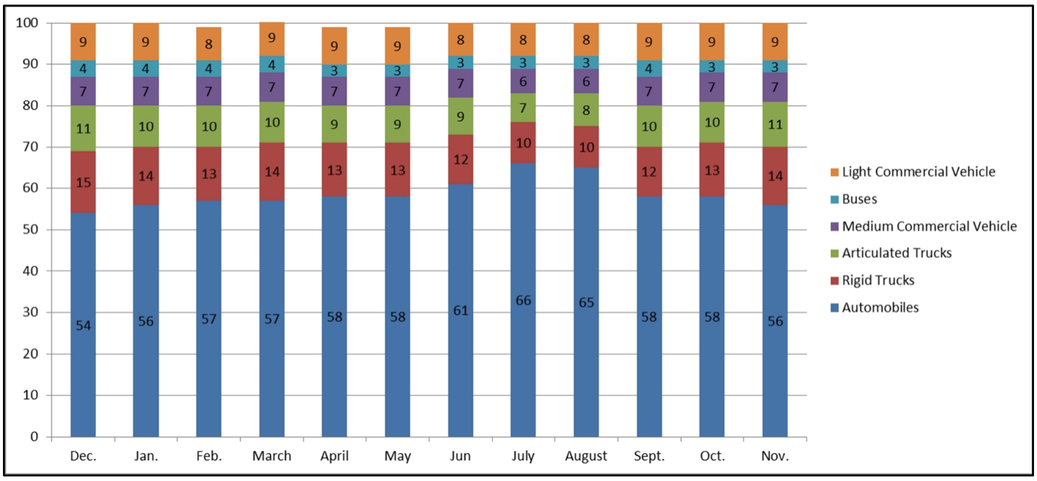


Figure D.17 Monthly traffic compositions in 2009 (Source: TGDH, 2011)

Figure D.18 presents seasonal hourly distribution of heavy vehicle traffic in 2009. As discussed earlier, truck volumes almost continuously increased between 4-5 am to 4-5 pm during day hours. On the other hand, they continuously decreased between 4-5 pm to 4-5 am during night hours. It is seen that there weren’t any significant differences between hourly distributions of truck traffic at different seasons. However, trucks tended to prefer day hours a little more, due to bad weather conditions in winter. Conversely, they prefer night hours due to weather conditions in the summer. The hourly distribution of heavy vehicles in spring and autumn were almost similar (TGDH, 2001).

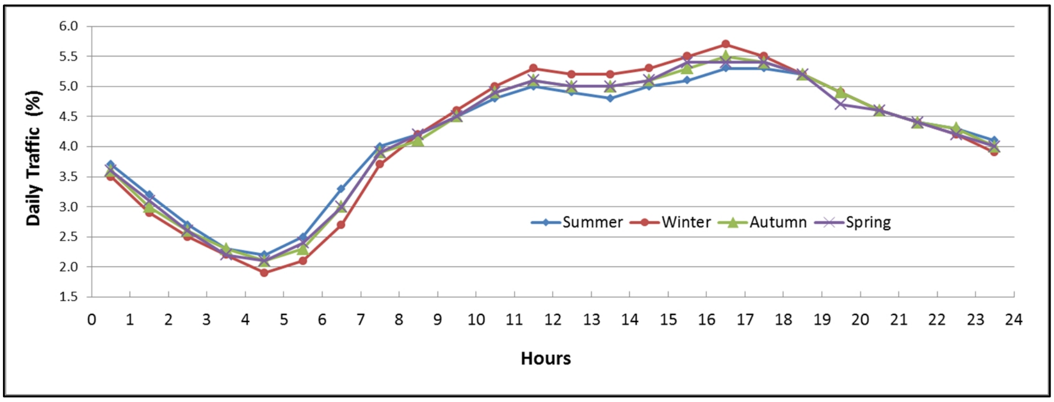


Figure D.18 Seasonal hourly volumes of truck traffic in 2009 (Source: TGDH, 2011)

D.5 Roadside Axle Survey Locations

As discussed in Chapter 3, each regional division of TGDH performs 2 or 3 annual surveys at different sessions on state roads. Annually, more than 40 surveys are performed on state roads. Table D.3 to Table D.5 presents dates and Annual Average Daily Truck Traffic (AADTT) of the survey locations. A total of 31,572 trucks were surveyed at 128 survey locations between 2007 and 2009. TGDH (2011) presented that almost 2% trucks in national vehicle fleet were surveyed each year.

Table D.3 Roadside axle survey locations in 2007 (Source: TGDH, 2011)

Date		Location	AADTT
SPRING	15-18 May	Keşan-Tekirdağ	1,474
	22-25 May	Kula-Uşak	2,066
	08-11 May	Konya-Yarma	2,216
	03-06 April	Kazan-Kızılcahamam	2,642
	22-25 May	Gaziantep-Nizip	3,372
	08-11 May	Aksaray-Nevşehir	1,079
	22-25 May	Samsun-Kavak	3,307
	29 May./01	Gölbaşı-Pazarcık	1,259
	22-25 May	Siverek-Diyarbakır	1,591
	15-18 May	Patnos-Erciş	640
	22-25 May	Dağ Ayr.-Bucak	1,442
	28-31 May	Kurşunlu-Ilgaz	1,578
SUMMER	21-24 August	Aydın-Çine	1,589
	12-15 Jun	Aksaray-Taşpınar	3,469
	05-08 Jun	Ankara-Polatlı	4,345
	21-24 August	Ceyhan-Adana	2,438
	05-08 Jun	Nevşehir-Derinkuyu	843
	12-15 Jun	Taşova-Erbaa	856
	19-22 Jun	(Erzurum-Bingöl) Ayr.-Solhan	587
	28-31 August	(Diyarbakır-Çınar) Ayr.-Bismil	1,571
	12-15 Jun	Görele-Eynesil	2,347
	21-23 August	Özel Sayım Maçka-Torul Ayr.	509
	19-22 Jun	Reşadiye-Gevaş	1,209
	14-17 August	Diyadin Ayr.-Çaldıran Ayr.	648
	07-10 August	Burdur Ayr.-Isparta	1,413
	24-27 July	(Bandırma-Susurluk) Ayr.-Karacabey	1.69
	05-08 Jun	Refahiye-Erzincan	1,073
AUTUMN	20-23 November	Adapazarı-Pamukova	4,764
	20-23 November	Manisa-Akhisar	4,581
	13-16 November	Afyon-Banaz	2,348
	16-19 October	Ankara-Elmadağ	5,907
	27-30 November	Kömürler-Türkoğlu	1,645
	23-26 October	Kayseri-Sarıoğlan	1,374
	16-19 October	Çolaklı-Kale	1,022
	06-09 November	(Diyarbakır-Bismil) Ayr.-Çınar	1,159
	23-26 October	Maçka-Torul Ayr.	509
	11-14 September	Horasan-Karakurt	428
	25-28 September	Aşkale-Erzurum	1,468
	30 Oct./02 Nov.	Çavdır-Korkuteli Ayr.	817
	21-23 November	Tavşanlı-Kütahya	863
	11-14 September	Devrek-Mengen	687
	26-29 November	Bartın-Safranbolu	256
	23-26 October	Kayadibi-(Sivas-Ulaş) Ayr.	702

Table D.4 Roadside axle survey locations in 2008 (Source: TGDH, 2011)

Date		Place	AADTT
SPRING	20-23 May	Keşan-Gelibolu	976
	20-23 May	Aliağa-Bergama	1.88
	27-30 May	Konya-Beyşehir	462
	27-30 May	Sivrihisar-Emirdağ Ayr.	1,298
	13-16 May	Yozgat-Yerköy	812
	20-23 May	Çarşamba-Terme	2,736
	20-23 May	Çolaklı-Kale	1,022
	15-18 April	Diyarbakır-Silvan	429
	05-09 May	Van-Muradiye	1,411
	13-16 May	Taşağıl Ayr.-Manavgat	4.32
	13-16 May	Karacabey-Bursa	5,296
	20-23 May	Karabük-Eskipazar	1,156
SUMMER	12-15 August	Torbalı-Selçuk	536
	26-29 August	Bolvadin-Emirdağ	1,608
	10-13 Jun	Sivrihisar-Eskişehir	1,507
	03-06 Jun	Adana-Ceyhan	2,627
	05-08 August	Göksun-Kahramanmaraş	887
	24-27 Jun	Himmetdede-Kayseri	2,386
	17-20 Jun	Merzifon-Osmancık	1,635
	03-06 Jun	Sivrice Ayr.-Maden	489
	21-25 July	Gümüşhane-Bayburt	463
	03-06 Jun	Tatvan-Korkut Ayr.	698
	19-22 August	Köprüköy-Horasan	1,097
	17-20 Jun	Dalaman-Fethiye	554
	19-22 August	İnegöl-(Bozüyük-Domaniç) Ayr.	2,939
	18-22 August	Kastamonu-Araç	455
	03-06 Jun	Erzincan-Üzümlü	1,154
AUTUMN	07-10 October	Adapazarı-Hendek	3,365
	21-24 October	Denizli-Çardak	2,515
	07-10 October	Karaman-Ayrancı	420
	21-24 October	Gölbaşı-Kulu Ayr.	3,527
	25-28 November	Silifke-Kızkalesi	1,292
	11-14 November	İncesu-Yeşilhisar	1,447
	21-24 October	Yazıhan Ayr.-Malatya	1,009
	21-24 October	Araklı-Of	2,030
	02-05 September	Maden-Aşkale	501
	13-16 October	Çankırı-(İskilip-Ankara) Ayr.	549
	02-05 September	Yıldızeli-Akdağmadeni	376

Table D.5 Roadside axle survey in 2009 (Source: TGDH, 2011)

Date		Place	AADTT
SPRING	26-29 May	İzmit-Sakarya	3,916
	12-15 May	(Salihli-Kula) Ayr.-Alaşehir	1,282
	26-29 May	Konya-Sarayönü	3,278
	26-29 May	Kırıkkale-Keskin	1,859
	26-29 May	Narlı-Pazarcık	1,778
	12-15 May	Kayseri-Malatya	1,148
	12-15 May	Ondokuz Mayıs-Samsun	4.77
	05-08 May	Elazığ-İçme	1,287
	12-15 May	Birecik-Şanlıurfa	2,170
	26-29 May	Torul-Gümüşhane	770
	26-29 May	Aşkale-Erzurum	1,468
	26-29 May	Sandıklı-Dinar Ayr.	1.928
	12-15 May	Bandırma-Karacabey	2.795
	26-29 May	Sivas-(Şarkışla-Ulaş) Ayr.	1,231
SUMMER	16-19 Jun	Lüleburgaz-Muratlı	1,340
	28-31 July	Turgutlu-Salihli	3,444
	11-14 August	Konya-Aksaray	915
	09-12 Jun	Bolu-Gerede	2,193
	04-07 August	Toprakkale Ayr.-İskenderun	2.025
	14-17 July	Ak. Madeni-16.Böl. Hud.	450
	16-19 Jun	Turhal-Tokat	1,324
	23-26 Jun	Malatya-Doğanşehir	1,482
	17-20 August	Siverek-Diyarbakır	1,591
	22-26 Jun	Rize-Pazar	2,149
	02-05 Jun	(Van-Muradiye) Ayr.-Erçiş	1,262
	02-05 Jun	Kars-(Selim-Kötek) Ayr.	601
	18-21 August	Eğirdir-Şarkikaraağaç	607
	14-17 July	İnönü-Kütahya	3,254
	01-04 Jun	Ereğli-Akçakoca	1,446
	04-07 August	Kurşunlu-Ilgaz	1.,578
	14-17 July	Suşehri-(Refahiye-İmranlı)Ayr.	715
AUTUMN	06-09 October	Tekirdağ-Kınalı Ayr.	2,302
	13-16 October	Aydın-Nazilli	2,524
	06-09 October	Afyon-Kütahya	1,832
	06-09 October	Kırıkkale-Delice Ayr.	2,195
	17-20 November	Ceyhan-Adana	2,438
	20-23 October	Kayseri-Sivas	1,350
	20-23 October	Çorum-Amasya	746
	06-09 October	Kürecik-Malatya	540
	23-26 November	Ergani-Diyarbakır	1,596
	03-06 November	Tirebolu-Beşikdüzü	2,191
	29 Sept./02 Oct.	Tatvan-Gevaş	1,117
	29 Sept./02 Oct.	Eleşkirt-Ağrı	992
	17-20 November	Kızılcadağ-Çavdır Ayr.	739
	06-09 October	Susurluk-Balıkesir	4,504
	05-08 October	Devrek-Mengen	687
	29 Sept./02 Oct.	Sivas-Hafik	677

APPENDIX E

SUPPLEMENTARY INFORMATION FOR FREIGHT MODELING

- 2011 values of the Province level Number of Employees, Population and Passenger Car Ownership per 1000 Households are presented in Table E.1.
- Province level trip production values estimated from trip generation function (Column A) and gravity model (Column B) are presented in Table E.2.
- Province level trip attraction values estimated from trip attraction function (Column A) and gravity model (Column B) are presented in Table E.3.

Table E.1 Trip generation and attraction variables in 2011 (TurkStat 2013a, 2013b, 2013c and 2013d)

Code	Province	Number of Employees	Population	Passenger Car per 1000 Households
1	Adana	594,699	2,108,805	415.8
2	Adiyaman	187,397	593,931	269.7
3	Afyonkarahisar	236,993	698,626	318.6
4	Agri	151,330	555,479	108.9
5	Amasya	116,192	323,079	402.8
6	Ankara	1,570,442	4,890,893	687.5
7	Antalya	789,875	2,043,482	527.7
8	Artvin	73,351	166,394	207.0
9	Aydin	358,684	999,163	378.6
10	Balikesir	426,057	1,154,314	353.3
11	Bilecik	72,086	203,849	323.7
12	Bingöl	78,478	262,263	100.6
13	Bitlis	91,103	336,624	123.0
14	Bolu	99,079	276,506	443.5
15	Burdur	97,189	250,527	478.3
16	Bursa	915,549	2,652,126	394.9
17	Canakkale	195,124	486,445	333.2
18	Cankiri	65,304	177,211	251.0
19	Corum	183,046	534,578	369.3
20	Denizli	360,150	942,278	445.7
21	Diyarbakir	346,887	1,570,943	173.3
22	Edirne	177,099	399,316	355.6
23	Elazig	158,744	558,556	322.9
24	Erzincan	74,209	215,277	326.3
25	Erzurum	242,053	780,847	266.6
26	Eskisehir	246,992	781,247	426.8
27	Gaziantep	459,585	1,753,596	386.5
28	Giresun	152,598	419,498	202.5
29	Gumushane	41,117	132,374	176.2
30	Hakkari	62,218	272,165	72.8
31	Hatay	422,950	1,474,223	370.1
32	Isparta	151,753	411,245	451.4
33	Mersin	516,671	1,667,939	372.6
34	Istanbul	4,565,486	13,624,240	515.6
35	Izmir	1,330,178	3,965,232	442.3
36	Kars	101,749	305,755	149.1
37	Kastamonu	155,626	359,759	412.6
38	Kayseri	367,865	1,255,349	500.0
39	Kirklareli	140,214	340,199	343.9
40	Kirsehir	74,586	221,015	395.3
41	Kocaeli	501,844	1,601,720	336.4
42	Konya	649,350	2,038,555	441.7

Table E.2 Trip generation and attraction variables in 2011 (cont`d)

Code	Province	Number of Employees	Population	Passenger Car per 1000 Households
43	Kutahya	194,731	564,264	443.6
44	Malatya	230,068	757,930	316.6
45	Manisa	520,192	1,340,074	352.8
46	Kahramanmaras	306,603	1,054,210	338.9
47	Mardin	177,164	764,033	148.0
48	Mugla	342,984	838,324	487.9
49	Mus	114,796	414,706	110.1
50	Nevsehir	109,865	283,247	415.3
51	Nigde	121,690	337,553	299.3
52	Ordu	282,479	714,390	230.9
53	Rize	107,678	323,012	236.2
54	Sakarya	281,335	888,556	387.2
55	Samsun	433,991	1,251,729	327.5
56	Siirt	72,560	310,468	120.9
57	Sinop	77,068	203,027	333.9
58	Sivas	193,696	627,056	332.7
59	Tekirdag	317,139	829,873	343.8
60	Tokat	206,687	608,299	326.8
61	Trabzon	280,861	757,353	284.0
62	Tunceli	34,729	85,062	94.2
63	Sanliurfa	400,271	1,716,254	296.5
64	Usak	132,224	339,731	424.9
65	Van	248,781	1,022,532	152.6
66	Yozgat	159,379	465,696	289.6
67	Zonguldak	220,239	612,406	382.8
68	Aksaray	139,174	378,823	416.3
69	Bayburt	31,640	76,724	222.5
70	Karaman	81,442	234,005	382.4
71	Kirikkale	75,285	274,992	366.0
72	Batman	112,005	524,499	166.6
73	Sirnak	92,728	457,997	59.9
74	Bartin	68,677	187,291	368.6
75	Ardahan	46,782	107,455	108.2
76	Igdir	65,570	188,857	132.1
77	Yalova	68,543	206,535	313.0
78	Karabuk	66,627	219,728	435.7
79	Kilis	40,836	124,452	260.6
80	Osmaniye	132,138	485,357	419.5
81	Duzce	129,506	342,146	370.0

Table E.3 Province level annual trip production estimations in 2011

Code	Province	Production Function (A)	Gravity Model (B)	B/A
1	Adana	654,386	2,857,280	4.4
2	Adiyaman	254,823	1,387,783	5.4
3	Afyonkarahisar	303,477	1,945,995	6.4
4	Agri	219,441	934,051	4.3
5	Amasya	184,971	1,282,944	6.9
6	Ankara	1,611,590	5,647,379	3.5
7	Antalya	1,148,017	3,381,896	2.9
8	Artvin	142,944	695,327	4.9
9	Aydin	422,856	1,898,241	4.5
10	Balikesir	488,948	2,195,184	4.5
11	Bilecik	141,703	1,298,006	9.2
12	Bingöl	147,973	926,440	6.3
13	Bitlis	160,359	877,236	5.5
14	Bolu	168,183	1,436,029	8.5
15	Burdur	166,329	1,195,246	7.2
16	Bursa	969,140	3,931,507	4.1
17	Canakkale	262,403	1,107,915	4.2
18	Cankiri	135,050	1,179,804	8.7
19	Corum	250,555	1,644,974	6.6
20	Denizli	424,294	2,066,790	4.9
21	Diyarbakir	411,283	1,782,581	4.3
22	Edirne	244,721	1,083,338	4.4
23	Elazig	226,714	1,261,296	5.6
24	Erzincan	143,786	924,747	6.4
25	Erzurum	308,441	1,358,293	4.4
26	Eskisehir	313,286	2,055,242	6.6
27	Gaziantep	521,839	2,314,327	4.4
28	Giresun	220,685	1,256,826	5.7
29	Gumushane	111,322	775,429	7.0
30	Hakkari	132,022	553,359	4.2
31	Hatay	788,064	2,461,690	3.1
32	Isparta	219,856	1,453,852	6.6
33	Mersin	880,004	2,923,602	3.3
34	Istanbul	4,851,892	8,652,850	1.8
35	Izmir	1,678,055	4,827,930	2.9
36	Kars	170,802	768,410	4.5
37	Kastamonu	223,656	1,399,835	6.3
38	Kayseri	431,862	2,294,318	5.3
39	Kirklareli	208,536	1,067,718	5.1
40	Kirsehir	144,155	1,237,540	8.6
41	Kocaeli	563,296	3,197,597	5.7
42	Konya	707,999	2,984,215	4.2

Table E.2 Province level annual trip production estimations in 2011 (cont`d)

Code	Province	Production Function (A)	Gravity Model (B)	B/A
43	Kutahya	262,018	1,799,355	6.9
44	Malatya	296,683	1,548,230	5.2
45	Manisa	581,295	2,806,501	4.8
46	Kahramanmaras	371,764	1,904,191	5.1
47	Mardin	244,784	1,173,364	4.8
48	Mugla	407,454	1,678,623	4.1
49	Mus	183,601	990,860	5.4
50	Nevsehir	178,764	1,423,273	8.0
51	Nigde	190,364	1,347,305	7.1
52	Ordu	348,098	1,678,798	4.8
53	Rize	176,619	929,767	5.3
54	Sakarya	346,976	2,458,082	7.1
55	Samsun	798,895	2,869,793	3.6
56	Siirt	142,168	795,791	5.6
57	Sinop	146,590	882,968	6.0
58	Sivas	261,002	1,519,373	5.8
59	Tekirdag	382,100	1,621,641	4.2
60	Tokat	273,747	1,609,748	5.9
61	Trabzon	648,675	2,232,312	3.4
62	Tunceli	105,056	728,561	6.9
63	Sanliurfa	463,652	1,930,651	4.2
64	Usak	200,698	1,405,872	7.0
65	Van	315,041	1,072,054	3.4
66	Yozgat	227,337	1,600,283	7.0
67	Zonguldak	287,041	1,717,607	6.0
68	Aksaray	207,516	1,540,523	7.4
69	Bayburt	102,025	726,701	7.1
70	Karaman	150,881	1,036,066	6.9
71	Kirikkale	144,841	1,328,338	9.2
72	Batman	180,863	995,788	5.5
73	Sirnak	161,953	755,491	4.7
74	Bartin	161,953	1,030,092	7.4
75	Ardahan	138,359	601,893	5.1
76	Igdir	116,880	616,677	4.6
77	Yalova	135,311	1,251,984	9.1
78	Karabuk	138,227	1,109,840	8.1
79	Kilis	136,348	839,831	7.6
80	Osmaniye	111,047	1,265,348	6.3
81	Duzce	200,614	1,645,767	8.3
Total		**31,723,037**	**138,994,361**	**4.4**

Table E.4 Province level annual trip attraction estimations in 2011

Code	Province	Production Function (A)	Gravity Model (B)	B/A
1	Adana	859,574	2,965,415	3.4
2	Adiyaman	326,527	1,451,678	4.4
3	Afyonkarahisar	389,463	1,983,622	5.1
4	Agri	207,260	828,650	4.0
5	Amasya	338,312	1,677,812	5.0
6	Ankara	1,840,906	5,129,130	2.8
7	Antalya	916,126	2,505,368	2.7
8	Artvin	161,596	700,082	4.3
9	Aydin	516,062	1,937,320	3.8
10	Balikesir	543,605	2,098,627	3.9
11	Bilecik	250,874	1,650,292	6.6
12	Bingöl	117,491	730,097	6.2
13	Bitlis	153,935	789,671	5.1
14	Bolu	352,368	1,997,215	5.7
15	Burdur	368,361	1,760,680	4.8
16	Bursa	1,001,482	3,454,727	3.4
17	Canakkale	338,394	1,169,758	3.5
18	Cankiri	194,349	1,292,160	6.6
19	Corum	376,481	1,859,266	4.9
20	Denizli	544,954	2,136,181	3.9
21	Diyarbakir	542,050	1,909,995	3.5
22	Edirne	328,442	1,176,457	3.6
23	Elazig	352,153	1,509,030	4.3
24	Erzincan	255,935	1,220,206	4.8
25	Erzurum	378,077	1,411,535	3.7
26	Eskisehir	485,967	2,361,351	4.9
27	Gaziantep	737,907	2,575,658	3.5
28	Giresun	231,212	1,198,210	5.2
29	Gumushane	131,092	798,614	6.1
30	Hakkari	101,645	433,173	4.3
31	Hatay	646,693	1,948,844	3.0
32	Isparta	396,345	1,860,282	4.7
33	Mersin	703,990	2,423,665	3.4
34	Istanbul	4,231,708	6,597,110	1.6
35	Izmir	1,410,208	3,791,722	2.7
36	Kars	162,644	692,338	4.3
37	Kastamonu	355,461	1,624,325	4.6
38	Kayseri	671,298	2,630,112	3.9
39	Kirklareli	303,641	1,233,252	4.1
40	Kirsehir	303,981	1,731,316	5.7
41	Kocaeli	660,662	3,098,116	4.7
42	Konya	856,870	2,916,409	3.4

Table E.3 Province level annual trip attraction estimations in 2011 (cont`d)

Id	Province	Production Function (A)	Gravity Model (B)	B/A
43	Kutahya	435,013	2,175,097	5.0
44	Malatya	405,125	1,683,448	4.2
45	Manisa	596,587	2,661,732	4.5
46	Kahramanmaras	505,164	2,081,118	4.1
47	Mardin	293,416	1,190,581	4.1
48	Mugla	543,509	1,800,622	3.3
49	Mus	167,646	859,477	5.1
50	Nevsehir	335,309	1,848,771	5.5
51	Nigde	272,853	1,504,676	5.5
52	Ordu	334,983	1,488,827	4.4
53	Rize	226,182	1,027,356	4.5
54	Sakarya	490,139	2,686,809	5.5
55	Samsun	554,173	1,960,442	3.5
56	Siirt	144,996	743,111	5.1
57	Sinop	257,503	1,132,679	4.4
58	Sivas	378,436	1,703,620	4.5
59	Tekirdag	444,069	1,617,938	3.6
60	Tokat	369,057	1,716,498	4.7
61	Trabzon	383,041	1,418,464	3.7
62	Tunceli	62,386	476,661	7.6
63	Sanliurfa	666,655	2,177,020	3.3
64	Usak	357,969	1,807,501	5.0
65	Van	370,729	1,093,055	2.9
66	Yozgat	303,072	1,662,935	5.5
67	Zonguldak	407,916	1,839,983	4.5
68	Aksaray	363,399	1,926,669	5.3
69	Bayburt	146,311	845,364	5.8
70	Karaman	299,079	1,448,196	4.8
71	Kirikkale	299,761	1,850,849	6.2
72	Batman	237,189	1,083,416	4.6
73	Sirnak	146,283	651,860	4.5
74	Bartin	276,364	1,383,201	5.0
75	Ardahan	78,183	433,960	5.6
76	Igdir	117,675	523,886	4.5
77	Yalova	244,452	1,626,782	6.7
78	Karabuk	330,854	1,689,702	5.1
79	Kilis	185,647	1,065,796	5.7
80	Osmaniye	396,163	1,874,546	4.7
81	Duzce	321,769	1,937,660	6.0
Total		**36,795,158**	**138,994,361**	**3.8**

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WORK EXPERINCE

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2003 – Current	Middle East Technical University, Department of Civil Engineering	Research Assistant
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FOREIGN LANGUAGES

Advanced English

PUBLICATIONS

Journal Articles

1. Ozen, M. and Guler, M. (2014). Assessment of Optimum Threshold and Particle Shape Parameter for the Image Analysis of Aggregate Size Distribution of Concrete Sections. Optics and Lasers in Engineering. Optics and Lasers in Engineering, 53, 122-132.
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