THE UNIVERSITY OF MANITOBA

TRUCK TRANSPORTATION OPERATING EFFICIENCY AND PERFORMANCE CONSIDERATIONS OF IMPORT TO HIGHWAY DEVELOPMENT IN NORTHEAST THAILAND:

Lessons from Canada and Other Countries

by

© **Pongrid Klungboonkrong**

A Report
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements for
the Degree of
Master of Engineering

DEPARTMENT OF CIVIL ENGINEERING

Winnipeg, Manitoba
January 1989

ISBN 0-315-51695-X

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ABSTRACT

A preliminary investigation of the existing truck transport situation and the nature of the governing vehicle weight and dimension (VWD) regulations in the northeast region of Thailand was conducted. A number of key aspects and problems relating to truck operation in the region are revealed. A summary of the state-of-the-art knowledge base concerning large truck transportation operating efficiency and performance based on a review of literature from Canada, the United States, and other countries was completed. The summary was focused on the potential interest of future developments in the VWD regulations governing large trucks in Northeast Thailand. Finally, suggestions for relevant research relating to VWD issues of apparent import to regulatory development opportunities concerning large truck transport in the northeast region of Thailand are presented.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my advisor, Professor Alan M. Clayton, for his guidance, comments, and suggestions.

I would like to thank Ms. Wendy Seversen for doing an excellent job with the typing on this report. In addition I would also like to gratefully acknowledge financial assistance from the Canadian International Development Agency (CIDA), Canada.

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CHAPTER 1

INTRODUCTION

1.1 THE MOTIVATION

The northeast region of Thailand is of a very rural nature, with a strong dependence upon agriculture and its related industries (agro-industries) such as rice mills, cassava processing plants, sugar processing plants, etc. Trucking is the most important mode of transport for these products both within and out of the region, as well as the major mode of freight movement into the area. The growth and development of the region's economy have a strong linkage with the development and provision of efficient and effective truck transport services, now and in the future.

Thailand is not unique in this regard, as the movement of freight by truck plays an increasingly important role in economies of both developed and developing countries throughout the world. Coupled with this growing dependence on trucking has been a worldwide trend to facilitate (through infrastructure improvement) and permit (through regulatory change) the utilization of larger and/or heavier trucks--with the objective of reducing freight transport operating costs and thereby increasing economic growth.

While larger and heavier trucks can potentially lead to substantial reductions in transport operating costs, in doing so, they also usually necessitate higher infrastructure costs - both in terms of initial construction costs and on-going rehabilitation and maintenance costs. Various aspects of the trade-off between the reduced operating costs and increment of infrastructure costs--as well as other impacts of general interest in considering large truck issues (i.e., traffic engineering considerations, truck safety considerations, etc.) - have been, and continue to be, the subject of major research around the world.

This research examines a wide variety of matters of import to guiding the highway development policies of all countries. While the state of this work is such that many fundamental questions remain unanswered (and in some cases indeed probably unasked), important advances in the knowledge base have been made. Some of the "leading-edge" research on the subject has been carried out in recent years in Canada.

It is against this background that this project has been conceived, with the goal of providing a comprehensive and timely knowledge base about truck operating efficiency and performance considerations of potential import to the future road development policies and projects in the northeast region of Thailand - giving particular attention to the issue of the regulation of truck size and weight.

1.2 PROJECT OBJECTIVE AND SCOPE

The project has three principal objectives:

(1) to develop a preliminary assessment of key aspects of the existing truck transport situation in northeast Thailand;

(2) to develop a summary of the state-of-the-art knowledge base concerning large truck transportation operating efficiency and performance considerations of potential interest to future developments in the weight and dimension regulations (and the related infrastructure design considerations) governing large truck operations in northeast Thailand;

(3) to develop suggestions for relevant research relating to truck weight and dimension issues of apparent import to regulatory development opportunities concerning large truck transport in the northeast region of Thailand.

The project is concerned with "medium" and "large" trucks and truck combinations - defined to mean vehicles designed to handle gross vehicle weight (GVW) of 12 tonnes or more, and regularly used in "ex-urban" (i.e., intercity) transport service.

1.3 METHODOLOGICAL CONSIDERATIONS

The project relies on three basic sources of information: (i) the literature; (ii) un-published material obtained from Canadian and American highway agencies, and; (iii) a limited field survey of truck operations in Thailand's northeast region carried out by the author in summer, 1987 and 1988. Published research findings of particular interest to the project include recent Canadian, US, and many other countries' work.

The first objective is based on the results of a limited field survey and a series of interviews and discussions with government officials and truck operators undertaken by the author in summer, 1987 and 1988.

The second objective is based on the collection and synthesis of recent research findings, and the "interpretation" and "extrapolation" of those findings into a knowledge base of relevance to northeast Thailand.

The third objective is concerned with the formulation of a series of research projects to be undertaken by staff and students at Khon Kaen University.

Chapter 2

THE CURRENT TRUCK TRANSPORT SITUATION IN NORTHEAST THAILAND

2.1 PURPOSE OF THE CHAPTER

As is the case in many countries, Thailand's economy is strongly dependent on the production and processing of agricultural products, and their shipment to market. In northeast Thailand, where more than 80% of the population are farmers, the shipment of agricultural products is exclusively based on truck transport. Truck transport is therefore a vital mode of freight transportation in the region. More efficient and effective truck transport can lead to an improvement in the economic situation of the region, and therefore, in the country itself.

The purpose of this chapter is:

(a) to present a general outline of the northeast region of Thailand;

(b) to determine the activity system relating to truck transport needs, the transportation system servicing truck transport, and the flow pattern of truck transport;

(c) to examine the region's governing vehicle weight and dimension (VWD) regulations;

(d) to examine the region's truck fleet and operating characteristics;

(e) to present three case studies of truck operations conducted in northeast Thailand; and

(f) to discuss apparent problems with, and opportunities for improvement of, truck transport in the region.

2.2 THE NORTHEAST REGION

Thailand is divided geographically into four regions, namely, the north, the northeast, the central, and the south. The northeast region consists of 17 cities (changwats) as shown in

Figure 2.1. The region lies between 14° and 18° north latitude and 101° and 106° east longitude. The northern and eastern boundaries of the region are separated from Laos by the Mekhong River, while the southern boundary is close to Kampuchea. The western and southwestern boundaries border the north and central regions of Thailand, respectively.

The northeast region occupies 169,500 square kilometres and in 1983 had a total population of 17,219,000, both of which are one-third of the whole country. The population growth rate of the region in the past eight years was 2.2% (compared to the national average growth rate of 1.8%). The region's gross regional product (GRP) in 1982 was 45,600 million baht at 1972 prices (21.0 baht = $1 Cdn approximately), which was 14.1% of the gross domestic product (GDP) of 324,300 million baht in the same year. The per capita GRP in that year was 2,658 baht, one-third of the national average per capita GDP of 6,690 baht (1972 constant price) [1].

The less developed economy of the region is due largely to the relatively low productivity of the agricultural sector, caused by poor natural conditions such as uneven rainfall and infertile soil [1]. Insufficient road networks in agricultural areas is also an important factor. Improvement in accessibility, and the provision of efficient and effective freight transportation would contribute to an increase in the farmgate prices of agricultural products, and a decrease in production costs--both of which would act as incentives for farmers to produce more. Consequently, improvement in the road network serving rural areas, and the development of more efficient and effective truck transport can play an important role in more efficient agricultural production. This would in turn help to alleviate regional disparities in personal income, living standards, and social environment.

0101 M. Loei
0102 Tha Li
0103 Chiang Khan
0104 Pak Chom
0105 Na Duang
0106 Na Haeo
0107 Dan Sai
0108 Phu Rua
0109 Wang Saphung
0110 Phu Kradung
0111 Phu Luang
0201 M. Udon Thani
0202 Nam Som
0203 Suwannakhuha
0204 Ban Phu
0205 Kut Chap
0206 Phen
0207 Sang Khom
0208 Ban Dung
0209 Thung Fon
0210 Na Klang
0211 Si Bun Ruang
0212 Nong Buo Lam Phu
0213 Non Sang
0214 Nong Wua So
0215 Non Sa-At
0216 Kumphawapi
0217 Nong Han
0218 Chaiwan
0219 Si That
0220 Wang Sam Mo
0221 Nong Saeng
0301 M. Nong Khai
0302 Sangkhom
0303 Si Chiang Mai
0304 Tha Bo
0305 Phon Phisai
0306 Pak Kad
0307 So Phisai
0308 Bung Kan
0309 Phon Charoen
0310 Seka
0401 M. Sakhon Nakhon
0402 Ban Muang
0403 Kham Ta Kla
0404 Sawang Daen Din
0405 Wanon Niwat
0406 Akat Amnuai
0407 Song Dao
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0412 Kusuman
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0501 M. Nakhon Phanom
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0602 Chumphae
0603 Si Chomphu
0604 Phu Wiang
0605 Nong Rua
0606 Ban Fang
0607 Ubolratana
0608 Kaosuankwang
0609 Nam Phong
0610 Kranuan
0611 Phra Yun
0612 Mancha Khiri
0613 Ban Phai
0614 Chonnabot
0615 Waeng Yai
0616 Waeng Noi
0617 Phon
0618 Nong Song Hon
0619 Phouy Noi
0620 Phu Pha Man
0701 M. Maha Sarakham
0702 Chiang Yun
0703 Kosum Phisai
0704 Kantharawichai
0705 Borabu
0706 Kae Dam
0707 Na Chuak
0708 Wapi Pathum
0709 Na Dum
0710 Phayakkhaphum Pisai
0801 M. Kalasin
0802 Tha Khantho
0803 Nong Kung Si
0804 Khom Muang
0805 Sahatsakhan
0806 Somdet
0807 Na Mon
0808 Khao Wong
0809 Kuchinarai
0810 Huai Mek
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0812 Kamalasai
0813 Rong Kham
0814 Huay Pung
0901 M. Roi Et
0902 Pho Chai
0903 Phon Thong
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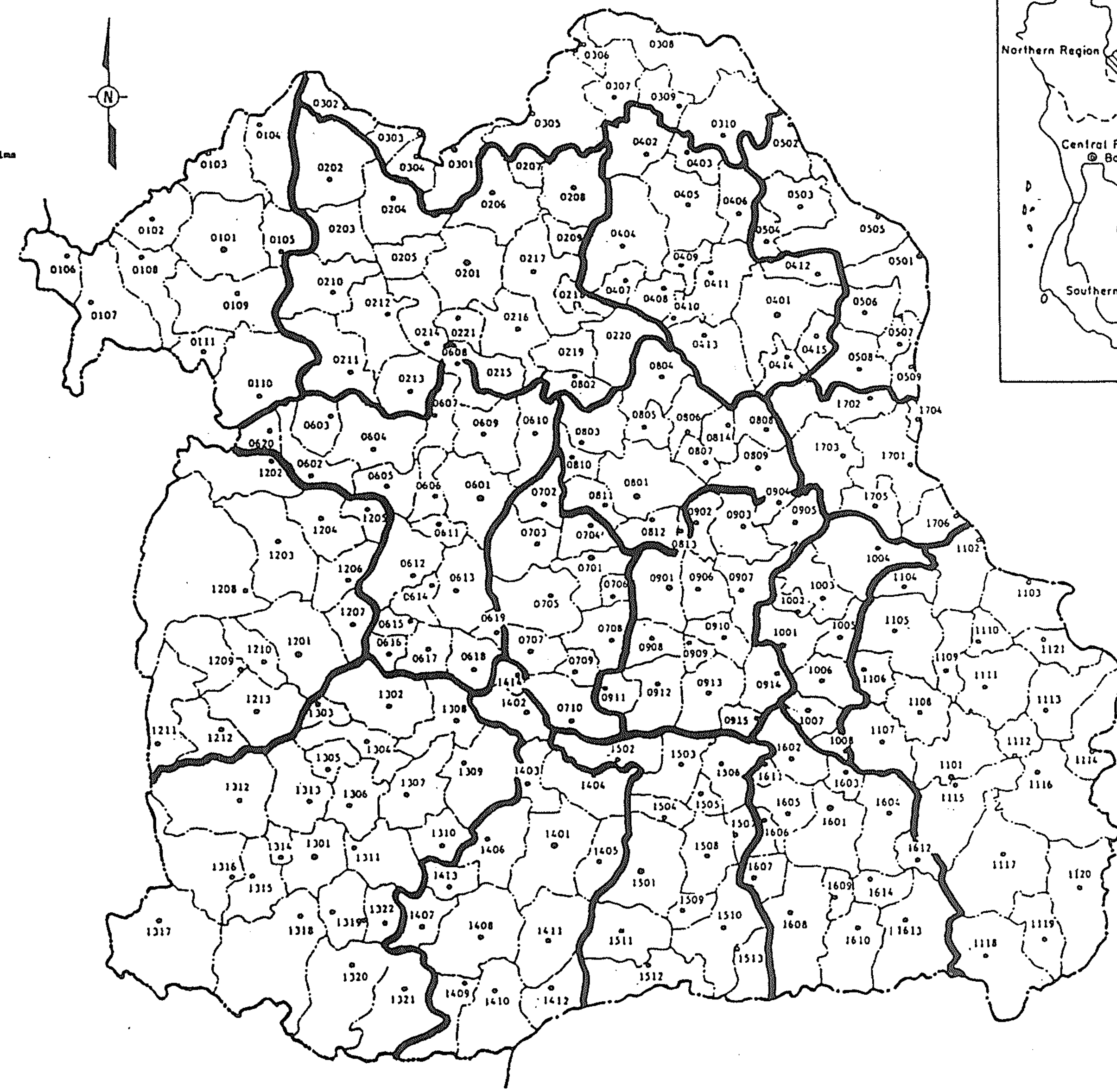
0905 Nong Phok
0906 Thawatchaburi
0907 Selaphum
0908 Chaturapak Pimun
0909 Muang Suang
0910 At Samat
0911 Pathum Rat
0912 Kaset Wisai
0913 Suwannaphum
0914 Phanom Phrai
0915 Phon Sai
1001 M. Yasothon
1002 Sai Mun
1003 Kut Chum
1004 Loeng Nok Tha
1005 Pa Tiu
1006 Kham Khuan Kaeo
1007 Maha Chana Chai
1008 Kho Wang
1101 M. Ubon Ratchathani
1102 Chanuman
1103 Khemaraj
1104 Senang Khanikhom
1105 Amnat Charoen
1106 Hua Thaphan
1107 Khueng Nai
1108 Muang Samsip
1109 Phana
1110 Kut Kaopun
1111 Trakan Phutphon
1112 Taiaum
1113 Si Muang Mai
1114 Khong Chiam
1115 Warin Chamrap
1116 Pibun Mungsahan
1117 Det Udom
1118 Nam Yun
1119 Na Chaiuai
1120 Buntharik
1121 Pho Sai
1201 M. Chaiyaphum
1202 Khon San
1203 Kaset Sombun
1204 Phu Khiao
1205 Ban Thaen
1206 Kaeng Khlo
1207 Khon Sawan
1208 Nong Bua Daeng
1209 Nong Bua Rahueo
1210 Ban Khwao
1211 Thep Satit
1212 Bamnet Narong
1213 Chatturat
1301 M. Nakhon Ratchasima
1302 Bua Yai
1303 Ban Luam
1304 Khong
1305 Kham Sakae Saeng
1306 Nong Sung
1307 Phimai
1308 Prathai
1309 Chum Phuang
1310 Huai Thalaeng
1311 Chakkaraj
1312 Dan Khun Thot
1313 Non Thai
1314 Kham Thalae So
1315 Sung Noen
1316 Sikhiu
1317 Pak Chong
1318 Pak Thong Chai
1319 Chok Chai
1320 Khon Buri
1321 Soeng Sang
1322 Nong Bunmak
1401 M. Buri Ram
1402 Phutthaisong
1403 Khu Muang
1404 Satuk
1405 Krasang
1406 Lam Plai Mat
1407 Nong Ki
1408 Nang Rong
1409 Pa khom
1410 Lahan Sai
1411 Prakhon Chai
1412 Ban Kruat
1413 Nong Hong
1414 Na Pho
1501 M. Surin
1502 Chumphon Buri
1503 Tha Tum
1504 Chom Phra
1505 Sanom
1506 Rattanaburi
1507 Samrong Thap
1508 Sikhoraphum
1509 Lamduan
1510 Sangkha
1511 Prasat
1512 Kap Choeng
1513 Bua Chet
1601 M. Si Sa Ket
1602 Rasi Salai
1603 Yang Chum Noi
1604 Kanthararom
1605 Uthumpon Phisai
1606 Huai Thap Than
1607 Prang Ku
1608 Khukhan
1609 Phrai Bung
1610 Khun Han
1611 Bung Boon
1612 Non Koon
1613 Kantharalak
1614 Sri Pattana
1701 Mukdahan
1702 Dong Luang
1703 Khamcha-I
1704 Wan Yai
1705 Nikhom Kham Soi
1706 Don Tan



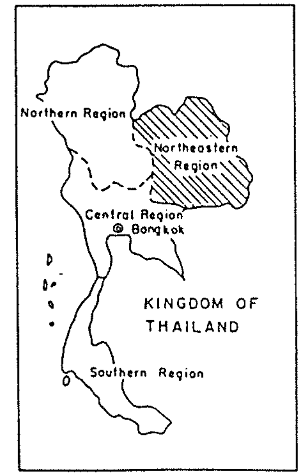


Figure 2.1 Changwats and Amphoes in the region
(Source: Reference [2])

2.3 AN OVERVIEW OF THE NEEDS FOR TRUCKING SERVICES IN THE REGION

Truck transport is the most important (and, indeed for much of the region, the only) mode of freight transportation within the region and between the region and the rest of the country. Consequently, truck transport plays a critical role in transporting agricultural products. The following sections describe key aspects of the regions activity and transportation systems concerning trucking.

2.3.1 The Activity System Relating to Truck Transport Needs

Thailand is an agricultural country. In the northeast region, as in the other regions, agricultural production and related industries are the dominant economic sector. Approximately 82% of the region's population (in 1983) was employed in or dependent on the farming sector [1]. This is about 42% of the total farm population of the whole country. Farmland in the region consists of 49% of the region's total land. The cultivated areas of the region are mainly planted with paddy (70%), upland crops (cassava, sugarcane, kenaf, maize, etc.) (20%), and tree crops, vegetables, flowers and others (10%) [1].

In terms of planted area and production, the four major crops in the region ranked in order are rice, cassava, sugarcane, and kenaf. These four crops are not only consumed within Thailand itself, but also are exported to other countries such as Japan, European Economic Community (EEC), etc. Therefore, these four crops have a strong effect on the northeast region economy. Table 2.1 shows the number and total production of processing factors for these four crops with respect to several cities (changwats) in the region.

Table 2.1 Agro-industry (location, number, and total product)

(1983)

Changwat	Rice Mill[1]				Cassava						Kenaf				Sugar			
	Big		Medium		Pellet		Chip		Flour		Baling		Textile		Brown		Refinery	
	NO.	T.P.	NO.	T.P.	NO.	T.P.	NO.	T.P.	NO.	T.P.	NO.	T.P.	NO.	T.P.	NO.	T.P.	NO.	T.P.
02 UDON THANI	11	390.5	15	303.2	33	601.8	160	248.2	1	18.2	11	43.6	1	N.A.	2	133.9	2	65.4
04 SAKHON NAKHON	3	131.4	6	73.6	3	17.9	60	50.2	-	-	1	3.5	-	-	-	-	-	-
06 KHON KAEN	12	487.6	18	368.5	64	780.3	207	663.4	1	10.9	45	120.0	2	N.A.	1	150.0	1	75.0
09 ROI ET	3	102.2	8	149.5	8	169.0	83	70.0	-	-	5	7.5	-	-	-	-	-	-
10 YASOTHON	1	32.8	4	58.3	4	12.0	8	20.0	-	-	3	2.4	-	-	-	-	-	-
11 UBON RATCHATHANI	7	278.9	13	217.0	39	38.0	6	9.2	-	-	24	17.1	2	N.A.	-	-	1	29.9
12 CHAIYAPHUM	1	36.5	7	138.3	14	55.4	26	35.8	-	-	11	45.7	-	-	-	-	-	-
13 NAKHON RATCHASIMA	12	459.9	21	317.3	119	4846.6	517	3735.4	10	178.2	21	37.8	5	N.A.	-	-	-	-
14 BURI RAM	5	189.8	31	514.9	19	100.0	93	82.9	-	-	2	1.3	-	-	1	40.3	2	160.0
15 SURIN	8	299.3	27	427.0	12	204.3	14	17.1	-	-	7	2.7	2	N.A.	-	-	-	-
16 SI SA KET	1	29.2	11	175.1	4	7.6	19	18.3	1	-	16	150.0	-	-	-	-	-	-

NOTE: [1] Big (80 tonnes/day), Medium (30-80 tonnes/day)
No: Number of factories
N.A.: Data not available
T.P.: Total Product (thousand tonnes/year)

SOURCE: Reference [2]

For rice, the total production was 5,180,900 tonnes per year, and the number of big and medium scale rice mills were 64 and 161, respectively. These rice mills were mainly located in changwat centers and in urbanized amphoes (small towns) in the rice producing areas. For cassava, the total production, including chips, pellets, and flour, was 11,990,700 tonnes per year and the number of chipping, pellet, and flour plants were 1193, 319, and 13, respectively. Most of the cassava processing plants are located in Nakhon Ratchasima, Khon Kaen, and Udon Thani. For kenaf, the total production, including baling and textiles was 431,600 tonnes per year and the number of baling and textile plants were 146 and 12, respectively. Kenaf plants are mainly located in changwat centers such as Khon Kaen, Ubon Ratchathani, Nakhon Ratchasima, Si Sa Ket, and Udon Thani. For sugarcane, the total production, including brown and refinery sugar, was 654,500 tonnes per year, and the number of brown and refinery sugar plants were 4 and 6, respectively. Large-scale sugar plants with processing capacity of more than 2,200 tonnes per day of sugarcane are in Khon Kaen, Udon Thani, and Buri Ram. It should be noted that Nakhon Ratchasima, Khon Kaen, and Udon Thani are the principal cities producing and processing the major crops.

Past production trends indicate that the production of the major crops in the region has increased. The production of upland crops such as cassava and sugarcane in particular has been increasing rapidly over the past ten years. This may be due to the improvement of the road network and the expansion of the planted area [1]. The need for truck transport in the region has increased in response to this trend.

2.3.2 The Transportation System Servicing Truck Transport

The major transportation modes in the northeast region are highways, railways, and air transport. Of these, highway (truck) transport is by far the most important mode of freight transportation. Most agricultural products in the region are transported by trucks.

The region's highway network consists of national (primary and secondary) and provincial highways owned by the Department of Highways (DOH). There are about 1,600 km of primary, 3,200 km of secondary, and 7,600 km of provincial highways [1]. The highway networks under DOH in the region are illustrated in Figure 2.2. This figure shows the arterial highway network which consists of five primary highways and 23 secondary highways. For the primary highways, routes 2 and 24 are the principal highway arteries and the rest, routes 12, 22, and 23, traverse the region east and west from route 2 and also constitute the spokes of the highway network. However, secondary highways interwoven between primary highways share an indispensable role in the highway transportation of the region. In addition, a number of provincial and rural roads supplement the primary and secondary highways. Typical cross sections for primary highways and provincial highways are illustrated in Appendix A-1.

There are two railway lines extending from Bangkok to Nong Khai and to Ubon Ratchthani after branching at Nakhon Ratchasima (Figure 2.2). Although these railway lines are sometimes used to transport some freight such as petrol, bamboo, etc., they are mainly used for passenger transport. It should be noted that one railway line parallels routes 2 and 24.

2.3.3 The Truck Transport Flow Pattern

As mentioned, agricultural products in the region are mainly transported by truck. These truck flows are principally divided into three segments, namely: (i) truck flows from farms to processing plants; (ii) truck flows from processing plants to the markets (domestic consumers) within the region, and between the region and the rest of the country; and (iii) truck flows from processing plants to exporters in Bangkok or in other cities of the central region, such as Chonburi and Chacheongsao. For example, in the case of cassava, cassava product will be

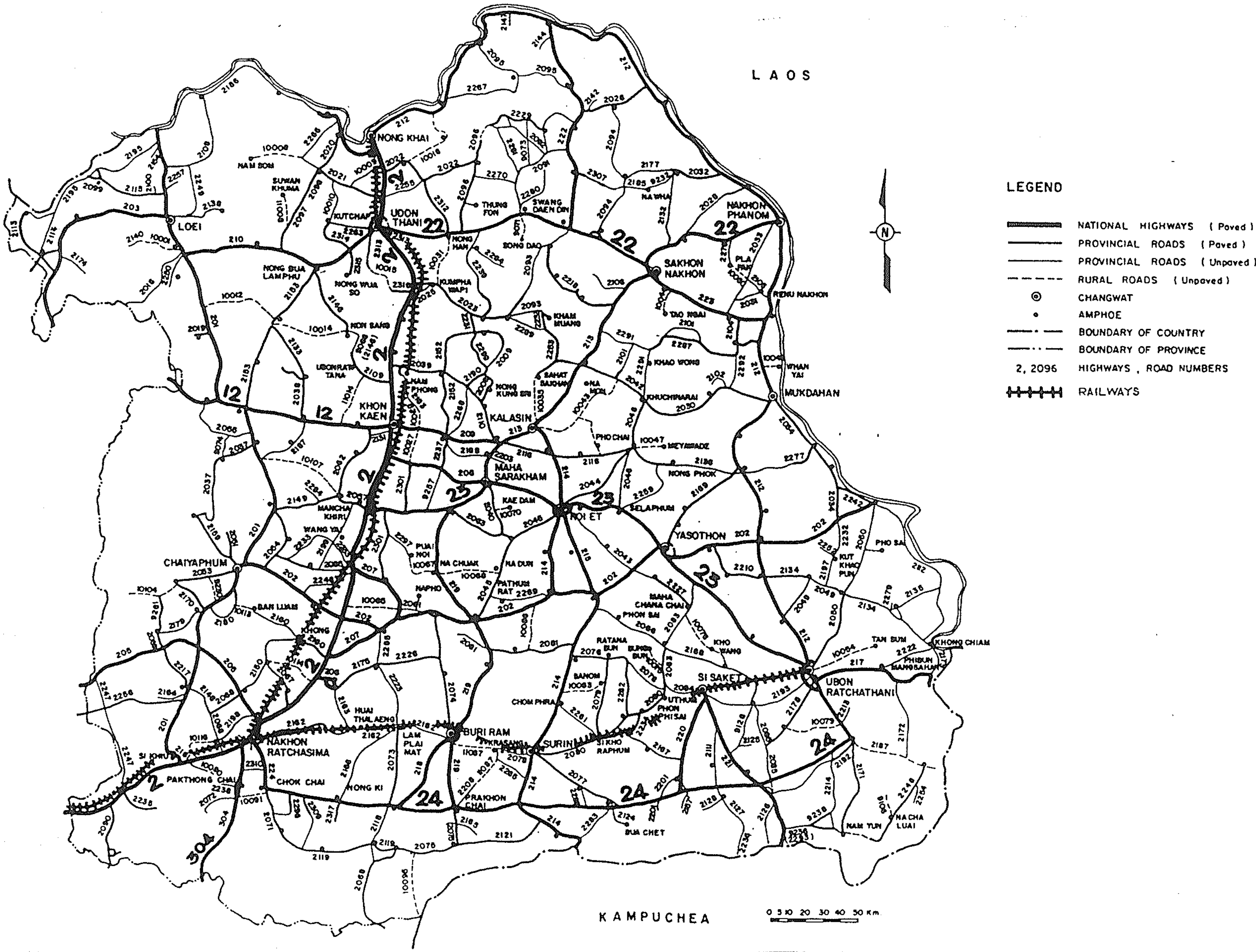


Figure 2.2 Highway networks under Department of Highways in the Northeast region

(Source: Reference [2])

transported to some small scale cassava chip plants along provincial roads near cassava producing areas. Cassava chips are mainly transported to large-scale pellet or flour plants to be processed. Then some processed materials (cassava flour) are distributed to the market within the region, and between the region and the rest of the country, but most of the processed materials go to exporters in Bangkok.

Commodity flows of the main crops (rice, cassava, kenaf, and sugarcane) are illustrated in Appendices A-2 to A-5. Most producing areas and processing plants are located along routes 2 and 24. The major routes used to transport processed material to exporters in Bangkok and other cities are Routes 2, 24, and 304. In general, the commodity flows of rice, cassava, and kenaf are quite similar, in that the processing plants are located adjacent to producing areas of each specific crop. Therefore, the flow lengths are generally short. However, for sugar cane, the flow lengths are relatively long, because of the small number of processing plants, and therefore, their less-distributed location.

Tables 2.2 and 2.3 show truck flow surveys for 6- and 10-wheel trucks, respectively. These surveys were conducted by DOH in 1980 at D1 to D7 locations, detailed and illustrated in

Table 2.2 Truck flow surveys for 6-wheel trucks

Truck Operation	Observed Location							TOTAL
	D_1	D_2	D_3	D_4	D_5	D_6	D_7	
Total Loaded Trucks (trucks/day)	81	40	39	101	50	17	15	343
Total Loaded Plus Empty Trucks (trucks/day)	305	256	274	421	336	64	62	1718
Empty Rate (%)	73	84	86	76	85	73	76	80

Table 2.3 Truck flow surveys for 10-wheel trucks

Truck Operation	Observed Location							TOTAL
	D_1	D_2	D_3	D_4	D_5	D_6	D_7	
Total Loaded Trucks (trucks/day)	352	121	70	114	316	195	32	1200
Total Loaded Plus Empty Trucks (trucks/day)	475	232	207	218	692	258	71	2153
Empty Rate (%)	26	48	66	48	54	24	55	44

Source: References [2] and [3].

Appendices A-6 and A-7. Observation points D1 and D2 are located on route 2, D5 and D6 on route 24, D3 on route 12, D4 on route 22, and D7 on route 212. It should be noted that four of seven observation points are located on the principal primary highways (routes 2 and 24) in the region. As such, this data probably represents the major commodity flows in the region. In the 24-hour surveys, the truck flow data were collected for 6- and 10-wheel trucks with respect to different GVW levels and the four different commodity types. The commodity types were: (i) vegetables, fruits, and animals; (ii) construction materials such as cement, steel, gravel, etc.; (iii) rice, fertilizer, and other major crops; and (iv) all others. According to the truck flow data observed, rice, fertilizer, and other major crops (i.e., commodity group iii) were the major commodities carried by those trucks. These commodities accounted for approximately 40% and 50% of the total number of 6- and 10-wheel loaded trucks, respectively.

It is difficult to compare the truck flow data illustrated in Tables 2.2 and 2.3 to the commodity flow patterns for the major crops shown in Appendices A-2 to A-5. While the flow patterns shown in those appendices are the truck flows from farms to processing plants, the truck flow data in Tables 2.2 and 2.3 represent the combined truck flows for different segments, as described previously. However, some relevant observations can be made:

(i) At location D1 on route 2 (Khon Kaen-Udon Thani), the total number of loaded trucks per day combined for both 6- and 10-wheel trucks is 433 (780 trucks per day for loaded plus empty trucks). This number is the highest value among the seven observed locations. The percentage of loaded trucks (combined 6- and 10-wheel trucks) carrying rice, fertilizer and other major crops is approximately 54% of the totals. At location D1 on route 2, rice, cassava, kenaf and sugarcane transported to processing plants at amphae Nam Pheng (no. 0609) have to pass by this observation point. In particular, the sugar plant at Nam Phong had a large capacity of more than 5,000 tonnes per day and each plant collected more than 1 million tonnes of sugarcane during the period from November to May in the 1983 crop year [1]. These considerations, coupled with the transportation of processed materials of those crops to the markets and exporters in Bangkok can explain the large number of loaded trucks per day observed at this point.

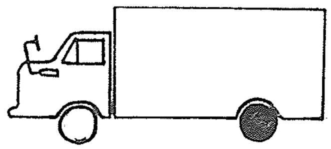
(ii) At location D5 on route 24 (Chok Chai-Hang Rong), the total number of loaded trucks per day combining both 6- and 10-wheel trucks is 366 (1028 trucks per day for loaded plus empty trucks). The percentage of loaded trucks carrying rice, fertilizer, and other major crops is approximately 41% of the total. At location D5 on route 24, rice and kenaf transported to processing plants at Nakhon Ratchasima and sugarcane transported to processing plants at Buri Ram will pass by this observation location. Particularly, route 24 has been mainly employed to transport cassava from adjacent producing areas to processing plants in amphoe Chok Chai. It should be noted that the total cassava processed materials (Chip, pellet, and flour) in changwat Nakhon Ratchasima, including amphoe Chok Chai, has the largest value of all 17 changwat in the northeast region [2]. In addition to these considerations, the truck flows carrying processed materials of those crops from processing plants along route 24 to the markets and exporters in Bangkok are significant reasons for the high total number of loaded trucks observed at location D5.

2.4 GOVERNING VEHICLE WEIGHT AND DIMENSION (VWD) REGULATIONS

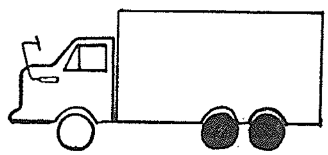
All regions in Thailand employ the same VWD regulations. These regulations are also applied for all roads throughout the country. However, for some rural roads, the trucks are limited by specific bridge capacity limits.

Figures 2.3 and 2.4 show the four most common truck types operated in the northeast region and Thailand. These truck types are:

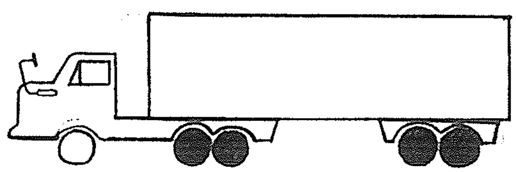
(i) 2-axle, 6-wheel (2) straight trucks (vehicle type I);
(ii) 3-axle, 10-wheel (3) straight truck (vehicle type II);
(iii) 5-axle tractor-semitrailer (3-S2) combination (vehicle type III);
(iv) 3-axle, 10-wheel straight truck plus 2-axle full-trailer (3-2) combination (vehicle type IV).



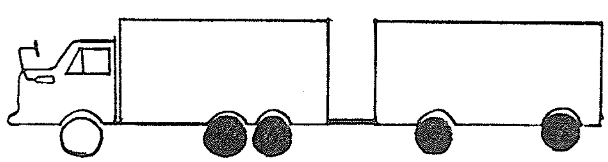
2-axle, 6-wheel (2) straight trucks (vehicle type I)



3-axle, 10-wheel (3) straight truck (vehicle type II)



5-axle tractor-semitrailer (3-S2) combination (vehicle type III)



3-axle, 10-wheel straight truck plus 2-axle full-trailer (3-2) combination (vehicle type IV)

○ Single wheel

● Dual Wheel

Figure 2.3 The four typical truck types in the Northeast Region

2-axle, 6-wheel single unit truck (Vehicle Type I)

2-axle, 10-wheel single unit truck (Vehicle Type II)

Figure 2.4 The real features of the four typical truck types in the Northeast Region

Tractor semitrailer combination (Vehicle Type III)

10-wheel truck plus full-trailer combination (Vehicle Type IV)

Figure 2.4 The real features of the four typical truck types in the Northeast Region (continued)

Table 2.4 The changes in basic maximum VWD regulations in 1976 for the four typical truck types operating in Thailand

Vehicle Characteristics	Vehicle Type I		II		III		IV	
	Pre-1976	Post-1976	Pre	Post	Pre	Post	Pre	Post
Maximum Dimension (m)								
Height	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Width	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Total Length	10.0	10.0	10.0	10.0	15.0	18.0	18.0	18.0
Maximum Axle Loads (kg)								
Steering Single Axle	2000	2900	3600	4600	3600	4600	3600	4600
Non-steering Single Axle	8000	9100	-	-	-	-	8000	9100
Tandem Axle	-	-	14400	16400	14400	16400	14400	16400
Maximum Gross Vehicle Weight (kg)	10000	12000	18000	21000	32400	37400	34000	39200

Table 2.4 shows the VWD regulatory changes in 1976 and the basic maximum VWD regulations governing in Thailand for the four common truck types. The maximum size limits (height, width, and total length) for those four vehicle types are constant except for the tractor-semitrailer combination. The individual semitrailer length was changed from 12.0 m to 12.5 m (not shown in the table) and the total tractor-semitrailer combination length was also changed from 15.0 m to 18.0 m in 1981.

On the other hand, there were many changes in axle load and gross vehicle weight (GVW) limits. Axle load limit changes are summarized as follows::

(i) the steering-single axle load limit was increased from 2,000 kg to 2,900 kg for vehicle type I, and from 3,600 kg to 4,600 kg for other vehicle types;
(ii) the non-steering single axle (dual tires) load limit was increased from 8,000 kg to 9,100 kg, and
(iii) the tandem axle load limit was increased from 14,400 kg to 16,400 kg;

GVW load limit changes are summarized as follows:

(i) GVW limits were raised from 10,000 kg to 12,000 kg for vehicle type I;
(ii) GVW limits were raised from 18,000 kg to 21,000 kg for vehicle type II;
(iii) GVW limits were raised from 32,400 kg to 37,400 kg for vehicle type III; and
(iv) GVW limits were raised from 34,000 kg to 39,200 kg for vehicle type IV.

Those changes were made for primarily economic reasons. The increase in axle load limits and and attendant increase in GVW limits lead to an increase in payload capacity and productivity for each truck type.

Table 2.5 shows the comparison of governing VWD regulations in Thailand to those in Canada, Europe, and the United States. A number of observations can be made:

Table 2.5. Comparisons of governing VWD regulations in many countries.

VWD Regulatory Elements	THAILAND	CANADA[1]	EUROPEAN COUNTRIES	U.S.A.
(I) DIMENSION LIMITS (metre)				
Max. height	3.80	4.15	4.0	4.11-4.27
Max. width	2.50	2.60	2.50-2.60	2.44-2.60
Max. length				
- straight truck & tractor	10.0	12.5	11.0-12.4	10.7-18.3
- trailer	8.0	12.5-14.7	11.0-12.5	8.5-15.2
- semitrailer	12.5	13.5-15.5	12.0-N.S.	14.6-N.R.
- tractor-semitrailer	18.0	20.0-23.0	15.5-24.0	**
- straight truck plus trailer	18.0	20.0-23.0	18.0-24.0	**
- double trailer	-	21.0-23.0	18.0-24.0*	**
(II) AXLE LOADS LIMITS (tonnes)				
Steering single axle	4.6	5.5-9.1	10.0-13.0	9.0-10.0
Non-steering single axle	9.1	9.0-10.0	10.0-13.0	9.0-10.0
Tandem axle	16.4	16.0-20.0	16.0-21.0	15.4-16.3
Triple axle	-	16.0-30.0	21.0-27.0	19.0-24.5
(III) GROSS VEHICLE WEIGHT LIMITS (tonnes)				
Straight truck	21.0	26.0-47.5	24.0-32.0	20.9-26.3
Tractor-semitrailer	37.4	37.5-57.5	38.0-44.0	36.3***
Straight truck plus trailer	39.2	50.0-63.5	38.0-44.0	36.3***
Double trailer	-	50.0-63.5	38.0-44.0	36.3***

SOURCE: References [6], [7], [9], and [41]
N.S.: not specified, N.R.: not restricted
* not permitted in some countries
** no length limits on the Interstate system (as per STAA, effective June 1988) [6]
*** GVW limits up to 36.3 tonnes (80,000 lbs) allowed on all Interstate highways [41].
[1] Pre-RTAC proposed VWD regulations

1. The maximum height limit of trucks in Thailand (3.80 m) is slightly less than that in Canada, Europe and the U.S. (4.0-4.27 m). This situation leads to a cubic capacity reduction, important to trucks operating under "cube-out" conditions, and also leads to inefficient container transportation. It is very difficult to transport a standard container on a flat-deck truck under the 3.80 m height limit. It would be suitable to raise the height limit up to a value which could facilitate container transport (approximately 4.20 m). However, it is essential to limit the height of trucks to within an appropriate value, because too much increase in height limits (and therefore, a higher center of gravity) can aggravate truck stability and control.

2. The maximum width limit in Thailand is equal to that used in several other countries. However, there is an increasing trend toward using trucks with 2.6 m rather than 2.5 m width. This can provide a higher cubic capacity and higher running stability, and facilitate the use of refrigerated trucks and the transport of standard pallets.

3. The maximum limits for both individual and combination lengths in Thailand are generally less than those in other countries. This is very important to the trucking industry in Thailand, particularly for "cube-out" truck operations, because the most efficient approach to increasing truck payload and therefore productivity is to employ longer trucks. The individual length limit for straight trucks (10.0 m) and trailers (8.0 m) have never simultaneously been achieved under the total length limit of 18.0 m for the straight truck plus full trailer combination, because part of the total combination length has to provide for draw bar length. It would be suitable to increase the overall length limit of this truck type to facilitate the utilization of both straight truck and full trailer at maximum length limits. Another issue is that while the overall length limit for a tractor-semitrailer unit is 18.0 m, the individual semitrailer length is restricted to 12.5 m. According to the individual semitrailer length limit (12.5 m), the overall length has never reached 18.0 m. Therefore, it would be appropriate to allow the use of a longer individual semitrailer length. Particularly when considering international freight (container) transportation, there is a strong pressure to change individual semitrailer length limits to facilitate the container transport. The new standard container lengths are 45 and 48 feet, which cannot be handled by existing Thai semitrailer length limits (12.50 m). However, off-tracking performance should be determined in this regard. It should be noted that the double trailer combination is not allowed to operate in Thailand.

4. A non-steering single axle load limit in Thailand is relatively compatible with those in other countries. However, for tandem axles, the axle load limit governing in Thailand lies approximately at the minimum values of those in Canada and Europe. This is possibly because there is no increasing tandem axle load allowance as a result of spreading out the axle. It should be noted that an axle load limit for tandems in Thailand lies at the maximum value of that in the U.S. For a steering single axle, the load limit in Thailand is significantly less than that in other countries. It should also be noted that the Thailand government has not allowed the use of triple axles.

5. The maximum GVW limit for all vehicle types in Thailand are generally less than those in Canada and European countries. The main reasons are the lower axle load limits for all axle types, no increases in tandem axle load limit as a result of spreading out the axle, and no allowance for using triple axles. For straight trucks, the GVW limit used in Thailand is less than that in the U.S.A. However, for tractor-semitrailers and straight truck plus trailer units, the GVW limits used in Thailand are greater than those in the U.S.A. The GVW limit for each vehicle type in Thailand is based on the summation of allowable axle load limits of axles in that vehicle type, for example, tractor-semitrailer units consist of a steering single axle, two sets of tandem axles with axle load limits of

4.6 tons and 16.4 tons, respectively. Therefore, the GVW limit for tractor-semitrailers is 37.4 tons (4.6 + 16.4 + 16.4).

2.5 TRUCK FLEET AND OPERATING CHARACTERISTICS IN THE NORTHEAST REGION

Vehicle types I and II are the principal truck types used to transport several agricultural commodities within the region, and between the region and the rest of the country. Nevertheless, based on discussion with truck operators and government officers in the summer of 1987, there is a growing use of heavier/larger truck combinations (in particular of types III and IV) in the region. These combinations provide higher payload capacity (higher productivity), lower operating costs, and lower fuel consumption. However, vehicle types I and II still dominate the truck fleet in the northeast region.

A principal factor influencing truck fleet and operating characteristics is VWD regulations. In general, the companies which produce various types of trucks understand such regulations and therefore try to design those trucks to match the governing regulations. Typically, trucks are designed to take as much advantage as possible of the opportunities available for maximizing payload capacity within the confines of the VWD regulations. However, the effects of VWD regulations on truck fleet and operating characteristics are complicated by a number of non-VWD factors, such as operational preferences, commodity characteristics, route characteristics, etc. The following description will introduce the general truck fleet and operating characteristics in the northeast region.

2.5.1 Truck Tare Weights

Table 2.6 [4] shows the average tare weights for 6- and 10-wheel trucks (vehicles type I and II, respectively). It can be seen that the tare weight for the 10-wheel truck (8.54 tons) is significantly greater than for the 6-wheel truck (4.75 tons).

Table 2.6 Truck tare weights

	6-Wheel	10-Wheel
No. of sample	43	75
Average Tare Weight (tonnes)	4.75	8.54
Standard deviation (tonnes)	1.35	0.44

SOURCE: Reference [4]

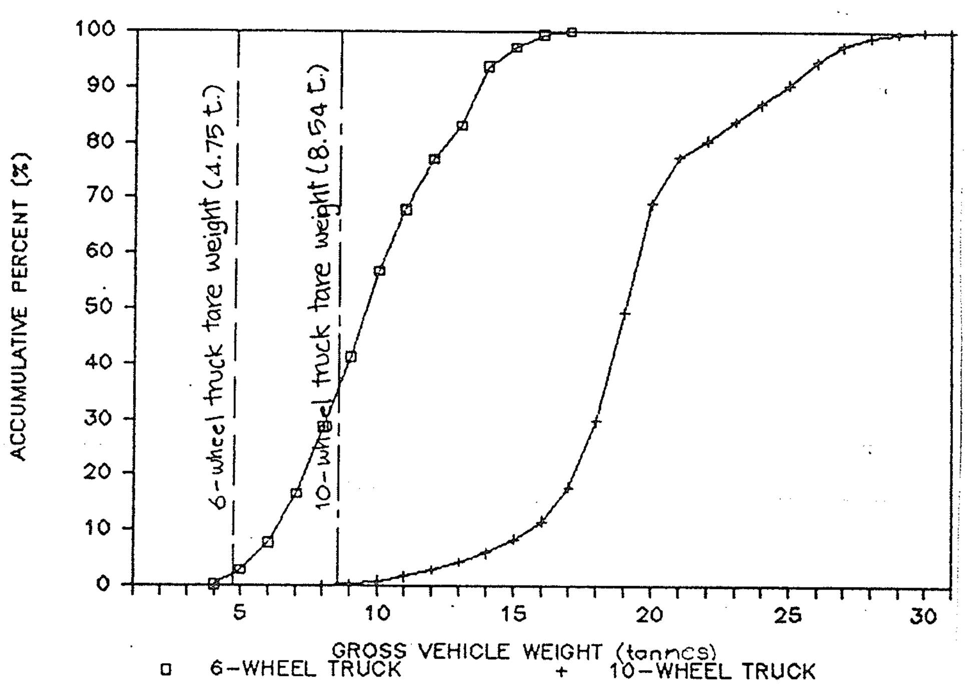


Figure 2.5 GVW Distributions of loaded 2-axle, 6-wheel and 3-axle, 10-wheel trucks observed in 1980 in the Northeast Region.

2.5.2 Gross Vehicle Weight Distribution

Surveys on the GVW distributions for 6- and 10-wheel trucks were conducted by DOH at the seven locations (D1-D7) in the northeast region in 1980. This survey is the same as that described in Section 2.3.3. Figure 2.5 shows the GVW cumulative distribution curves for 6- and 10-wheel trucks operated in the region. Details of GVW distributions and GVW cumulative distributions of those truck types are illustrated in Appendix A-8. It should be noted that Figure 2.5 is the result of the analysis of weight of loaded trucks only. Some observations are as follows:

1. The average GVW's of loaded 6- and 10-wheel trucks are approximately 10.3 tons and 20.0 tons, respectively, and the standard deviation of GVW distributions of 6- and 10-wheel trucks are 2.8 tons and 3.6 tons. This means that the GVW distribution of 10-wheel trucks is more dispersed than that of 6-wheel trucks. Although these trucks are restricted under the same size regulations, 6-wheel trucks are suitable for low density commodities, but 10-wheel trucks are suitable for high density commodities. This is because the maximum GVW limit and actual average GVW of 6-wheel trucks are significantly lower than those of 10-wheel trucks.

2. For both 6- and 10-wheel trucks, approximately 77% of all loaded trucks are operated at less than these respective GVW limits (12 tons for 6-wheel trucks and 21 tons for 10-wheel trucks). The remaining 23% are overloaded. The observed maximum GVW of 6- and 10-wheel trucks are approximately 17.0 tons and 31.0 tons, respectively. It should be noted that incidence of overloaded truck operation is very high.

3. 10-wheel trucks are more important to traffic and bridge engineers than 6-wheel trucks, because 10-wheel trucks are operated at greater GVW levels and the number of loaded and overloaded 10-wheel trucks are greater than those of 6-wheel trucks. The number of loaded and overloaded trucks for 10-wheel trucks is 1,200 and 272 trucks per day, while the number for 6-wheel trucks is 343 and 79 trucks per day.

2.5.3 Payload Distribution

This analysis relates the GVW distribution curves for 6- and 10-wheel trucks (described in Section 2.5.2) to the typical tare weight of those truck types (described in Section 2.5.1). The difference between those two values represents the distribution of weight payload handled by these truck types. Key observations are as follows:

Based on maximum GVW limits, the weight payload capacity for 6-wheel trucks is 7.25 tons (i.e., 12.0 tons, max. GVW limit - 4.75 tons, average tare weight) and that for 10-wheel trucks is 12.46 tons (i.e., 21.0 tons - 8.54 tons). The average actual weight payload for 6-wheel trucks is 5.55 tons (i.e., 10.3 tons, average GVW - 4.75 tons), and that for 10-wheel trucks is 11.46 tons (i.e., 20.0 tons - 8.54 tons). This means that the average actual weight payload of 10-wheel trucks is more than double that of 6-wheel trucks. Figure 2.5 shows that, while 77% of all 6-wheel trucks are operated under the maximum weight payload of 7.25 tons, only approximately 11% of all 10-wheel trucks are operated under that value. In other words, 89% of 10-wheel trucks are operated at higher payload than the maximum payload capacity of 6-wheel trucks.

According to these findings, 10-wheel trucks are more productive, in case of the "weight-out" operating situation, than 6-wheel trucks. Although the tare weight of 10-wheel trucks is higher than that of 6-wheel trucks, this situation is compensated for by the fact that the 10-wheel truck can operate at a substantially greater weight payload capacity.

2.5.4 Truck Operating Characteristics in the Northeast Region

Table 2.7 shows the percent share by farmers, factories, and middlemen in collecting and transporting the raw materials from farms to processing plants for the four major crops (rice, cassava, kenaf, and sugarcane). Almost all sugarcane and more than 80% of cassava are transported to processing plants by farmers in their own or hired trucks. However, while 50% of the paddy crop is still dealt with by middlemen, kenaf is mainly collected by the factories [1]. Generally, farmers are poor and rarely own either 6-wheel or 10-wheel trucks. Farmers usually own small trucks (2-axle, 4-wheel trucks), or "Eatan" trucks as shown in Figure 2.6 and described in Appendix A-9. Farmers will employ these trucks to transport their product from their farms to the factories. However, when the distance between farm and factory is large and a large amount of product is to be transported, farmers will hire a larger truck such as 6- or 10-wheel trucks, to transport their products.

Table 2.7 Transportation of raw material from farm to factory in the northeast Region

Crop	Transport by (%)		
	Farmer	Factory	Middlemen
Sugarcane	100	-	-
Cassava	82	5	13
Rice	37	13	50
Kenaf	13	69	18

SOURCE: Reference [1], pp. 2-18.

Figure 2.6 The "Eatan" truck

The factories and middlemen generally employ 6-wheel trucks and 10-wheel trucks to transport the raw products from farms to the factories. It should be noted that utilization of larger/heavier truck types such as vehicle type III or IV to transport such products from farms to factories is often unsuitable, because these truck combinations are too long and too heavy for the route to the farms.

Ten-wheel trucks are the main truck type for the transportation of processed material from the processing plants to the markets or exporters in Bangkok or in other cities in the central region. However, there is an increasing trend toward using tractor-semitrailer units and/or 10-wheel trucks with a full trailer to accomplish this activity. However, 6-wheel and 10-wheel trucks still dominate agricultural product transportation in the northeast region.

It should be noted that based on the truck flow data described in Section 2.3.3, the percentage of empty trucks for both 6-wheel (80%) and for 10-wheel trucks (44%) is very high. The situation for 6-wheel trucks is worse than that for 10-wheel trucks. This can be partly explained by the fact that there is considerable competition among 6- and 10-wheel truck operators [4]. This percentage of overloaded trucks for both 6- and 10-wheel trucks (the same 23%) is also very high. The reason for this truck overload situation is inappropriate enforcement.

2.6 CASE STUDIES

This section presents the results of interviews with truck operators conducted by the author during the summers of 1987 and 1988 in the northeast region of Thailand.

2.6.1 Case Study I

Place: Changwat Khalasin

Number of Trucks Owned: 3

Truck Characteristics: See Appendix A-10

Principal Commodities Handled: Cassava processed products, milled rice, fertilizer, and construction materials such as cement, steel, etc.

Operation Routing: Khalasin-Bangkok (approximately 530 km).

Commodity Sources: Two cassava processing plants and rice mills in Khalasin, and the cooperative company in Bangkok.

Cassava Product Transport: Cassava products are mainly transported from farms to processing plants by farmers. The farmers generally use small trucks (2-axle, 4-wheel trucks) and/or "Eatan" trucks as described in Section 2.5.4 to transport these products. Occasionally, farmers hire 6- or 10-wheel trucks to carry out this activity. When the trucks arrive at the processing plants, they are weighed at the scale, and then drop off the product at designated areas. They are then weighed again to determine the actual load carried. A typical processing plant is shown in Figure 2.7.

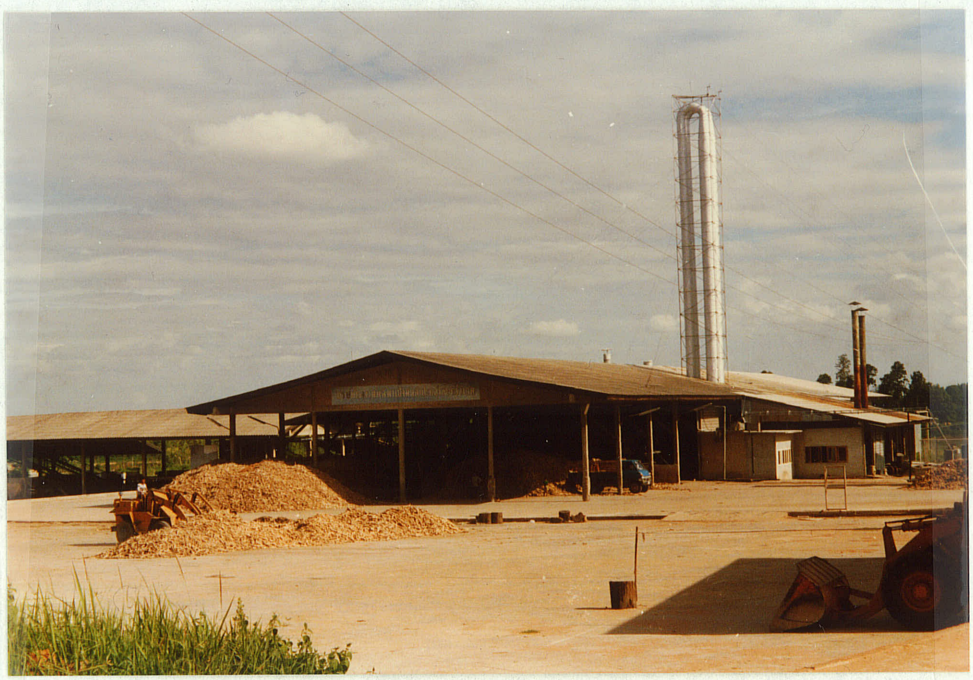


Figure 2.7 A cassava processing plant in changwat Khalasin

Processed products will generally be transported from the plants to the markets in Bangkok by 10-wheel trucks. 10-wheel truck plus full trailer and tractor-semitrailer combinations are sometimes employed for this purpose. However, since there is high competition within the trucking industry and there are sometimes not enough cassava products to transport, many trucks are often used to haul other commodities such as milled rice, kenaf, etc.

Cost Considerations: Usually, farmers will plant cassava in May-June with the growing period being 6 to 14 months. The harvesting period will depend upon the market price and government policy. In the northeastern region, the price of cassava product (raw cassava) is set by the processing plant and government policy.

Effects on Farmers: If the market price of cassava product is high, the cassava processing plant will raise the buying price of cassava product in order to encourage the farmers to harvest and sell their products to the processing plant. The truck operator mentioned that the price of cassava fluctuates. For example, the low price is approximately 500 baht/tonne, the high price is about 1,250 baht/tonne, and the normal price is 800-900 baht/tonne (approximate exchange rate is 21.00 baht to $1 Cdn).

Effects on Truck Operators: Because the cassava processing plants usually adjust freight shipments to match the markets in order to maximize their profits under the fluctuating market prices, the plant usually has a large capacity to store the products from the processing plants for long periods of time. This is the main reason for the fluctuation of truck traffic and transporting price. For example, when there is a large amount of processed cassava product in storage, and at the same time, the market price of such product is high, the plants will hire a number of trucks to transport such products to the markets in Bangkok. This is because the processing plant owners want to sell their products at the highest possible profits. The transport rate will therefore be high. The same scenario works in reverse. The truck operator said that the transport rate in October-March is high, approximately 290 baht/tonne as compared with the normal rate of 160-170 baht/tonne.

Profit Versus Loss: The truck operator stated that he hires one driver per truck at a wage of 6,000 baht/month. In addition, for each Khalasin-Bangkok round trip, the operator has to pay 2,300-2,400 baht/trip to cover the overhead cost, fuel cost, and small maintenance costs (i.e., oil, tire repair, etc.). In the back-haul trip, if the truck returns loaded, the truck operator usually earns approximately 1,600-2,000 baht/trip.

It is assumed that the truck carries 14 tonnes from Khalasin to Bangkok at a rate of 170 baht/ton and also carries commodities for the return trip (receiving 1,800 baht). The net revenue will be roughly 1,880 baht/trip ([170 x 14] + 1,800 - 2300). However, if the returning truck is empty, the net revenue will be 80 baht/trip. In the latter case, it is not worthwhile to operate a truck under a one-way loading situation.

In a real situation, it is even worse for both cases, because the following costs must also be taken into account: driver salary (approximately 6,000 baht/month), maintenance cost, tire replacement cost, depreciation cost, annual licence fee (6,000 baht/year), insurance cost (12,000 baht/year), and administration cost.

VWD Regulation Considerations: The truck operator explained that a 10-wheel truck plus a full trailer (vehicle type IV) can provide more benefit than a 10-wheel truck without a trailer. However, there are a number of difficulties in shifting from a 10-wheel truck to a truck plus full trailer. These difficulties are as follows:

(i) the stock engine power of the 10-wheel truck (120 hp) is not enough to haul a full trailer. Therefore, the original engine must be modified in order to raise the power to 170 hp. In addition, the truck operator has to buy a full trailer for each 10-wheel truck. The initial investment cost is very high:
- engine modification cost = 50,000 baht
- full trailer cost = 150,000 baht
- net payment = 200,000 baht

(ii) there is a fluctuation in the amount of commodity to be transported and high competition in the trucking industry.

(iii) the flexibility in operation of such a combination is less than that of 10-wheel trucks. For example, it is difficult for the combination to pass on the small roads and to negotiate sharp turns in rural planting areas.

2.6.2 Case Study II

Place: The storage office of the Shell Company Ltd., Khon Kaen

Capacity of Storage Tanks:

Premium tank: 500,000 litres
Benzine tank: 500,000 litres
Gasoline tank: 1,700,000 litres

Changwats being served: Khon Kaen, Loei, Sakhol Nakhon, Udon Thani, Nong Khai, Roiet, Maha Sarakham

Truck Characteristics: As shown in Appendix A-11

The manager of the Shell office explained that there have been three storage offices in the northeastern region - at Nakhon Ratchasima, Ubon Ratchathani, and Khon Kaen. At the Khon Kaen storage office, fuel (premium, benzine, and gasoline) is transported from the central storage tank in Bangkok to Khon Kaen by rail, and then is pumped from the railway station to separate storage tanks for each type of fuel.

The Shell Company makes an annual contract with a trucking company and the trucks of that company serve the petrol pump stations in the changwats previously described.

Cost Considerations: In each fuel delivery from storage tank to any pump station, the total costs including cost of fuel and fuel transportation can be calculated from the following expression:

$$\text{COST} = \Sigma\,[(C - D) \times L] + P \times T$$

where: C = the unit fuel price (baht/litre) depending on fuel type,
D = the discounted rate (baht/litre) of fuel price depending on fuel type,
L = amount of fuel to be transported (litres)
P = maximum fuel carrying capacity of trucks or truck combination (litres)
T = fuel delivery rate charged (baht/litre)

The fuel price (C) is specified by the government. The discounted rate (D) will be applied only when the pump station owners immediately pay for their bill in cash; this rate is set by Shell. The delivery rate (T) is established by Shell based on the distance between the storage tank and the pump station. It can be seen that the total fuel delivery cost consists of fuel cost (Σ [(C - D) x L] and delivery cost (P x T). The delivery cost (P x T) is independent of the type and amount of fuel delivered. This means that no matter which type and how much fuel is to be transported, the delivery cost is still the same. Therefore, all pump stations try to order as much fuel as possible in each order. Furthermore, the manager of the Shell office stated that because the delivery cost is high, many pump stations buy their own trucks to transport the fuel.

Truck Operator Opinion on VWD Regulations: The truck operator explained that his trucks have never violated the governing VWD regulations, because the trucks were designed according to the regulations. This implies that his trucks were influenced by VWD regulations only during design and construction. The operator also stated that he preferred not to use larger truck combinations. His reasons were as follows:

- existing trucks are suitable to handle the amount of fuel to be transported
- if the demand for fuel remains constant and the operator decides to use heavier and larger truck combinations such as vehicle types III or IV, the truck operator would have to dispose of trucks and drivers. This situation is worsened if the demand for fuel decreases.
- many pump stations buy their own trucks to transport fuel from storage tank to the stations because the transporting cost is cheaper. This situation would reduce the demand for fuel delivered by the operator's truck.
- the initial investment cost is quite high for engine improvement, purchasing new full trailers and/or new semi-trailers.

2.6.3 Case Study III

Place: Phoenix Pulp & Paper Company Limited, as shown in Figure 2.8, amphoe Nam Pong, Khon Kaen

Capacity of the Company: 350 tonnes per day

Major Raw Materials: bamboo and kenaf

Sources of Raw Materials: Changwat Kanchanaburi (570 km) and Prachinburi (380 km) for bamboo, and changwat Khon Kaen, Udon Thani, and adjacent planting areas for kenaf.

Kenaf Transportation: The head of the transportation division of the company explained that this company is the biggest company producing pulp to supply many paper making companies in Thailand. The Phoenix company is located in the northeast region because the region produces the greatest amount of kenaf in the country (based on average kenaf production from 1981 - 1983, 97% of total kenaf products in Thailand are produced in the northeast region).

The company set up many center collection points to purchase kenaf product from farmers throughout the region. Each center collection point collects that product and then contracts with trucking companies to transport it to the processing plant at amphoe Nam Pong. The vehicle types used to transport kenaf product are 10-wheel trucks, 10-wheel trucks with full trailers, and tractor-semitrailer units. However, the farmers will sometimes hire 6-wheel or 10-wheel trucks to transport and directly sell their products to the processing plant at Nam Pong. Figure 2.9 shows kenaf transportation carried by 10-wheel trucks.

Figure 2.8 A pulp producing plant at Amphoe Nam Pong, Khon Kaen

Figure 2.9 Kenaf transportation by a 10-wheel truck

Bamboo Transportation: Bamboo is another raw material for paper making. The two main sources of bamboo are in changwat Kanchanaburi and Prachinburi in the central region. Some is also collected from many places throughout the northeast region.

There are two ways to transport bamboo from Kachanaburi to the processing plant in Nam Pong: First, bamboo can be hauled from Kanchanaburi to Non Payom train station (approximately 20 km from the plant) and then transferred to trucks (i.e., 6-wheel trucks, 10-wheel trucks, 10-wheel trucks with full trailers or tractor-semitrailers). Some of these vehicles are shown in Figure 2.10. Those trucks will carry that amount of bamboo directly to the processing plant and drop it off at designated areas. Second, the 10-wheel truck plus full trailer and tractor-semitrailer combinations used to transport the processed product (bales of pulp) from the plant to the markets in Bangkok will carry bamboo from Kanchanaburi back to the plant. Therefore, these truck combinations are loaded for both forehaul and backhaul trips. For each 10-wheel truck plus full trailer unit, the same facilities, both truck and trailer, are used for forehaul and backhaul trips. This is because both truck and trailer in that combination are owned by the same person, and he does not want to leave his own trailer at Bangkok and haul someone else's trailer back to the plant. However, for tractor-semitrailers, the operator usually owns only a tractor, and rents the semitrailer from the plant. Therefore, the truck driver will drop the semitrailer holding processed product at Bangkok and haul a new semitrailer containing bamboo back to the plant at Nampong.

It should be noted that the second approach is the main one. The first approach is used only when the demand for bamboo is high. Although the cost for both approaches is approximately the same, the first causes longer travel time and the availability of the service and its capacity cannot be ensured all the time.

Bamboo transportation from Prachinburi to the processing plant can be carried out only by truck transport. The plant will make a contract with carriers to transport bamboo. The larger/heavier truck combinations such as truck plus trailer and tractor-semitrailer combinations have been used. However, in the rainy season the amount of bamboo from Prachinburi decreases because of the difficulties of getting trucks into the bamboo growing areas.

The Utilization of Larger/Heavier Truck Combinations:

In order to transport bamboo from Kanchanaburi or Prachinburi, the larger/heavier truck combinations are principally used. This is because those combinations can carry a larger amount of bamboo in each trip and the distance between origin and destination is quite far (570 km for Kanchanaburi and 380 km for Prachinburi). Further, these combinations will carry commodities for both forehaul and backhaul trips, which in turn increase benefits.

2.7 APPARENT PROBLEMS AND OPPORTUNITIES FOR IMPROVEMENT

According to the previous sections, a number of truck transportation problems related to the VWD regulations are revealed. These problems and opportunities for improvement are summarized as follows:

6-wheel trucks

A 10-wheel truck plus a full trailer combination

Figure 2.10 Bamboo transportation from Non Payom Railway Station to a pulp producing plant

2.7.1 VWD Regulatory Problems

There are a number of VWD regulatory problems potentially causing inefficient and therefore less productive truck transportation. These problems and ways to alleviate them are discussed below.

The maximum height limit (3.80 m) of truck vehicles operating in Thailand is relatively low. According to the international freight transportation, there is an increasing trend toward using standard containers to carry freight between countries. This consideration suggests that it is necessary to increase height limit up to the value which will facilitate a container on a flat-deck truck operation. This means that the height limit should be raised to 4.20 m. This consideration will also raise, to some extent, the cubic capacity of trucks for other commodity types (mainly low density commodities). However, height is still limited by vertical clearance of bridges and truck stability and control performance (the higher the center of gravity, the lower the manoeuvring stability).

The maximum width limit (2.50 m) in Thailand is compatible to that in other countries. However, there is a strong pressure to increase the width limit from 2.50 m to 2.60 m in many countries (i.e., European countries). This is because the 2.60-m width limit provides more efficient truck operation such as for refrigerated trucks, trucks handling standard pallets (i.e., 120 x 80 cm) or other standardized building elements. This consideration is also applicable to the Thailand situation, and suggests that it is necessary to increase the width limit in Thailand to 2.60 m. It should be noted that the increase in width limit can also increase stability and control performance, and cubic capacity of these trucks.

Individual vehicle length limits and overall combination length limits were not appropriately set up. The first issue is that while individual truck and trailer length limits are restricted to 10.0

m and 8.0 m, respectively, the overall truck plus full trailer length limit is 18.0 m. This means that the individual truck and trailer lengths can never simultaneously reach their limits within the overall combination length limit of 18.0 m because part of the overall length is occupied by drawbar length. This consideration suggests that the overall truck plus full trailer length limit should be increased to allow the truck and trailer to operate up to their individual length limits. The second issue is that while the overall length of tractor-semitrailer is limited to within 18.0 m, the individual semitrailer length is limited to 12.5 m. This means that the actual combination length never reaches the limit of 18.0 m whenever the semitrailer length is 12.5 m. This consideration suggests that the individual semitrailer length limit should be raised up to the value allowing the overall combination length of 18.0 m.

The increases in individual truck vehicle and overall combination length limits will improve truck operational efficiency and productivity. However, these length limit increases would potentially cause unacceptable problems involving turning characteristics or associated with highway geometry requirements in the case of individual vehicle length. For the combination length, the length limits should be restricted by highway geometry considerations (i.e., passing sight distance, turning characteristics, etc.), traffic considerations (i.e., highway capacity, level of service, etc.), vehicle load distribution on bridges, safety considerations (stability and control). It should be noted that in many countries including Thailand, these technical bases have never been clearly used to determine length limits [6, 9]. Truck vehicles operating under "cube-out" situations require increased length limits, and there is pressure for individual and/or combination length limit to accommodate standard containers. Therefore, it should be appropriate to increase the individual and combination length limits at least up to the values facilitating the handling of containers (the standard lengths of containers are 45 and 48 feet).

The load limit on single steering axles is relatively low. This limit should be increased and restricted in the same manner as non-steering single-tire single axles. Tandem axles can carry more load when the axles are spread out. This suggests that the axle spreading regulations should be established to facilitate this matter, and to control the damaging effects of different axle types (i.e., tandem and triple axle) on highway pavements. Triple axle should be allowed because such axles can carry more load than tandem axles. However, load carrying capacity of triples must be based on the axle spread and suspension system [6, 9].

GVW limits in Thailand are based on the summation of axle load limits of all axles in the vehicle, and can be enhanced by increasing axle load limits and/or adding more axles. The addition of more axles in the vehicle will reduce load bearing on each axle, while increasing GVW of that vehicle. This will reduce adverse effects on pavements, but possibly increase adverse effects on bridges. Therefore, the axle spacing regulations should be established to control the effects of heavier vehicles (higher GVW) on bridges. For 10-wheel trucks, the GVW limit may be able to be enhanced by increasing the steering single axle load limit up to the limit of the non-steering single axle, and by increasing the tandem axle load limit by spreading out the axles. For tractor-semitrailer combinations, GVW limit can be efficiently increased by changing the semitrailer axle from tandem to triple axle, as shown in Figure 2.11. The distance between the tandem axle of the tractor unit and the triple axle of the semitrailer must satisfy the axle spacing regulation, and axle spread of the triple should be kept within an appropriate range because the triple axle with wide spread can aggravate dynamic manoeuvres of the combination [8]. For a 10-wheel truck plus full trailer unit, the GVW limit can be efficiently enhanced by changing the rear axle of the trailer unit from a single to a tandem axle, as shown in Figure 2.12. The axle spacing limit must also be applied for this consideration.

Although axle spread and spacing regulations can be used to control the damages of load on pavements and bridges, another type of regulation, namely "Bridge Formula" has been used in this regard in many countries (i.e., U.S.A., Canada (Ontario)). The bridge formula is quite

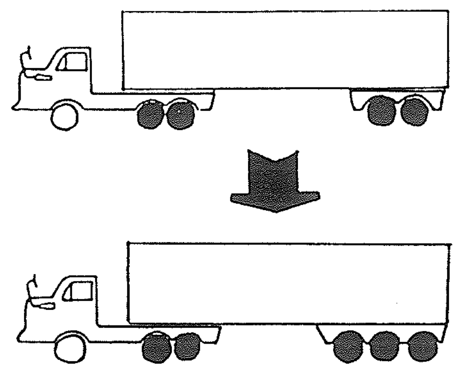


Figure 2.11 Semitrailer axle change from tandem to triple axle

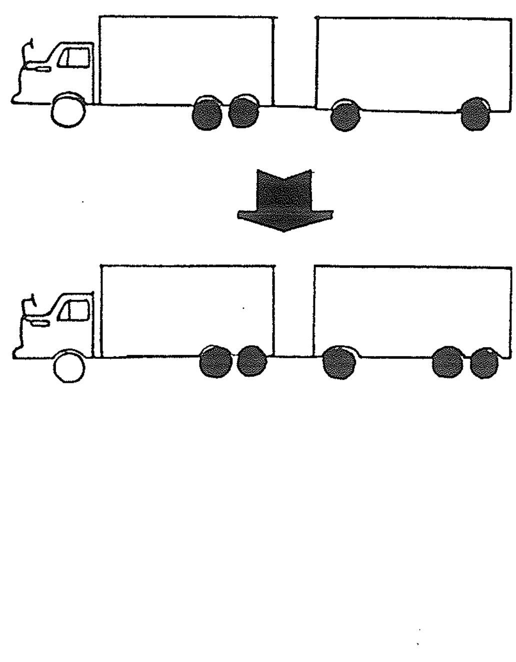


Figure 2.12 Full trailer axle change fro two single to one single and one tamdem axle

complex, but it works well in controlling pavement and bridge damage, and at the same time furnishes a more efficient and productive truck operation. Therefore, it would be more appropriate for the Thailand government to develop a bridge formula to regulate the trucking industry in future.

2.7.2 Overweight Enforcement

It is apparent that approximately one-fourth of both loaded 6- and 10-wheel trucks are operated under highly overweight situations. This possibly results from inadequate enforcement control. The overweight circumstance is worse for 10-wheel trucks in particular, because the overloaded10-wheel trucks are operated at much greater GVW than overloaded 6-wheel trucks, and the total number of overloaded 10-wheel trucks per day (272) is significantly higher than the number of overloaded 6-wheel trucks per day (79). Overloaded trucks have an adverse effect on both highway pavements and bridges. It is recommended that effective enforcement programs must be increased; as well, the expected cost of fines, coupled with the probability of being detected, must be greater than the incentive to overload [5].

2.7.3 Larger/Heavier Truck Utilization

According to discussion with government officers and truck operators, it was found that 6- and 10-wheel trucks have been dominant in the trucking industry in the northeast region. There has been little increase in number of tractor-semitrailer and truck plus full trailer units, even though utilization of these combinations will lead to an increase in payload capacity and therefore in productivity. The following factors are reasons for such circumstances:

- there is very high competition in the trucking industry
- there is as seasonal fluctuation in the amount of freight to be hauled. This factor, coupled with the highly competitive trucking situation, can force truck operators to stop operation for some period of a year because of lack of freight to be handled.

- the legal increases in axle load limits, as well as illegal increases (resulting from overloaded truck operation) encourage truck operators to continue using their existing trucks, because they can operate their trucks at higher GVW and therefore productivity, without any investment for new trucks.

- truck operators indicated that larger truck combinations such as tractor semitrailers or trucks with full trailer combinations have difficulties in accessing the farms.

- the capital investment for modifying the engines of existing trucks or for purchasing new trucks such as tractors, semitrailers, or full trailers, is relatively high.

- cultural and traditional factors play a part. For example, the operator does not want to shift from two 10-wheel trucks to a truck plus a full trailer combination, because he would have to lay off one driver.

CHAPTER 3

TRUCK FLEET AND OPERATING CHARACTERISTICS AS A FUNCTION OF GOVERNING WEIGHT AND DIMENSION REGULATIONS

3.1 THE PURPOSE OF THE CHAPTER

In Canada, Vehicle Weight and Dimension (VWD) regulations governing the trucking industry have had a marked effect on truck fleet and operating characteristics. In examining these regulations and the trucking industry's response to them, certain patterns emerge which can be applied to the situation in Thailand. The purpose of this chapter, then, is to review recent literature in this area, in order to extract these areas of relevance.

For the purpose of clarity in reviewing the complex literature in this field, the chapter has been organized to address the following objectives:

(a) to examine general Canadian VWD regulations;
(b) to examine how VWD regulations affect truck fleet selections;
(c) to examine how VWD regulations affect truck fleet mix;
(d) to examine how VWD regulations affect actual gross vehicle weight (GVW);
(e) to examine how non-VWD factors affect truck fleet characteristics;
(f) to determine the limitations in existing knowledge.

3.2 CANADIAN VWD REGULATIONS

VWD regulations are the governmental tool to protect highway infrastructure such as pavements, vertical and horizontal roadway geometry, and bridges from rapid deterioration due to operation of too heavy and large truck configurations. In addition, the effects of truck operating performances such as offtracking, braking, passing manoeuvres, stopping distance requirement, etc. on traffic flow capacity and level of service, accident records, environment (vibration, noise, air pollution), and public concerns also have some influence on VWD regulatory setting. VWD regulations generally restrict the maximum size (height, width and length) and maximum weight (tire load, axle weight and gross vehicle weight) of different types of vehicles. However, in some cases, the bigger and heavier vehicles are allowed to operate under special permits.

The Canadian VWD regulations are composed of six basic elements [6]. These elements are

- vehicle height
- vehicle width
- vehicle length (for trucks and tractors, trailers, semitrailers, and combinations)
- tire loads
- axle loads (for single-front-steering, other-front-steering, single, tandem, triple)
- gross vehicle weights

In addition to these principal elements, there are a number of VWD regulatory elements such as axle spread, axle spacing, kingpin-to-rear of unit, behind cab-to-rear, etc., interacting and complicating the six principal elements mentioned above.

For example, GVW limits have been mainly affected by axle load limits, axle spread regulations, axle spacing regulations, and axle number limitations [6]. GVW limits for a particular vehicle can be increased by directly increasing GVW limits up to the values equal to sum of existing axle load limits of all axles in that vehicle, directly increasing axle load limits, allowing higher axle load limits by spreading out the axles (for tandem and triple axle) and adding more axles by allowing the use of triple, tri-, and quad axles. As a result of adding more axles in the truck, axle spacing regulations will be applied to ensure that the allowable GVW of the truck will not deteriorate bridge structure.

These VWD regulatory elements are established and administered differently among the different provinces. This, coupled with the complicated jurisdictional structure (e.g., municipal, territorial, provincial, and federal governments) leads to a complex and non-uniform VWD regulatory structure. The complexity and non-uniformity of the VWD regulations potentially affect truck fleet characteristics and their operations. For example, most of the truck transport operated under multiple VWD regulations in different regions must conform to the least common regulatory denominators, or must reduce the load carried or change the vehicle prior to passing through the higher restrictive region.

Over time, the Canadian VWD regulations have been changed in the direction of providing the use of bigger and heavier trucks. For example, the single-axle load, tandem-axle load, and GVW limits were increased from 18000, 32000, and 74000 pounds to 20000, 35000, and 110000 pounds, respectively, on primary highways in the Prairies according to the Prairie Highway Strengthening Program (H.S.P.) in 1974. The single-axle load, tandem-axle load, and GVW limits were raised to 20000, 40000, and 110000 pounds, respectively, on all major highways in the Atlantic provinces according to the Atlantic Highway Strengthening Program in 1978. For primary highways, the GVW limit was increased to 118000 pounds in Alberta and Saskatchewan and to 124600 pounds in Manitoba, and for secondary highways, the GVW limit was raised from 74000 to 108000 pounds in the prairie provinces according to their VWD regulatory changes in 1981/82 [12]. The main reason for introducing these VWD regulatory changes was to improve economy and uniformity in truck operations because the utilization of bigger and heavier trucks operating under the more uniform VWD regulations among several regions would lead to higher efficiency and productivity in truck transportation. The truck productivity consideration is even more important when the trucking industry is currently subjected to recession, rising fuel prices, inflation, etc.

Table 3.1 summarizes allowable limits on height, width, length, tire load, axle load and GVW for various truck types in different provinces as of January, 1988 [11] (it should be noted that a lot of other considerations about VWD regulations have not been included in this table).

3.3 TRUCK CHARACTERISTICS AND VWD REGULATIONS

There are many factors influencing the dimension, shape, weight, and configuration characteristics of large trucks operating on highway systems. One of the principal factors is VWD regulations. Lill [13] pointed out that "...Trucks are designed to obtain the most effective use of what the size and weight laws permit". The relationship between VWD regulations and truck-fleet characteristics is important to highway and bridge engineers and planners regarding, for example, how the configurations (fleet mix) and GVW of large trucks responding to the VWD regulatory changes affect highway structural capacity (the higher the axle load, the more deterioration), highway bridge strength (the higher the GVW and the less distributed, the more deterioration), and highway geometry (the wider and longer the vehicle, the more highway improving requirements, such as lane-widening at intersections, passing lanes, and so on.

The following subsections discuss the effects of VWD regulations on truck fleet selections, fleet mix, and actual G.V.W. It should be noted that these effects are based on pre-RTAC VWD regulations (before February 12, 1988).

3.3.1 The Effects of VWD Regulations on Truck Fleet Selection

The operator faces three basic options in response to changes in VWD regulations. The first option is to continue using the old truck configurations. In this situation, the truck operator can take advantage of the regulatory changes only by directly increasing GVW limits up to the

Table 3.1 Canadian weight and dimension regulations

	ALLOWABLE DIMENSIONS (metres)								
	height	width	length						
						combinations			
			truck or tractor	full trailer	semi trailer	tractor -semi	truck + trailer	A-train	B-train
Nfld	4.15	2.6	12.5	14.65	14.65	20.0	20.0	*	21.0
NS	4.15	2.6	12.5	14.65	14.65	21.0	21.0	*	21.0
PEI	4.5	2.6	12.2	none	none	20.0	*	*	*
NB	4.12	2.6	12.5	14.65	14.65	21.0	21.0	*	21.0
Que	4.15	2.6	12.5	14.65	15.5	23.0	23.0	23.0	23.0
Ont	4.15	2.6	12.5	12.5	14.65	23.0	23.0	23.0	23.0
Man	4.15	2.6	12.5	12.5	none	20.0	21.5	23.0	23.0
Sask	4.15	2.6	12.5	12.5	14.6	20.0	23.0	23.0	23.0
Alta	4.15	2.6	12.5	12.5	none	20.0	23.0	23.0	23.0
BC	4.15	2.6	12.5	12.5	14.65	20.0	23.0	23.0	23.0
Yukon	4.2	2.6	12.5	13.5	13.5	22.5	22.0	*	*
NWT	4.2	3.05	12.5	12.5	none	21.5	21.5	24.4	24.4

	ALLOWABLE LOADS (kg, except tire loads) (3)								
	tires kg/mm	single axle		tandem axle	triple and/or triaxle	maximum gvw			
		front steer	non-front			truck	truck + trailer	tractor semi	train (2)
Nfld	10	9,000	9,000	18,000	27,000	34,000	52,500	48,500	52,500
PEI	10.7	9,000	9,000	18,000	27,000	26,082	*	53,296	*
NS	rating	9,000	9,000	18,000	27,000	34,000	50,000	48,500	50,000
NB	10.7	9,000	9,000	18,000	27,000	34,000	56,500	48,500	56,500
Que	rating	8,500	10,000	20,000	30,000	37,500	57,500	57,500	57,500
Ont	11	9,000	10,000	19,100	30,000	47,500	63,500	63,500	63,500
Man	9	8,190	9,100	16,000	16,000	32,000	56,190	40,190	56,500
Sask	9	5,500	9,100	16,000	16,000	27,000	53,500	37,500	53,500
Alta	9	7,300	9,100	16,800	16,800	30,400	53,500	40,900	53,500
BC	11	9,100	9,100	17,000	26,100	34,000	60,100	52,200	63,500
Yukon	11	9,000	10,000	19,100	28,600	47,500	63,500	63,500	*
NWT	8	6,500	8,128	16,256	16,256	29,256	54,500	39,012	54,500

Table 1 Weight and Dimension Regulations (1)

NOTES

1) *The information is subject to qualifications and/or conditions. These regulations apply to most trucks, on primary highways, in summer driving conditions. Various area, vehicle, commodity or hauling-type, seasonal, highway, and other exceptions apply (but are not shown).*

2) *In some cases, lower GVWs apply depending on whether the combination is an A- or B-train.*

3) *Tolerances have not been included. There are a number of axle-spread and axle-spacing requirements that must be met.*

* *Special permits required.*

(Source: Reference [11], pp. 14)

values equal to the sum of the existing axle load limits of all axles in that vehicles and by increasing axle load limits (and therefore GVW limits). A second option is to modify an old truck configuration to be more productive (e.g., adding more axles, changing axle position/spreads, adding a trailer). The third option is to adopt a new vehicle for operation (e.g., purchasing 7-axle double-trailer (A- or B-train)) to replace a 5-axle (3-S2) tractor semi-trailer combinations). It should be noted that the second and third options involve the increases in size limits (length limits of individual vehicles and combinations) and/or weight limit (axle load limits (and therefore GVW) or only GVW (by increasing axle numbers)).

The responsive outcome resulting from VWD regulatory changes is also significantly affected by the operating situations ("weight-out" or "cube-out" operation involving commodity density). "Weight-out" operation involves the truck reaching the GVW limit, prior to the truck space being filled. Therefore, "weight-out" operation involves the handling of "high-density commodities", and the truck needs more weight rather than space. In contrast, "cube-out" operation involves the truck being fully filled in cube prior to reaching its GVW limit. This operation involves "low-density" commodities and the truck needs more space rather than weight. It should be noted that any truck operated at "weight-out" level is sensitive primarily to the changes of axle load limits and GVW limits, but the truck operated at "cube-out" level is sensitive primarily to changes of length limit.

The truck operator operating his own trucks under a single VWD regulatory regime will take the highest advantage from the governing VWD regulations based on "weight- or cube-out" operating situations. For example, for "weight-out" situations, the operator will employ the truck configuration providing the greatest GVW handling capability, but for "cube-out" situations, the operator will adopt the one which provides the greatest cubic capacity (in practice, usually the longest configuration). However, whenever those trucks are subject to multiple VWD regulatory regimes, the operator has three basic options to respond to this circumstance: (i) to employ truck configurations matching the least common regulatory denominators; (ii) to employ the truck configuration which can be modified to operate under several regulations by means of placing many adjustable devices on that configuration such as sliding fifth wheels, moveable kingpins, liftable axles, sliding axles, etc.; (iii) or to employ the existing configurations, but the operator will have to reduce the load carried (less than truckload operation) or change the vehicle (i.e., turnpike double combination will drop the second trailer off at the border between different regulatory jurisdictions) prior to passing through the more restrictive region [11, 17]. Each of these responses leads to truck transportation inefficiencies and increase truck operating costs.

3.3.2 The Effects of VWD Regulations on Truck Fleet Mix

The increases in axle load limits (and therefore GVW limits) or only in GVW limits (by adding more axles) will potentially stimulate the truck configurations currently operating under "weight-out" situations to carry more payload by adopting bigger and/or heavier truck configuration types. As a result of the Prairie VWD regulatory changes in 1974 and in 1981-82, in Manitoba, double-trailer proportions in the truck fleet mix are gradually increasing over time, while the proportions of straight trucks and single drive axle tractors and vehicle combinations employing single drive axle tractors are declining [14]. This is because the maximum GVW limits can be achieved only by using double trailer combinations, as straight trucks and any other truck configurations towed by single drive axle tractors cannot even come close to that GVW limit. It should be noted that A-train combinations are dominant in double-trailer configurations rather than B-train units because A-train units can carry freight at higher GVW value than B-train units (maximum GVW of 56,500 kg versus 53,500 kg).

Other evidence shows that according to the Atlantic Highway Strengthening Program in 1978, 5-axle tractor-semitrailer units (3-S2's) have decreased in terms of the total number of trips and total amount of freight carried, while 6-axle (3-S3's) tractor-semitrailer units have significantly increased in those two aspects [10]. This is because 6-axle tractor-semitrailers can carry freight at higher GVW value than 5-axle ones.

However, the use of existing truck configurations to carry more payload due to increases of axle load limits and therefore GVW limits will possibly have a quicker response than the use of a new and more productive configuration. The evidence for this is that, in response to the Western Canadian Provinces Highway Strengthening Program (HSP) in 1974 and in 1981-82 in Manitoba, standard 5-axle tractor-semitrailer combinations rapidly registered at higher GVW limits (i.e., because of increased limits on axle loads), while the double-trailer combinations progressively registered at higher GVW limit [15, 16].

This is because the operators can directly obtain benefit from the VWD regulatory changes by using the old configurations without any concern about the capital investment for a new configuration, existing useful life of an old configuration, tare weight increase, enough commodity quantity, or any operational problems.

Although the existing truck configurations will respond to the increases of axle load limits and therefore GVW limit in a faster manner, the absolute GVW increases are, however, small when compared to the GVW increased due to using bigger/heavier configurations and the further increases in axle load limits will be restricted by highway pavement strength. This regard, coupled with competitive and economic pressures, will force truck operators to employ the bigger/heavier truck configurations. For example, the operators previously operating straight trucks and/or single drive axle tractor-semitrailer units (2-S1 or 2-S2) have shifted to such a larger/heavier configuration as 3-S2 units and, in another case, the operators have changed from 3-S2 units to double trailer units such as 3-S2-2 (A-train) or 3-S2-S2 (B-train) combinations. It should be noted that the above considerations deal with "weight-out" situations only.

The increases in individual vehicle length and/or combination length limits will potentially encourage the truck configurations presently operating at "cube-out" situations to employ the bigger truck configurations. In Canada, there are three apparent cases illustrating the response of those VWD regulatory changes: (i) the use of a longer semitrailer (48 ft versus 45 ft) in a tractor-semitrailer unit; (ii) the use of a long wheel-base tractor carrying a drome box in a tractor-semitrailer unit; and (iii) the use of a double-trailer unit (3-S1-2 (A-train) unit) are apparent evidence. In the second case, in addition to the individual vehicle and combination length limits, these truck configurations are also affected by restrictions on load-carrying devices (dromes) on tractors. As regulated by the combination length limit, the double-trailer units are also subjected to the kingpin-to-rear or behind cab-to-rear length limits in some provinces. In some cases, while the double-trailer units (28 ft) fit well with the 23-metre combination length limit, these units have difficulty operating within the 16.75 metre kingpin-to-rear limit [11]. In order to allow double-trailer units to take advantage of increasing length limits (increase cubic capacity), the kingpin-to-rear limit should also be increased.

In addition to the VWD regulatory changes, the differences of VWD regulations among various different regions also affected truck configuration types and fleet mix operating in those regions. In 1984, Atlantic-provincial truck fleet mix consists of 52.5% of straight trucks, 45.0% of tractor-semitrailers, and 2.5% of double combinations and, in 1978, the prairie-provincial mix consists of 16.2% of straight trucks, 72.0% of tractor-semitrailers, and 11.7% of double combinations [11]. This shows that, in Atlantic provinces, the straight truck is the most important configuration type and more important than tractor semitrailer units, while the reverse is true for the prairie provinces.

It should be noted that the proportion of double trailer combinations in truck fleet mix in the Prairie provinces is greater than that in the Atlantic provinces. Therefore, double-trailer units are more important to the trucking industry in the prairies than that in the Atlantic provinces. there are a number of reasons which might explain this consideration: (i) while it is difficult to configure double trailer units within a total length limit of 21.0 m in the Atlantic region, there is no such difficulty in the 23.0 m total length limit in the Prairies; (ii) as double trailer (A-train) units are operated under special permits in the Atlantic region, such units are legally operated under normal VWD regulations on the Prairies; and (iii) in the Atlantic provinces, the tractor-semitrailer (3-S3) units can be operated at GVW values close to the maximum GVW limit (48,500 versus 50,000 kg, in Nova Scotia), but this regard is not the case in the Prairies. Here, the maximum GVW limit allowing for tractor-semitrailer units (3-S2) is 37,500 kg, while that for double trailer units (3-S2-2 (A-train)) is 56,500 kg [11].

Another important aspect is that the different VWD regulations for different regions can lead to the different configuration types actually operating at the governing maximum GVW limits. In the case of petroleum haulers representing "weight-out" situations, there were three different typical truck configurations (3-S3-S2 (B-train), 3-S2-S2 (B-train), and 3-S4 tractor-semitrailer units) operated under Ontario VWD regulations. There was only one typical truck configuration (3-S2-2 (A-train) double unit and 3-S3 tractor semitrailer units) operated under Manitoba and Atlantic VWD regulations, respectively [11]. It should be noted that in Ontario, the VWD regulations have been based on the Ontario Bridge Formulas (OBF) which have furnished various truck configuration alternatives under a specific GVW value. This regard will explain the situation of three different truck types operating under the same regulations.

3.3.3 The Effects of VWD Regulations on Gross Vehicle Weight (GVW)

All truck configurations operated at "weight-out" and/or "cube-out" will increase their gross weight in response to the VWD regulatory changes. However, the ones operated at "weight-out" level have a more critical and sensitive response than "cube-out" ones. This is because the "weight-out" truck units requiring more weight payload rather than more cubic capacity will possibly carry their commodities up to the new maximum allowable GVW levels while the "cube-out" trucks requiring only cubic capacity will increase their GVW due to the weight of added commodity cube only. For a particular vehicle configuration type, the heavier trucks, implying "weight-out" operations will have the quicker response to the GVW and/or axle load changes in comparison to the lighter ones, implying "cube-out", or less-than-truckload (LTL) operation. In Manitoba, for 5-axle (3-S2) tractor-semitrailer units, as the units operated at GVW's lower than the median GVW value have little change in their GVW, the units operated at higher GVW's than the median GVW value illustrate a trend of significantly and progressively higher GVW operations over time, responding to the Prairie Highway Strengthening Program (HSP) in 1974 [14]. Figure 3.1 illustrates the upper half of the GVW cumulative frequency distribution curves (1974-1984) for 3-S2 tractor-semitrailer combinations in responding to VWD regulatory changes [14]. According to the Prairie HSP in 1974, the 3-S2 units hauling freight at GVW's above the median GVW value (approximately 31,700 kg) previous to 1974 were employed to carry freight at higher GVW levels provided by greater maximum GVW allowance. Consequently, the GVW cumulative frequency distribution curves of 3-S2 units operating at greater than the median GVW value shifted to the right approaching the new GVW limit. The rate of shift to the right was fast, from 1974 to 1978, and then slowed down but progressed in the years after 1978. However, the 3-S2 units operating under the average GVW value had little change in their GVW characteristics because they operated under "cube-out" or "less-than-truckload" (LTL) situations which were unaffected by GVW limit changes.

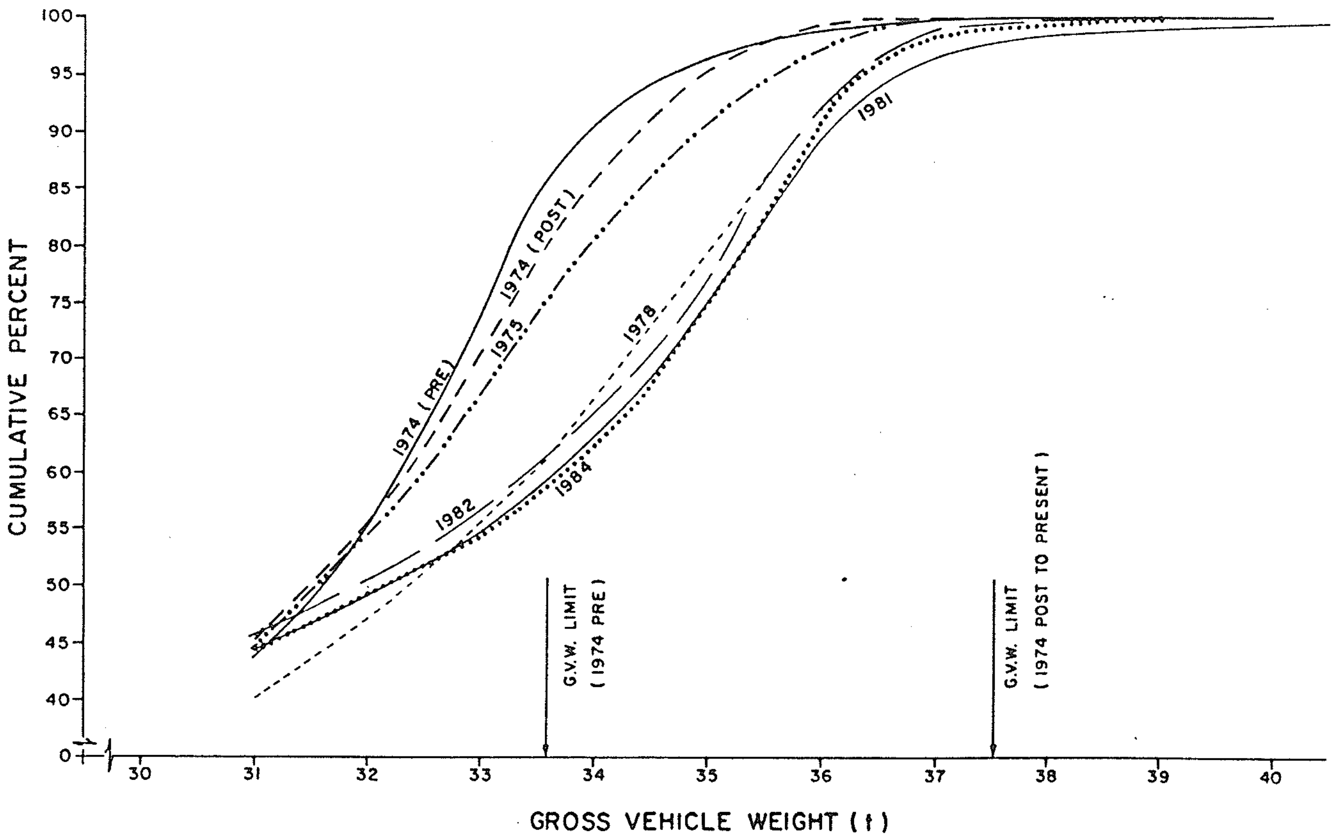


Figure 3.1 GVW cumulative frequency distribution curves for 3-S2 combinations operating on primary highways in Manitoba (1974-1984). (Source: Reference [14])

Clayton et al. [14] found that in Manitoba, 6-axle (A-train) double trailer combinations have been operated at "cube-out" situations. All of these units were operated at GVW levels significantly lower than their maximum GVW limits. This implies that the extra weight-carrying capacity provided by their allowable GVW limit is not necessary to them. Therefore, this truck type will be insensitive to the GVW limit change. However, truck configurations operating at "weight-out" and "cube-out" situations at the same time will be affected by both weight and size regulations. Therefore, any VWD regulatory changes to allow those trucks to operate at more productive levels must simultaneously relax both size and weight limits.

In truck GVW distribution observations (including all vehicle types) in Canada, Nix et al. [11] found that the heavier trucks have increased their proportion in truck fleet mix over time in response to the VWD regulatory changes, while the lighter trucks have decreased in that regard. Table 3.2 shows that as a result of the Prairie HSP in 1974 and the Atlantic HSP in 1978, the heavier trucks (GVW greater than 38.0 tonnes) in both the Prairie and Atlantic provinces increased significantly over time, while the lighter trucks declined. However, the rates of change in for the Prairie and Atlantic provinces were different, and in this case, the rate for the prairies was higher than that for the Atlantic region. For example, the proportion of trucks registering at GVW's between 38.0 and 45.0 tonnes increased from 0.0% in 1973 to 61.5% in 1978 for the Prairies, as the trucks registering in the same range of GVW increased from 37.0% in 1979 to 47.6% in 1981 for the Atlantic provinces. The response of the trucking industry in both regions to the VWD regulatory changes was similar in terms of directional trend, but different in terms of rate of change. The main factor contributing to the difference in rate is the VWD regulatory differences, particularly in maximum allowable GVW limits. This regard also links to the difference in axle load limits according to axle spreading restrictions and additional axle allowances. Ervin [18] stated that the two most important factors contributing to the differences in allowable GVW limits among many provinces across Canada are: (i) tandem axle load limits according to axle spread restrictions; and (ii) additional axle allowances in truck combinations.

Table 3.2 Distribution of registered GVW (RGVW) for all truck types

Region	Year	RGVW (tonnes)				
		0-30	30-38	38-45	45-54.5	54.5+
Western Canada	1973	29.7	70.3	0.0	0.0	0.0
	1974	44.4	21.7	33.3	0.7	-
	1978	21.1	6.2	61.5	9.5	0.6
Atlantic Canada	1979	49.3	3.7	37.0	10.1	-
	1980	42.2	3.1	41.9	12.6	-
	1981	34.1	2.6	47.6	15.7	-

Source: Reference [11]

It should be noted that in the Ontario situation, while the same trend as described above was observed, no recent VWD regulatory changes were made to encourage such a trend. Nix et al. [11] suggested that economic forces are the main reason. This consideration meant that even though there is no change in VWD regulations, truck operators try to carry more payload by using the bigger and heavier truck configurations, possibly provided by the governing VWD regulations. It should be noted that the Ontario VWD regulations permit various truck configuration choices to operate under the same or compatible weight-carrying capacities.

In summary, the above explanation clearly shows the influences of VWD regulations on truck fleet characteristics (truck fleet selection, truck fleet mix, configuration and GVW) which, in turn, affect truck operating characteristics. The major changes in truck fleet mix and physical characteristics of truck combinations result mainly from the VWD regulatory changes. The differences in truck fleet characteristics among various regions could potentially contribute to the different VWD regulatory environments.

In addition to the differences and changes of VWD regulatory limits, the VWD regulatory enforcement also affects truck fleet characteristics. The inappropriate enforcement programs will lead to overweight and/or overdimension truck operation. For example, many long wheel-base tractor pulling 48-foot semitrailer combinations have been used in the Atlantic region, although this combination exceeded the overall length limit (21 metres) [11] and tractor-semitrailer (3-S2) units are operated at GVW's greater than 37,500 kg (say, 45,000 kg) on primary highway networks in Manitoba. In the first example, the legal tractor-semitrailer units should be short wheel-base tractors with 48-foot semitrailers or long wheel-base tractors with 45-foot semitrailer combinations, and in the second example, the legal combination should be double trailer combinations such as 3-S2-2 units. These simple examples show that under the same VWD regulatory environment, the differences in degree of VWD regulatory enforcement will result in different truck fleet characteristics in terms of overall length, axle load, GVW and truck configuration types. Nix et al. [19] pointed out that "the relationship between VWD regulations and fleet cannot be fully understood without considering the method and/or vigour of enforcement practices".

3.4 THE EFFECTS OF NON-VWD FACTORS ON TRUCK FLEET CHARACTERISTICS

While VWD regulatory factors strongly influence truck fleet characteristics, there are a number of non-VWD regulatory factors which also affect such characteristics. Some of the non-VWD regulatory factors will be described as follows:

(a) **Freight Characteristics:** liquid, dry bulk, and general freight have strong influences on trailer type. For example, liquid freight will be transported in tanks, dry bulk freight is generally transported in dumps (for gravel and sand), and in hoppers (for grains and other crops, wheat, maize, etc.), and general freight is usually transported in vans. However, the most important freight characteristic is density. Freight density mainly affects truck configuration type. For example, under Manitoba VWD regulatory environments, 6-axle double trailer (3-S1-2) combinations are usually employed to transport low-density freight under "cube-out" operation. The reverse is true for 7/8-axle double trailer (3-S2-2 or 3-S2-3) combinations [14].

(b) **Route Characteristics:** trip length, highway classification, geometry layout, and geographic characteristics also affect truck fleet characteristics. For example, for a short trip length such as pick up and delivery service in urban areas, small truck configurations such as 3-axle straight trucks versus (3-S2) tractor semitrailer units or (3-S2) tractor-semitrailer units versus double trailer (3-S2-2) units are more appropriate because those smaller trucks can easily negotiate city streets and sharp turns, and require less time for loading and unloading their carried commodities. In contrast, for a long haul trip such as the commodity delivery between cities, the bigger and heavier configurations (i.e., double trailer (3-S2-2) units) are more suitable. One of the reasons why double trailer units are not widely used in the Atlantic provinces is that most of the major highways in that region are two-lane highways and consist of many steep grades and sharp curves [20].

(c) **Vehicle Operational Characteristics:** Some truck configurations are more advantageous than others in terms of weight and/or space capacity, but not in terms of operational performance. For example, some carriers prefer A-train to B-train doubles, because B-train doubles have some difficulty in backing up the first trailer (with its protruding fifth wheel) to loading docks [20]. However, some carriers still employ tractor-semitrailers rather than A-train double trailers because A-train doubles require more terminal time for hitching/unhitching and loading/unloading [20]. Some carriers prefer long-wheelbase tractors rather than short ones, because the long wheelbase tractors provide greater running stability, better riding, and aerodynamic performance [11].

(d) **Terminal and End-Point Characteristics:** The capability of equipment and space of terminals and end-points restricts the utilization of some truck configurations. For example, some carriers did not use tractor-semitrailer combinations carrying drome on the tractors because the terminal has to be redesigned to handle dromes, and some carriers did not shift from tractor-semitrailers to double trailer combinations because the turning space at terminals could not handle doubles [14].

3.5 LIMITATIONS IN THE KNOWLEDGE BASE

Although the recent research in Canada and elsewhere has found that VWD regulations have a strong relationship to truck fleet characteristics, this relationship is very complicated and not yet fully understood. In this research, there are a number of deficiencies which can lead to misunderstanding in the relationship between VWD regulations and truck fleet characteristics. Such deficiencies are enumerated as follows:

(a) Most research has been conducted to analyze the relationship between VWD regulations and truck fleet characteristics in an aggregate manner. This means that such research did not take into account operational situations ("weight-out" or "cube-out"), commodity characteristics (general freight - low density, bulk freight - high density), origin-destination (intra-, extra-, and inter-regional), combination and configuration type, etc. This consideration is very important, because trucks operating under different situations, carrying different commodities, and running on different routes have a different response to VWD regulatory changes.

(b) Some researchers assumed a certain period of time within which a full response to VWD changes will have occurred, although no research has fully understood the responsive mechanism of the trucking industry to the VWD regulatory changes. It is therefore very difficult to predict when truck operators will fully respond to VWD regulatory changes, and even then whether the full response to VWD changes will occur or not. Walton et al. [21] stated that "It has been difficult to predict future truck weight distribution patterns as affected by the alternative legislation that governs truck weight. Consequently, it has become implausible to try to forecast precisely the benefits and costs associated with changes in size and weight limits."

(c) Most research has been based only on weight payload consideration, which is the higher the allowable GVW, the greater payload. This is appropriate for trucks operated under the "weight-out" situation, but not for the "cube-out" situation, or the case of the simultaneous "weight-out" and "cube-out" situation.

(d) Some researchers have assumed particular truck characteristics scenarios responding to the VWD regulatory changes only. This is too simple, because there are various factors involved in such considerations, such as multi-layers of governing VWD regulations (road classes, time of year), nature of truck operation ("cube-out" versus "weight-out"), and so on.

(e) Probably the most important deficiency is that the researchers do not really understand the structure, interaction, and implications of VWD regulations, the importance of each element of weight and size restrictions, the complexity of VWD regulations in terms of multi-layers in single VWD regulatory regimes, and the difference between different regimes, enforcement levels, and special permits.

(f) The last deficiency is the quantity and quality of data. It is quite often the case that the data in hand cannot be used to analyze the current area of interest. This is probably because the problem and issues are changing over time, resulting in the need for a more detailed database.

CHAPTER 4

TRUCK TRANSPORT PAYLOAD PRODUCTIVITY AS A FUNCTION OF SIZE

4.1 THE PURPOSE OF CHAPTER

The main factor encouraging the use of bigger and heavier truck combinations is productivity improvement. The bigger and heavier truck combinations are potentially able to carry greater payload and therefore have higher productivity. The purpose of this chapter is:

(a) to examine the indicators of truck productivity;

(b) to illustrate how truck tare weight and commodity density affect truck productivity;

(c) to examine the theoretical truck payload capacity and actual truck payloads as a function of truck size.

4.2 MEASURING TRUCK PRODUCTIVITY

It is known that large vehicle combinations carry freight more productively than smaller one. Truck productivity can be measured in many different ways as shown in Clayton [24], Sparks [22, 23] and Organization for Economic Cooperation and Development (OECD) [7]. One of the most widely used indicators of truck productivity is total truck operating cost per unit of outcome received. Such an indicator is usually measured in terms of cents per payload tonne-km or for a given truck, in terms of $ per loaded km or $ per traveled km [23].

In some cases, the simple productivity indicators of weight payload capacity and cubic capacity of any truck vehicle are useful in assessing potential truck productivity of each truck combination type.

4.3 TRUCK TARE WEIGHTS

The gross vehicle weight (GVW) of a particular truck combination consists of weight payload handled by that vehicle plus empty weight of the vehicle combination. It is known that payload is a principal factor in determining truck productivity. Therefore, truck tare weight or empty weight of a given vehicle is an important element facilitating truck productivity analysis.

Clayton et al. [14] found that truck tare weight increases as the number of axles increases and that there were wide variations in the tare weight values of vehicles under the same classes and/or the same number of axles, possibly because of the body type differences.

Sparks [22] presented the physical characteristics of typical large vehicle combinations in Canada as shown in Table 4.1. It is clear that truck tare weight increases as truck size monitored in terms of combination length or number of axles increases.

4.4 THEORETICAL TRUCK PAYLOAD AS A FUNCTION OF SIZE

4.4.1 Weight

Weight payload is the most important and widely used parameter to monitor truck productivity. Weight payload capacity for a particular truck combination is equal to the maximum allowable gross vehicle weight of the truck minus the tare weight of that truck. In general, carriers seek

Table 4.1 Physical Characteristics of Typical Large Vehicle Combinations.

	Single Trailers	Western Doubles	Over-Lengths		
			Rocky Mtn. Doubles	Turnpike Doubles	Triples
Combination Length (m)	17-19	21-22	27	30-35	31
Number of Axles	5-6	5-7	6-8	7-9	7-9
Total Trailer Length (m)	12-15	16-17	22	24-29	25
(ft)	(40-48)	(52-56)	(72)	(80-96)	(81)
Cubic Capacity (m^3)	77-92	100-108	139	154-185	156
($x10^3 ft^3$)	(2.7-3.3)	(3.5-3.8)	(4.9)	(5.4-6.5)	(5.5)
Tare Weight (t)	12-15	13-18	16-20	17-20	17-20

Source: Reference [22], pp. 4)

the vehicle which minimizes costs by maximizing weight payload. It is known that the larger truck combinations can generally carry freight at higher allowable GVW limit, and have higher truck tare weights. However, it is found that a larger truck can carry higher payload than a smaller truck. This is because the rate of increase in the allowable gross vehicle weight limit is greater than that of an increase in truck tare weight as the size of truck combinations increase. This is shown in Figure 4.1. It should be noted that weight payload as shown in Figure 4.1 is the theoretical weight payload achieved from maximum allowable GVW minus typical tare weight for a particular truck type. It does not represent the actual payload carried for that particular truck.

The weight payload is principally related to high density commodities because high density commodities are mainly involved with "weight out" operation in which the truck reaches the GVW limit before the volume of the trailer is completely filled. Therefore, for a particular truck combination, an increase in axle load limits and/or in GVW limits (up to the value which is equal to the sum of axle load limits of all axles in that combination) will directly lead to increase in payload capacity and therefore productivity of that truck combination. However, an increase in GVW limit by employing larger truck combination usually results in a greater increase of its payload capacity and therefore, productivity.

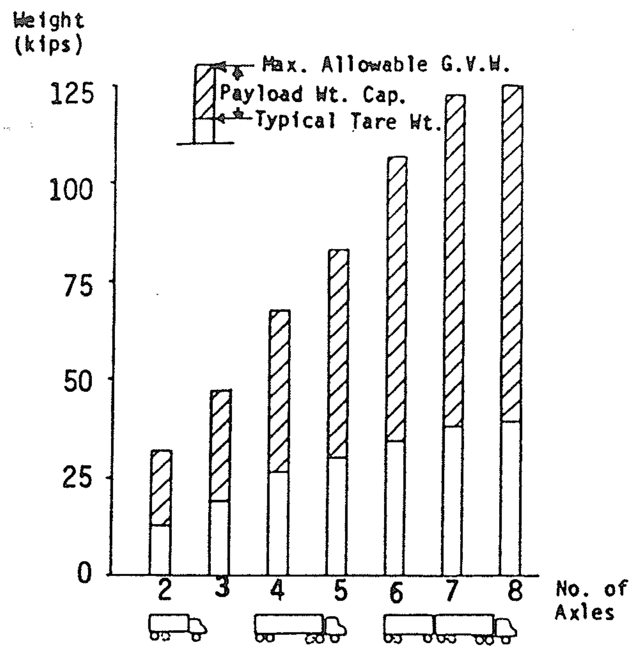


Figure 4.1 Weight characteristics by number of axles (Source: Reference [25], pp. 7.21)

4.4.2 Cube

The cubic capacity is the interior space available in a given truck type. This interior space can be considered from interior width, height and length of that truck. Cubic capacity is important to a carrier of low density commodities, who generally experiences a "cube-out" situation in which the trailer volume is filled before the truck reaches the GVW limit. The cubic capacities of truck combinations can be increased by increasing width, height and length of the trailers. However, it is generally considered impractical to increase truck cubic capacity by enhancing trailer's width and/or height [26]. It is, therefore, more practical and more efficient to achieve greater cubic capacity and productivity for low-density commodity carriers by increasing the individual vehicle and/or combination lengths. Table 4.1 shows that a longer truck combination (with longer trailer length available) will generally have greater cubic capacity than a shorter one. The approximate available cubic capacity of various commonly used vehicle types and configurations in the United States expressed in cubic feet is presented below [17].

- 40-ft (12.2-m) long trailer	- 2,500 cu ft (70.8 cu m)
- 45-ft (13.7-m) long trailer	- 2,900 cu ft (82.1 cu m)
- 27-ft (8.2-m) long trailer	- 1,700 cu ft (48.1 cu m)
- twin 27-ft (8.2-m) trailers	- 3,400 cu ft (96.3 cu m)
- twin 40 ft (12.2-m) trailers	- 5,000 cu ft (141.6 cu m)
- twin 45-ft (13.7-m) trailers	- 5,800 cu ft (164.3 cu m)
- triple 27 ft (8.2-m) trailers	- 5,100 cu ft (144.4 cu m)
- 26-ft (7.9-m) truck with 35-ft (10.7-m) trailer	- 3,400 cu ft (96.3 cu m)

The same relationship between the size of truck and the cubic capacity can be observed in Figure 4.2. Figure 4.2 also shows that the cubic capacity of each truck combination can be increased by using shorter tractors (using the short cab-over-engine (COE) tractor rather than the conventional cab-behind-engine (CBE)) and using longer trailers while keeping within the same length limit. In addition, Figure 4.2 also shows the increases in cubic capacity as a result of changing trailer width from 96 inches to 102 inches [27].

Finally, it should be noted that the cubic capacity of truck combination used to transport low-density commodities is mainly related to size limits rather than weight limits. Therefore, an increase of truck productivity, in this circumstance, can be achieved by increasing length limits or shifting to use the shorter tractor with the longer trailer length.

4.4.3 Commodity Density

Density is the most important commodity characteristic relating to truck payload and, therefore, productivity. In general, carriers try to choose the equipment fitting well to the commodity to

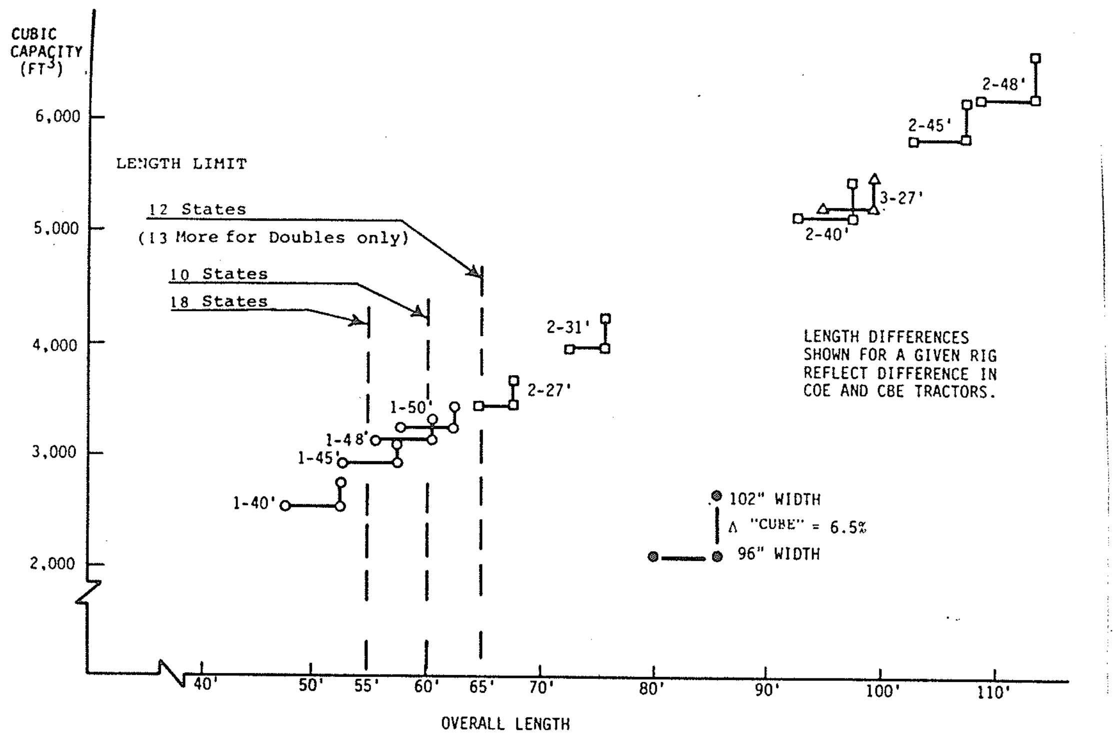


Figure 4.2 Cubic capacity versus length, width and tractor cab configurations (Source: Reference [27], pp. 15)

be carried. Each truck combination is generally designed to carry a particular freight density, namely "design density" [27]. This means the truck combination will be simultaneously filled with loads and reach its maximum GVW limit when employed to carry the commodity having its design density. Whenever this truck combination is used to transport a commodity density which is lower than the design density, the truck will be in a "cube-out" situation. The reverse is true for transporting commodity density higher than the design density, which is called a "weight-out" situation. Therefore, the design density will be used as the dividing line between commodities which will be hauled under "cube-out" or "weight-out" situations. However, because the total space of a trailer is rarely filled with loads, the design density should be emloyed only as an approximate dividing line between commodities that will cause a "cube-out" or a "weight-out" operation [27].

Truck productivity is often measured in terms of cents per tonne-km of payload. It is clear that such a productivity indicator is related to weight payload which is suitable for "weight-out" circumstances only. Therefore, if the vehicle is operated under "cube-out" situation, a more useful measure of output may be cents per cubic metre-km of payload based on volume carried. One of the reasons why truck productivity based on weight consideration is more widely used than that based on cube is that the actual cube of commodity is very difficult to measure.

Sparks et al. [22] showed the effects of density of commodity to truck productivity considerations. Sparks assumed that dry freight is a "cube-out" (low density) commodity and that bulk commodities are "weight-out" (high density) commodities. Table 4.2 shows the difference of potential cost productivity between double and single trailer combinations for both "cube-out" and "weight-out" situations. The key observations are:

> First, for the cube-out situation, the double provides cubic payload capacity at a cost of 1.185 cents/m^3-km versus 1.273 cents/m^3-km for the 5-axle unit, a situation saving of 7 percent [22].
>
> Second, for the weight-out situation, the double provides weight payload capacity at a cost of 2.43-3.56 cents/tonne-km versus 4.17 cents/tonne-km for the 5-axle unit, a saving of 15-42 percent, depending on the GVW limit [22].

It is found that for both "weight-out" and "cube-out", the larger truck combination provides more productive operation. However, the potential improvement in productivity for the larger truck combinations are different for "weight-out" and "cube-out" situations. In this case, the productivity improvement for "weight-out" operation is greater than that for "cube-out".

Table 4.2 Truck productivity characteristics of 5-axle single trailer combination and 7/8-axle Western Doubles combination

	5-axle Single Trailer Combination	7/8-axle Western Double Combination
Maximum cubic capacity (m^3)	88	108
Maximum payload capacity (t)	24	32[a]-47[b]
Operating cost @ 160,000 km/yr		
- dry freight (Cdn ¢/km)	112	128
- bulk freight (Cdn ¢/km)	100	114

[a] applies to 50.0 t GVW [b] applies to 63.5 t GVW
Source: Reference [22], pp. 3.

4.5 ACTUAL TRUCK PAYLOAD AS A FUNCTION OF SIZE

Clayton et al. [14] analyzed payload distribution for some of the truck combination types operated on Manitoba Primary Highways. The payload distributions were achieved from the differences between the GVW distribution curves and their typical tare weight for each vehicle type. Figure 4.3 illustrates the distribution of actual weight payload in various vehicle classes. The key observations summarized from this analysis [14] are presented as follows:

> First, for 3-S2 units, the potentially increasing productivity provided by higher axle weight limits was offset by tare weight increases. Therefore, the average payload slightly decreased from 16.1 t in early 1974 to 15.9 t in 1984.
>
> Second, the 6-axle A trains were obviously operated at a "cube-out" situation. The largest weight payload observed and the average weight payload handled in 1981-82 were 26.0 t and 14.8 t, respectively, while the weight payload capacity was 29.5 t.
>
> Third, both 7-axle A and B-train units were obviously operated at "weight-out" situations. In 1981-82, more than 50% of these units were being loaded at a weight payload of 29.6 t or greater, while the weight payload capacity in 1981 was 31.6 5. It should be noted that the payload distributions of both 7-axle A- and B-train units were very similar.

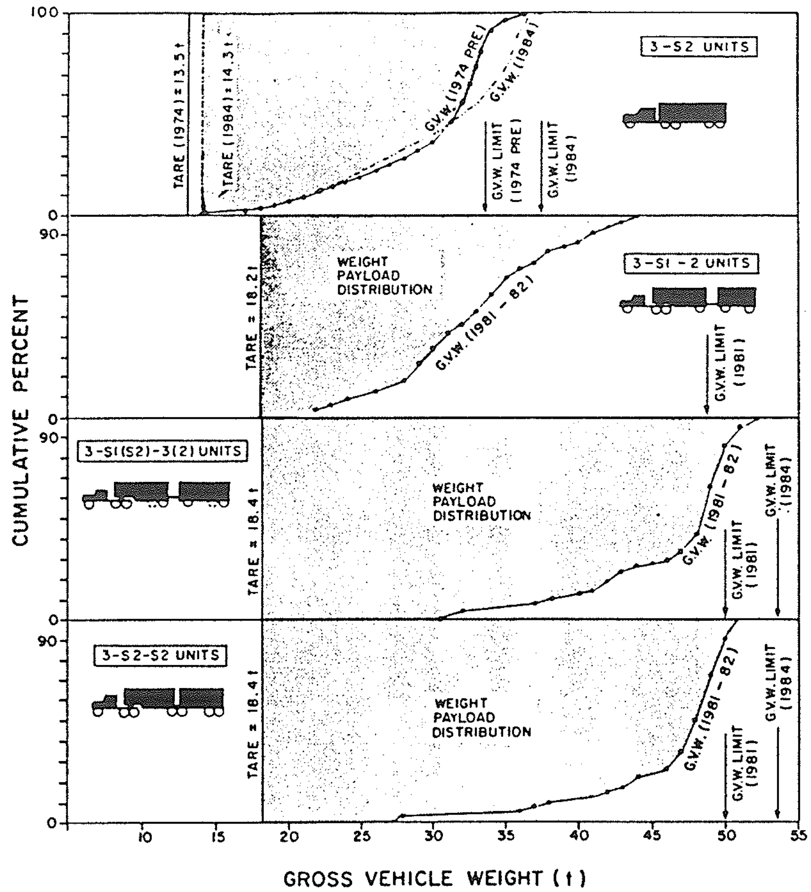


Figure 4.3 Payload distributions on laden trucks operating on primary highways in Manitoba by truck type and year
(Source: Reference [14], pp. 26).

It should be noted that the bigger truck combinations (7-axle A- and B-train units) carried higher average weight payload (29.6t versus 15.9 t) than the smaller units (5-axle tractor-semitrailer units). The 6-axle A-train units were not considered because those units were operating under "cube-out" situations which means that weight payload was not an appropriate indicator for comparison.

The above observations reveal that the 6-axle A train units mainly handle the low density commodities, while the 7-axle A and B-train units principally haul the high density commodities. This implies that the 6-axle A-train units are potentially sensitive to increases in size limits rather than weight limits, the reverse is true for the 7-axle A- and B-train units.

It can be seen that payload capacity in terms of weight payload capacity and cubic capacity is a function of vehicle capacity, commodity density, and allowable vehicle weight and dimension limitations. Therefore, in order to determine truck payload productivity, these three factors should be considered simultaneously. The implications of these three factors on truck productivity have to be understood clearly by regulatory authorities to ensure that the direction of any changes in VWD regulations are suitable for truck operation situations. Sparks et al. [22] pointed out that "the design of an appropriate regulatory regime for large truck should be much more sensitive to the realities of the freight flows to be served".

Chapter 5

TRUCK OPERATING COSTS AS A FUNCTION OF SIZE

5.1 INTRODUCTION

Truck operating cost is an important component of the total cost of transportation. Therefore, a reduction in truck operating cost can result in a significant reduction in total transportation cost. Utilization of bigger and heavier truck combinations can decrease truck operating cost and contribute to economic improvement in the country.

Several deterministic and stochastic models have been developed in order to calculate truck operating costs. Such models can also be used to consider the effect of truck size on truck operating costs. The purpose of this chapter is:

(a) to examine a deterministic cost model (the TRIMAC cost model) and a stochastic cost model;

(b) to consider fuel economy as a function of truck size;

(c) to consider truck operating cost as a function of truck size; and

(d) to examine the general implications for VWD regulations.

5.2 A CLASSICAL DETERMINISTIC COST MODEL: THE TRIMAC MODEL

Most truck operating cost models are deterministic. Such models are normally used to calculate truck operating costs by considering various typical operational situations, and a number of the most likely parameters. The TRIMAC model [28], developed by TRIMAC Consulting Services Ltd., has been used to determine Canadian truck operational costs and truck rates on a biennial basis. The model is able to consider typical truck operational activities on a regional basis, and to reflect the influences of several truck regulatory and operational factors across Canada for both dry freight and bulk carriers, and for a number of typical truck configurations.

A number of parameters of common truck operating characteristics for each of the provincial and territorial regions in Canada are input into the TRIMAC model to assist the regional comparisons. These parameters are: vehicle configuration (2-axle straight truck, 5-axle tractor-semitrailer, and 7- or 8-axle tractor train); commodity type (dry freight or bulk); annual equipment mileage utilization; province or territory of operation; and road surface (paved or gravel). However, other operational situations are the same for all regions and the results achieved from the model are base-case costs. In addition to base-case analysis, the TRIMAC model also takes into account variations in some operational situations such as seasonal variations, payload variations, trip length variations, and annual utilization levels.

5.2.1 Assumptions

The TRIMAC cost model [28] incorporates various detailed assumptions which represent typical truck operational situations. The most important of these assumptions are:

- for the base-case analysis, an average round trip distance assumed are 100 and 320 km for 2-axle straight trucks and the larger combinatins, respectively.
- for the base-case analysis, all-hauls are evaluated as forehauls only. Therefore, the costs represent one payload per round trip.
- for the base-case analysis, annual utilization levels assumed for 2-axle straight trucks are 40,000, 80,000, and 120,000 km. For the larger combinations, annual utilization levels assumed are 80,000, 160,000, and 240,000 km.

5.2.2 Structure of TRIMAC Cost Model

The TRIMAC cost structure was separated into two components--fixed and variable costs. Fixed costs are a function of time and are unrelated to the level of utilization, while variable costs are a function of a utilization level, which is distance travelled. The fixed cost components determined are depreciation and licence costs. The variable cost components are driver costs, fuel costs, repair costs, cleaning costs, transport costs, and tire costs. In addition, the model also considers insurance costs, administration and interest costs, and profit to operators. The structure of these cost components is shown in Appendix B-1.

5.2.3 Simple Analysis of the TRIMAC Cost Model

The Manitoba bulk-payload base-case costs [28] in 1986 were determined. These base-case costs represented "truckload" (TL) conditions, and the driver wage costs resulting from driving activity and pickup and delivery (i.e., loading and unloading). These costs can possibly reflect a median truck condition in Manitoba. The three typical truck types considered are the 2-axle single unit truck, the standard 5-axle tractor-semitrailer, and 7-(8-) axle (A-train) double-trailer units. The characteristics, unit costs, and productivity considerations of these truck types are given in Table 5.1. The detailed operating costs are illustrated in Appendix B-2, and the results of this analysis are shown in Table 5.2.

A number of observations can be made:

1. Truck operating costs are dominated by variable costs, accounting for approximately 47-63% of total operating cost. The major variable cost components, in order of their importance, are driver wages (16-37% of total operating cost), fuel cost (8-19%), and repair costs (8-15%).

2. As vehicle utilization level increases, the total operating cost (Canadian cents per km) considerably decreases, as shown in Figure 5.1. This is because the fixed cost components are spread over a greater utilization (travelled distance).

Table 5.1 Vehicle characteristics, unit costs and productivity considerations (referencing the TRIMAC Cost Model)

	2-Axle Dual Rear Wheel Straight Truck	Standard 5-Axle Tractor Semi-Trailer Combination	7/8 Axle Tractor Double-Trailer (A-Train) Combination
VEHICLE CHARACTERISTICS			
Maximum Weight on Steering Axle (kg)	5500	5500	5500
Maximum Weight on Single Axle (kg)	9100	9100	9100
Maximum Weight on Tandem Axle (kg)	N/A	16000	16000
Maximum Gross Vehicle Weight (kg)	14600	37500	56500
Typical Tare Weight (kg)	7300	12300	15800
Typical Payload Capacity (kg)	7300	25200	40700
Maximum Overall Length (m)	12.5	20.0	23.0
1986 UNIT COSTS ($ Canadian)			
New Capital Cost (Diesel-Powered Truck)	81620	N/A	N/A
New Capital Cost (Diesel-Powered Tractor)	N/A	96550	98520
New Capital Cost (Trailer(s))	N/A	52311	101170
Fuel Cost (Cdn $/litre)	0.426	0.426	0.426
PRODUCTIVITY CONSIDERATION			
Running Speed (Paved) (km/hr)	40	100	100
Running Speed (Gravel) (km/hr)	40	80	80
Average Round-Trip Length (km)	100	320	320
Load/Unload Rate (hr)	0.25	0.75	1.25
Average Fuel Consumption Rate (km/litre)	3.838	2.303	2.230
Maximum Yearly Mileage (km)	120000	240000	240000

N/A = not applicable
Source: References [25] and [28]

Table 5.2 TRIMAC cost analysis for paved road (1986)

COMPONENT COSTS AS A PERCENT OF TOTAL OPERATING COST

Vehicle	2-Axle			5-Axle			7/8-Axle		
Utilization (x 1000 km)	40	80	120	80	160	240	80	160	240
Fuel	8.3	10.1	10.9	14.2	17.3	18.7	12.5	15.5	16.9
Depreciation	24.3	14.8	10.7	20.6	12.6	9.0	22.8	14.2	10.4
Transport	0.8	0.5	0.4	3.3	2.0	1.4	2.8	1.8	1.2
Repairs	8.0	9.7	10.4	11.0	13.3	14.4	10.7	13.3	14.5
Tires	2.4	2.9	3.1	3.5	4.2	4.5	3.9	4.9	5.3
Sub	43.8	38.0	35.5	52.6	49.4	48.0	52.7	49.7	48.3
Driver	27.8	33.8	36.5	16.4	19.9	21.4	15.9	19.6	21.4
Licence/Insurance	3.9	3.6	3.3	4.9	4.1	3.8	5.9	4.8	4.3
Cleaning	0.5	0.6	0.7	2.1	2.6	2.8	1.5	1.9	2.0
Sub	32.2	38.0	40.5	23.4	26.6	28.0	23.3	26.3	27.7
Administration/Interest	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Profit	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Sub	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Total Operating Cost (Cdn ¢/km)	**133.1**	**109.5**	**101.6**	**130.4**	**107.2**	**99.6**	**152.4**	**122.9**	**112.9**

VARIABLE AND FIXED COSTS AS PERCENT OF TOTAL OPERATING COST

Vehicle	2-Axle			5-Axle			7/8-Axle		
Utilization (x 1000 km)	40	80	120	80	160	240	80	160	240
Variable Costs	47.9	57.7	62.0	50.4	59.3	63.2	47.4	57.0	61.4
Fixed Costs	25.1	15.3	11.0	22.6	13.7	9.8	25.6	16.0	11.6
Insurance/Administration/ Interest/Profit	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

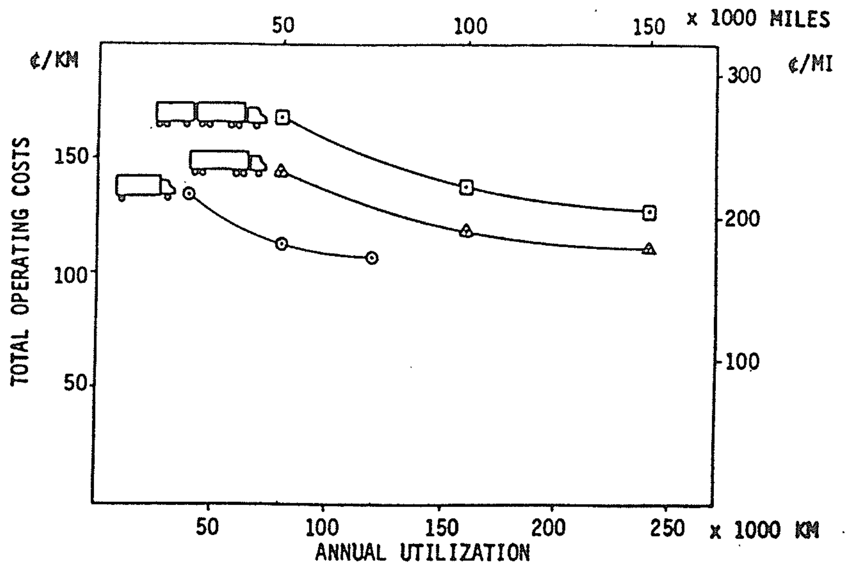


Figure 5.1 Total operating costs vs. annual utilization (gravel roads)

3. Figures 5.1 and 5.2 show that at a specific annual utilization level, total operating costs (Cdn. cents per km) increase as truck sizes and GVW's increase. For example, at the utilization level of 80,000 km/year, the total operating costs for 2-axle, 5-axle and 7/8-axle vehicle types operated on gravel roads are 114.2, 144.2, and 167.5 cents/km, respectively. However, total operating costs per payload tonne-km (Cdn. cents per payload tonne-km) significantly decreases as truck size and GVW's increase. For example, at the same level of utilization, the total operating cost per payload tonne-km for 2-axle, 5-axle and 7/8-axle vehicle types are 17.4, 6.4, and 4.5 cents/tonne-km.

4. Although the fuel unit cost relatively increased from 41.9 Cdn. cents per litre in 1984 to 42.6 Cdn. cents per litre in 1986, fuel costs (Cdn. cents per km) compared between 1984 and 1986 operations significantly decreased, as shown in Table 5.3. This is a result of the introduction of significantly enhanced fuel economy technology in Canada's trucking industry since the beginning of the 1980's [28].

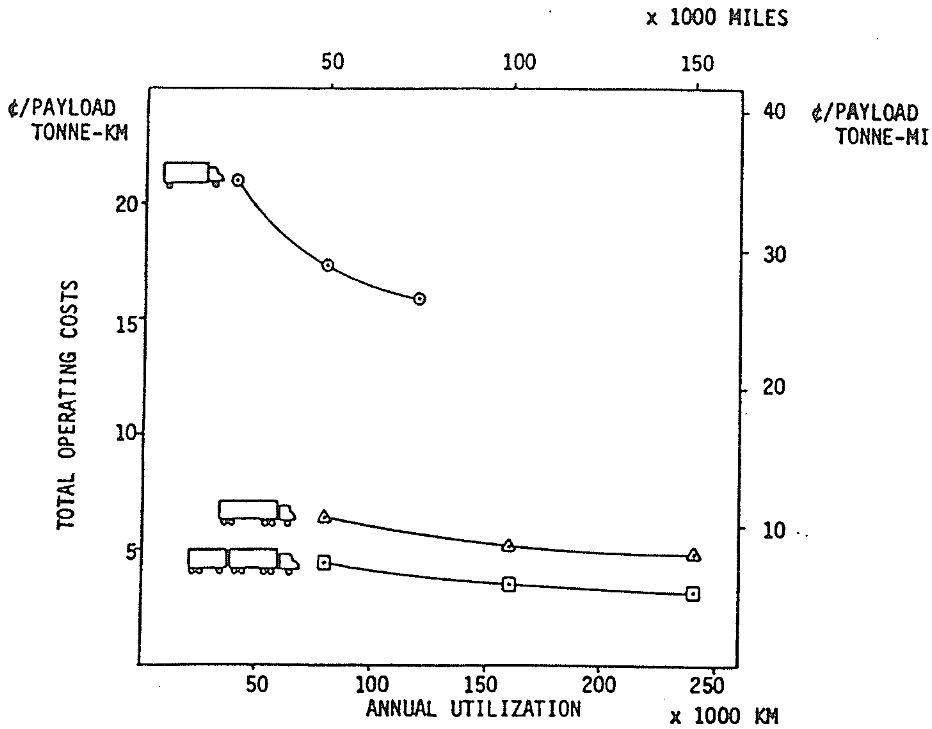


Figure 5.2 Costs per payload tonne-km vs. annual utilization levels (gravel roads)

Table 5.3 Fuel cost and fuel consumption between 1984 and 1986

Item	Year	Truck Combination		
		2-axle	5-axle	7/8-axle
Fuel Cost (Cdn. cents/km)	1984 1986	18.8 11.1	23.7 18.5	26.3 19.1
Fuel Consumption Rate (km/litre)	1984 1986	2.23 3.84	1.77 2.30	1.59 2.23

5.3 A STOCHASTIC COST MODEL

Truck operating costs are generally considered by deterministic models. However, the most important disadvantage of these models is that they cannot simultaneously take into account a wide range of potential values for several variables. This means that such models are not able to deal with the combined effects of uncertainties in several parameters on truck operating costs. Sparks et al. [23] has developed another operating cost model--a stochastic cost model--designed to address this disadvantage of the deterministic model.

5.3.1 The Structure of the Stochastic Cost Model

The Sparks model consists of three phases: (i) a deterministic sensitivity analysis; (ii) a probabilistic model development; and (iii) a stochastic sensitivity analysis. The first phase determines how sensitive truck operating cost is to change in each parameter, based on a deterministic model having similar structure to the TRIMAC Cost Model. All parameters are classified with respect to the degree (sensitivity) of their effect on truck operating costs. The second phase develops a probabilistic model to take into account the combined effects of the varying values of these sensitive parameters. The truck operating cost distribution will be achieved at the end of this phase. The last phase determines the effect of varying probability distributions of any sensitive parameter on truck operating cost distribution.

5.3.2 The Application of the Stochastic Cost Model

The major advantage of the stochastic approach is that the stochastic model can deal with variations in a number of potential values of sensitive parameters when such parameters are considered simultaneously. The combined effects of those simultaneous variations are reflected in the characteristics of the stochastic cost distribution achieved from the model.

Sparks et al. [23] applied the stochastic model to show how VWD regulatory changes and differences affect truck operating costs and therefore, productivity. It was found that utilization of bigger and heavier vehicles operating under higher GVW limits potentially leads to lower operating cost and a change in sensitive parameter(s). For example, the expected operating costs per payload tonne-km will decrease from 2.4 cents/tonne-km to 1.9 cents/tonne-km according to the VWD regulatory changes allowing the use of a 7-axle (A-train) flat deck combination at a GVW of 53,500 kg when only a 5-axle tractor-semitrailer unit is permitted under current VWD regulations at a GVW of 37,500 kg. One of the three most sensitive parameters (annual distance, distance wage rate and vehicle tare weight) was changed because of the VWD regulatory changes. That is, vehicle tare weight has been replaced by fuel consumption [29].

It was also found that differences in typical truck characteristics may result from VWD regulatory differences. In the case of similar vehicles, the one operating under a higher GVW limit will be able to achieve lower operating costs. However, in the case of different truck configurations, truck operating cost is strongly related to payload capacity of these configurations. The greater the truck configuration (and therefore, its payload capacity), the lower the operating costs. For example, the expected operating costs per payload tonne-km (approximately 2.4 cents/tonne-km) of the tractor-semitrailer (3-S3) petroleum haulers operating at GVW's of 50,000 kg in New Brunswick is higher than that (approximately 2.0 cents/tonne-km) of the same configuration operating at a GVW of 54,203 kg in Quebec [23]. The expected operating cost per payload tonne-km (approximately 1.9 cents/tonne-km) of double B-train (3-S3-S2) petroleum haulers operating at 63,500 kg in British Columbia is lower than those of both 3-S3 combinations operating in New Brunswick and in Quebec, as described above [23].

5.4 FUEL ECONOMY AS A FUNCTION OF TRUCK SIZE

One of the important components of truck operating cost is fuel cost. As mentioned previously, fuel cost comprises approximately 8-19% of total operating cost, depending on truck type and utilization level. Therefore, reduction of fuel cost has a strong effect in decreasing total truck operating cost.

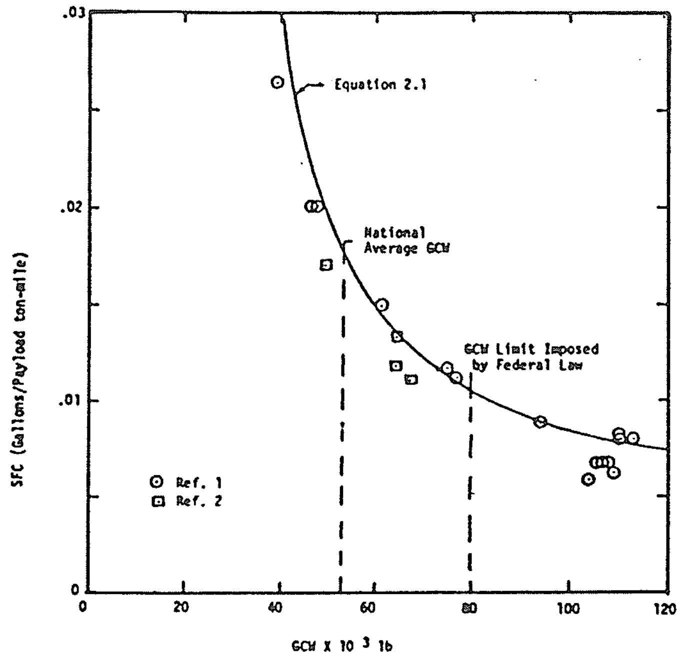
There are a number of factors affecting fuel consumption rate. Key factors include: road alignment (gradient, curve, etc.); surface condition (paved versus unpaved road); operating conditions (operating speed, traffic congestion, etc.); climatic condition (temperature, wind, humidity, etc.); geographic condition (level, rolling, mountainous); GVW; and driving performance. However, the following explanation will illustrate how the fuel consumption rate of a truck changes as its GVW varies, assuming that other factors are constant.

For a particular truck type, more fuel is required to transport its commodity at greater weight payload and, therefore, greater GVW. However, fuel consumption (gallons per mile - GPM) increases at a lower rate than the weight does [30]. This means that the amount of fuel increase required to transport a unit of freight at greater GVW level is less than that at a lower GVW level. It is logical to use fuel consumption per unit of output to represent fuel productivity. The most widely used fuel-productivity unit is gallons per ton-mile or litres per tonne-km. Figure 5.3 illustrates the relationship between fuel consumption (gallons) per ton-mile and GVW. It is shown that fuel consumption per ton-mile significantly decreases as GVW increases, and that the rate of decrease at a lower GVW is greater than that at a higher GVW. For a given truck type, an increase in allowable GVW limit will potentially reduce the fuel consumption of that truck when used to carry a given amount of freight ton-miles.

Some operators would choose to employ a bigger and heavier truck type operating at a higher maximum GVW limit. This also results in lower fuel consumption per payload ton-mile. In the Western Highway Institute (WHI) study [31], different types of truck combinations were assumed to carry a specific amount of freight (2,000 tons) over a given distance (400 miles) and those vehicles were also assumed to carry freight at the maximum GVW limit, based on freight density. It was found that, as expected, the fuel consumption rate (gallons per mile) for a given truck configuration increases as freight density and GVW increases. However, the total amount of fuel consumed and fuel consumption per payload ton-mile decreases as freight density and GVW increases. It was also found that the total amount of fuel consumed decreases when the larger truck combination operating at a greater GVW is employed.

Clayton et al. [32] has developed a linear relationship between fuel performance, in terms of miles per gallon, and GVW for truck combinations actually operating in Canada, and for different seasons. Figure 5.4 shows such a linear relationship for different seasons. It is clear that regardless of seasonal differences, the number of miles travelled per gallon of fuel decreases as the GVW increases. In other words, the amount of fuel required to travel one mile increases as GVW increases. Clayton et al. [32] also found that the higher the GVW, the lower fuel consumption per ton-mile (gallon per payload ton-mile), and commented that little fuel saving would be achieved when the truck combinations are operated at a very high GVW. It should be noted that the "gallon" appearing in Figure 5.3 is in the U.S. unit, while the "gallon" appearing in Figure 5.4 is in Imperial units.

Fuel consumption tests for overlength vehicles [34] were conducted in Saskatchewan to determine fuel savings per payload tonne-km according to utilizing overlength vehicles (twin 45-foot semitrailers, Rocky Mountain Doubles, and Triples) compared to the legal length combination unit (27-foot twin doubles) and the 5-axle tractor-(45-foot) semitrailer when carrying



1 Fax and Kaye, "Truck Noise IIID, The Economics of Quieting the Freightliner Cab-Over-Engine Diesel Truck," DOT-TSC-75-22, October 1974, p. 8

2 Hutton, T.D., "Freightliner Comparative Fuel Economy Test," Freightliner

Figure 5.3 Fuel consumption per payload ton-mile as a function of GVW (Source: Reference [17], pp. 28)

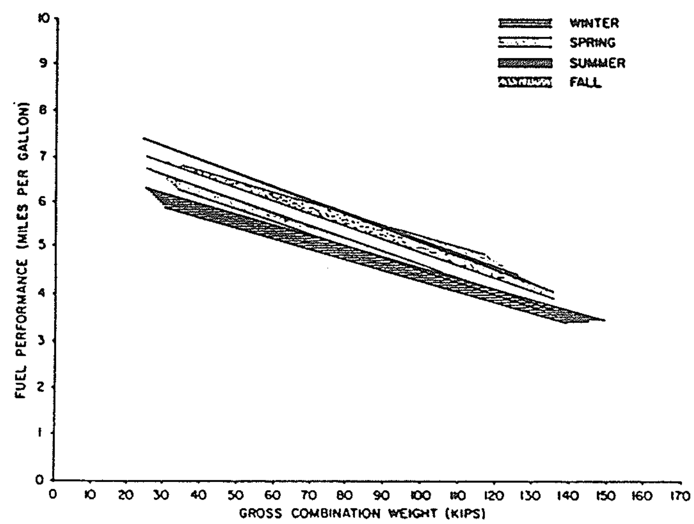


Figure 5.4 Fuel performance as a function of GVW for different seasons (Source: Reference [32], pp. 18)

a low density commodity. The testing results are shown in Table 5.4. It is clear that utilization of bigger and heavier truck combinations will decrease fuel consumption per payload tonne-km.

Table 5.4 Percent fuel savings for combination configurations

Combination Configuration	Percent Fuel Savings per Tonne-km: Versus Semi-Trailer	Percent Fuel Savings per Tonne-km: Versus Doubles
Twin 45	28.0	23.2
Rocky Mountain Doubles	24.0	19.2
Triples	19.0	14.2
Doubles	4.8	-

(Source: Reference [34], pp. 12)

5.5 TRUCK OPERATING COSTS AS A FUNCTION OF SIZE

Truck operating costs have two main components: (i) fixed costs as a function of time; and (ii) variable costs as a function of distance travelled. For example, fixed costs are depreciation cost, overhead cost, insurance cost, vehicle taxes, etc., and variable costs are driver costs, fuel cost, tire cost, repair cost, etc. Many factors influence truck operating costs, such as road alignment, surface conditions, operating conditions, geographic conditions, GVW, and so on. In this regard, it is assumed that truck operating costs is a function of GVW, and that other factors are constant.

The relationship between truck operating costs and GVW is similar to that between fuel consumption and GVW. Truck operating costs, in terms of cost per unit distance (cents per mile) increase as GVW increases. However, truck operating costs per payload ton-mile (cents per payload ton-mile) significantly decrease as GVW increases [17, 24, 26, 31, 35, and 36]. Figure 5.5 [26] shows such a relationship in an aggregate manner in which one curve represents truck operating cost characteristics for all truck combinations. It should be noted that the reduction rate of truck operating cost per payload ton-mile corresponding to GVW increase at lower GVW value is greater than that at higher GVW value, and that truck operating cost per payload ton-mile for two-way loaded trucks is significantly lower than that for one-way loaded trucks. Further, the National Cooperative Highway Research Program (NCHRP) Report 198 [17] illustrated truck operating costs per mile (cents per mile) as a function of GVW for different truck types, as shown in Figure 5.6. For each truck type, truck operating cost per vehicle-mile increases as GVW increases. Within the certain range of GVW values (from zero up to approximately 50 tons), the truck operating cost per vehicle-mile of large truck types is higher than that of smaller truck types. However, beyond this range, the conclusion could not be given.

The Western Highway Institute (WHI) [31] developed linear equations to calculate truck operating costs for different truck combination types. Such equations were modified from the truck operating cost study in NCHRP 198. In the WHI study [31], truck operating costs for various truck combination types were calculated. It was assumed that those truck types were employed to haul the 2,000 tons of freight for different density levels over 400-mile distance. The major finding was that for each truck combination type, truck operating cost in terms of cost per mile increases as GVW and freight density increase, but the absolute operating cost value decreases because travelled distance is reduced according to higher weight-payload capacity at higher GVW. The bigger and heavier truck combinations operating fully loaded level at higher GVW have a lower operating cost than the smaller and lighter ones. WHI [31] also

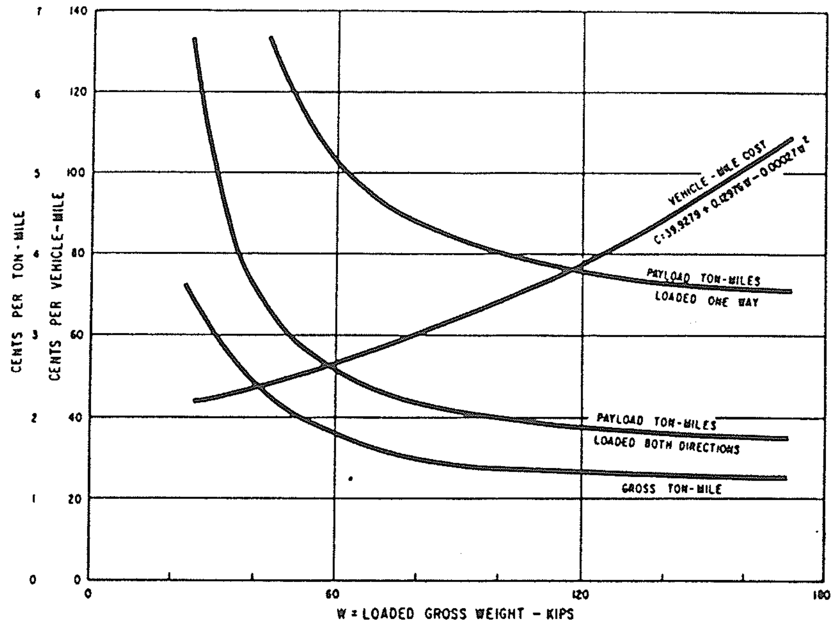


Figure 5.5 Truck operating costs by gross ton-miles, payload ton-miles (for loaded one way and loaded both ways, and vehicle-miles)
(Source: Reference [26], pp. 108)

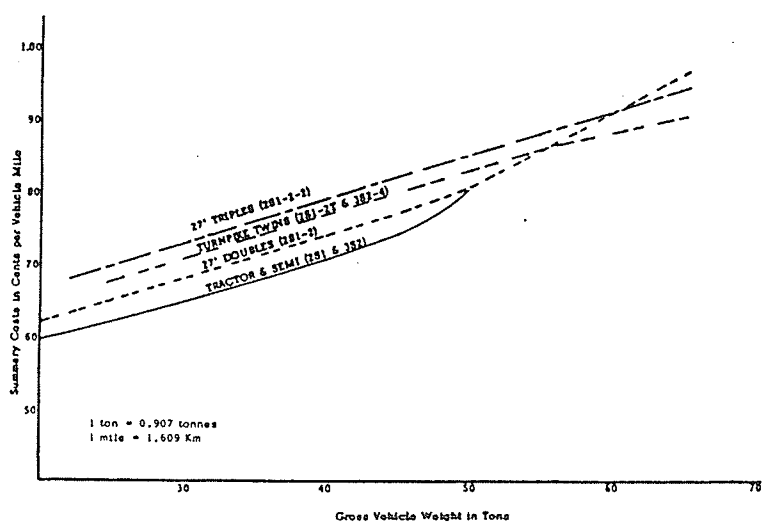


Figure 5.6 Summary truck operating cost per vehicle-mile for different vehicles
(Source: Reference [17], pp. 32)

found that the operating cost savings among different truck combinations operating at lower GVW and lower freight density are greater than those operating at higher GVW and higher freight density.

As described in Section 5.2, for each combination unit, the total operating cost in terms of cents per km decreases as truck utilization (travelled distance) increases. For a specific utilization level, the total operating cost (cents per km) increases as truck size and weight increases. However, for the same utilization level, the total operating cost (cents per payload tonne-km) significantly decreases as truck size and weight increase. It should be noted that while the TRIMAC cost analysis keeps travelled distance constant and varies amount of freight carried (the bigger the truck size, the greater the amount of freight to be transported), the WHI [31] analysis keeps the amount of freight to be carried constant, and varies the travelled distance (the larger the truck, the less distance travelled).

In case of "weigh-out" operation dealing with high density freight, truck combinations need greater GVW allowance. Hence, if the maximum allowable GVW limit of a particular truck is increased and/or the bigger and heavier truck combinations operating at the higher GVW are employed, an operating cost saving will be achieved. In the case of "cube-out" operation dealing with low density freight, truck combinations need greater size allowance. By ignoring height and width changes, if a longer truck combination is employed, operating cost savings will be realized. However, if the weight increments for "cube-out" and "weight-out" operations are equal, the operating cost savings for "cube-out" situations will be greater than that for "weight-out" situations. This is because operating cost difference per unit GVW increase at lower GVW is greater than that at higher GVW.

5.6 GENERAL IMPLICATIONS FOR VWD REGULATIONS

The utilization of bigger and heavier truck combinations will lead to a reduction in operating cost. However, there has been a concern that such utilization will bring about higher highway and bridge costs. VWD regulations are therefore set up to control the size and weight of truck combinations operating on highway systems. Nevertheless, in many countries, including Thailand, the VWD regulations have gradually been changed to allow the use of bigger and heavier truck combinations.

In the case of size limit changes, significant increases in vehicle height and width limits generally are impractical approaches to raising truck productivity. Significant increase in height limits could necessitate redesigning warehouses, docks, etc., reducing truck stability as a result of higher center of gravity, and increasing highway and bridge construction costs from the increasing vertical clearance of bridge and underpasses, etc. [26]. Significant increase of width limits could also require modification of the terminal facilities' existing driveways, alleys, warehouses, and public alleys, leading to an increase in highway construction costs due to extra lane width [26]. Consequently, width and height limits have remained relatively constant for many years. However, it should be noted that the height and width limits are important to standardization of shipment size (i.e., size of containers) between countries. Therefore, the change in height and width limits should facilitate the shipment of commodities between countries by conforming to the world standard size of shipment (i.e., containers).

The most appropriate way to achieve greater truck cubic capacity is to increase the individual vehicle length and/or combination length. This consideration is very important to trucks operating under "cube-out" situation and, in some cases, it facilitates the use of bigger (longer) and heavier truck combinations operating under "weight-out" situations.

In the case of weight limit changes, increases in GVW limits could be translated into increases in weight payload capacity and therefore, truck productivity. The GVW limit increases could be achieved in the three following ways, among others:

(a) increasing the number of axles, while keeping allowable axle load limits constant;

(b) increasing the allowable axle load limits while keeping the number of axles constant; and

(c) increasing both the allowable axle load limits and the number of axles.

These three ways of increasing GVW limits are important only to truck configurations operating under "weight-out" situations. However, truck configurations operating under "weight-out" and "cube-out" situations simultaneously need changes in both size and weight limits.

Walton et al. [37] suggested three approaches to increasing size and weight limits:

- First, keeping size limits constant, while increasing axle load and therefore, GVW limits;
- Second, keeping axle load limit constant, while increasing size and GVW limits; and
- Third, increasing the size, axle load, and GVW limit.

Walton et al. [37] also noted that these three approaches would increase truck productivity by decreasing truck operating costs and fuel consumption, but that they would adversely affect highway and bridge cost, highway geometric requirements, highway safety, and the environment. The trade-off of these considerations is a critical matter for the northeastern region of Thailand, because the regional development depends on the shipment of high weight (implying high density) and relatively low-valued commodities to the market places. Also there are severe budget constraints, as well as limited resources available for construction and maintenance of highway systems.

Consequently, the most appropriate approach to VWD regulatory changes would be where the productivity of the existing transport systems can be increased with minimum capital investment. This means that the VWD regulations should be relaxed in a way which minimizes adverse effects on highway systems (pavements and bridges), thereby minimizing requirements of construction and maintenance while increasing truck productivity.

According to the WHI study [31], it was found that the heavier and longer truck combinations coupled with GVW distribution over the greater length, and provided a sufficient number of axles is potentially beneficial to both highway pavements and bridges. In addition, the utilization of these truck combinations potentially reduces fuel consumption, operating costs, and negative effects on environmental quality (i.e., noise pollution, air pollution, safety, vibration, etc.).

Therefore, the most appropriate approach to increase VWD regulations is to increase GVW limits while holding the axle load limits constant, and distributing the GVW over the longer truck length by providing for enough axles. It should be noted that keeping axle load limits fixed by adding a number of axles while increasing GVW limits reduces the adverse effect on pavements. Spreading these axles over the longer truck length is intended to reduce the adverse effects on bridges.

Chapter 6

OPERATIONAL PERFORMANCE AND SAFETY CONSIDERATIONS REGARDING LARGE TRUCKS

6.1 THE PURPOSE OF THE CHAPTER

There has been an increasing trend toward use of bigger and heavier trucks, primarily for economic reasons. There is a concern that this can lead to a decrease in highway capacity and level of service, and in highway safety. The greater sizes and weights of the trucks can aggravate truck manoeuvring performance (such as offtracking, passing, splash and spray, accelerating, etc.) and increase truck accident frequency and severity. The purpose of this chapter is:

(a) to examine truck offtracking, passing manoeuvres, passenger-car-equivalence, and splash and spray as functions of truck sizes, weights, and types;

(b) to examine truck stability and control as a function of vehicle type, weights and sizes;

(c) to examine actual truck accident records as a function of truck weights, sizes, and types.

6.2 OFFTRACKING

Offtracking is defined as the difference between the path of the frontmost inside wheel and the rearmost inside wheel of a given truck configuration when negotiating turns or at-grade intersections [38]. Offtracking leads to (possibly dangerous) intrusion by the last trailer of a truck combination into the lane next to the one being negotiated, and can damage roadside structures such as curbs, traffic signs, guardrails, etc. Offtracking can therefore lead to an accident involving pedestrians and vehicles in adjacent lanes.

There are two kinds of offtracking: (i) low speed offtracking in which the rear wheels are pulled inward relative to the steering wheels, and (ii) high speed offtracking, in which the rear wheels track outward relative to the steering wheels. Low speed offtracking is (potentially) much more hazardous than high speed offtracking, because the magnitude of low speed offtracking is significantly greater than that of high speed offtracking [49]. However, high speed offtracking can lead to severe collision because of the greater speed involved.

It should be noted that while a given truck combination is negotiating a curve at increasing speed, the low speed offtracking will decrease and become zero at a certain speed [39]. If the truck combination increases its speed beyond the speed causing low speed offtracking equal to zero, high speed offtracking will occur. The magnitude of offtracking is influenced by running speed, radius and degree of turn, wheel base length, number of trailers, number and position of articulation point, kingpin offset, the axle-to-pintle hook distance, the towbar length, type of vehicle configuration, driver skills, inflation and condition of the tires, load on steering axles, amount of superelevation, pavement condition, etc. [26, 39]. The following descriptions concentrate on offtracking as a function of size and type of vehicle combination.

The Western Highway Institute (WHI) developed a simple equation to calculate the magnitude of (low speed) offtracking, as follows [40]:

$$MOT = R_1 - \sqrt{R_1^2 - \Sigma (L^2)} \qquad (1)$$

where MOT = maximum offtracking;
R_1 = turning radius of outside front wheel;
L = distance between centerpoints of axles or tandem axle groups or between such centerpoints and intermediate points of articulation

Table 6.1 shows maximum offtracking of various truck combinations [40]. The offtracking values are calculated by Equation (1) based on 165-foot curve radius negotiations. It is found that for the same configuration, the longer the wheelbase length, the more offtracking. Although the overall wheelbase of a multiple trailer combination is longer than that of a tractor-semitrailer, the magnitude of offtracking of such combination may be less. This is because longer combinations consist of shorter wheelbase trailers with the additional joints of articulation, and therefore, when the offtracking effect of each shorter wheelbase trailer is summed up, the total offtracking magnitude is smaller [31]. In 1974, the Utah Department of Transportation [33] conducted offtracking tests to compare the calculated values. It was found that the field results compared well to the values obtained from Equation (1) as shown in Table 6.2.

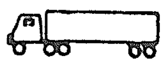
In some cases, the magnitude of low speed offtracking is expressed in terms of the maximum swept path width, which is the maximum distance between the track of the outward wheel of the steering axle and the track of the inward wheel of the rearmost axle. Figure 6.1 [41] (developed from computer simulations) shows low speed offtracking (swept path) and high speed offtracking as a function of trailer length and number of trailers. It can be seen that for low speed offtracking, the swept path increases as the number and length (wheelbase length) of trailers increases [41]. Sometimes, the effect of multiple trailers can be offset by the effect of individual longer trailer length. For example, the swept path of a triple 28-foot trailer unit is approximately 2 feet less than that of a tractor (48-foot) semitrailer unit when negotiating a 90 degree turn at a 35-ft radius. For high speed offtracking, the magnitude of offtracking increases as the number of trailers and travelling speed increases [41]. The high speed offtracking has a maximum value in a specific range (25 to 30 ft) and then declines as trailer length increases. It should also be noted that high speed offtracking for the same truck combination negotiating the same turn or curve is significantly less in terms of magnitude than slow speed offtracking.

Table 6.1 Maximum offtracking of various truck combinations.

Type	Profiles	Symbol	Overall Length (Ft)	Length Each Trailer (Ft)	Maximum Offtracking 165' Curve Radius (ft)
Single Unit Truck		3	40	33	3.4
3-Axle Tractor-Semitrailer		2-S1	40	27	2.3
4-Axle Tractor-Semitrailer		2-S2	50	40	4.0
5-Axle Tractor-Semitrailer		3-S2	50	40	4.0
5-Axle Tractor-Semitrailer		3-S2	55	40	4.2
5-Axle Tractor-Semitrailer		3-S2	60	45	5.4
5-Axle Tractor-Semitrailer		3-S2 Stinger	65	40	3.4
5-Axle Truck and Trailer		3-2	60	27	2.4
5-Axle Truck and Trailer		3-2	65	30	3.5
5-Axle Doubles		2-S1-2	65	27	3.0
7-Axle Triples		2-S1-2-2	95	27	4.5
9-Axle Doubles		3-S2-4	100	40	8.1

(Source: Reference [40], pp. 46-47)

Table 6.2. Comparison of measured and calculated offtracking for different types of trucks

TYPE	PROFILE	SYMBOL	OVERALL LENGTH FT.	LENGTH EACH TRAILER	CURVE RADIUS FT.	MAXIMUM OFFTRACKING (FT)	
						Measured Value	Calculated Value
Five-Axle Tractor-Semitrailer		3-S2	51	40	90.0	7.6	8.5
Seven-Axle Triplets		2-S1-2-2	91.6	26	90.0	8.8	7.8
Five-Axle Doubles		2-S1-2	65	26	90.0	6.0	5.3
Three-Axle Tractor Semitrailer		2-S1	35	26	90.0	3.3	2.7

(Source: Reference [33], pp. 34)

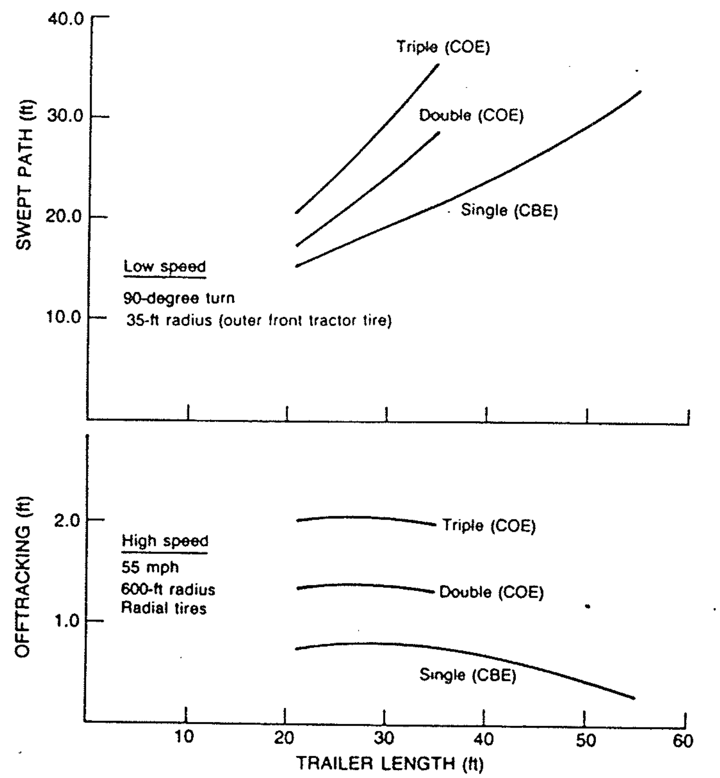


Figure 6.1 Effects of trailer length and truck configuration on offtracking behaviour (Source: Reference [41], pp. 272)

For vehicle width, even though the wider truck can reduce lateral clearance between turning vehicles and other vehicles in adjacent lanes, and cause intrusion into the adjacent lane, it does not, however, involve offtracking performance [41].

6.3 PASSING MANOEUVRES

The impact of large truck combinations on passing manoeuvres is more important to two-lane undivided highways than to multilane divided highways, because on multilane divided highways, the passing chance of higher speed vehicles is not reduced by sight distance limitations and opposing traffic disturbances [41]. It is most appropriate, therefore, to concentrate on the effect of vehicle size upon two-lane, undivided highways.

The manoeuvre period on two-lane highways is separated into three phases [26]: "(i) perception and reaction time; (ii) time the passing vehicle occupies the left lane in passing the slower vehicle, and (iii) time required to return to the right lane." The passing sight distances allowed in highway design are considered from the distance travelled during the three previous phases, and the distance and placement of an opposing vehicle. There are a number of factors affecting passing manoeuvres. These factors are the flow rate of the traffic mix, presence of opposing traffic, sight distance availability, traffic speed distribution, acceleration capability, grade, and sizes and weights of passing and passed vehicles [41]. The large trucks, operating on high gradient, two-lane, undivided highways, can potentially reduce level of service and traffic flow, because those trucks have low manoeuvring performances according to their greater sizes and weights, low running speed, and low acceleration performance. The following description will focus on the effects of truck size and weight on passing manoeuvres.

WHI [42] conducted a full scale acceleration test of diesel trucks having weight-to-horsepower ratios of 100 to 400 lb/hp. The passing distance versus weight-to-horsepower ratio and the passing time versus weight-to-horsepower ratios were plotted and combined to develop the passing characteristic envelopes as illustrated in Figure 6.2. It was found that passing distances and times increase as the weight-to-horsepower increases. Therefore, when a given truck combination carries more payload of freight (thereby increasing weight-to-horsepower ratio), it needs a greater distance and more time to pass slower vehicles.

It is known that the length of the two vehicles involved in any passing manoeuvre and the differences of their speeds affect passing time and therefore, passing distance. The relationship between both vehicle lengths and speed difference on the passing time (T_p) on two-lane, undivided highways [26] is:

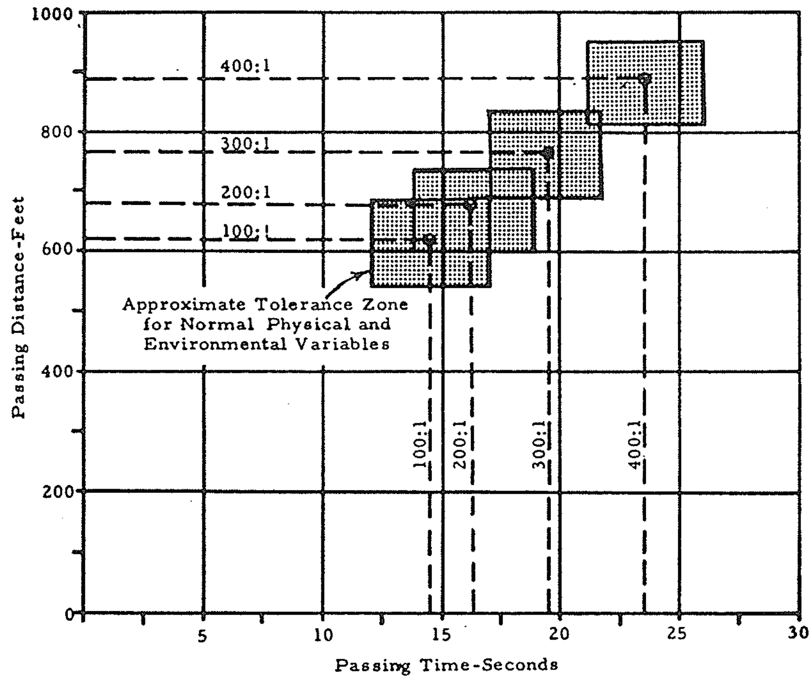


Figure 6.2 Passing time and distance for low speed pass by various weight-horsepower ratio expressed in the per gross horsepower (Source: Reference [42], pp. 56)

$$T_p = \frac{L_f + L_s + 150}{1.47\ V} \qquad (2)$$

where:

L_f	=	length of faster vehicle (car)
L_s	=	length of slower vehicle (truck)
150	=	75 ft allowance for pull-to distance, and 75 ft allowance for return-to-lane
1.47	=	conversion factor (mph to fps); and
V	=	speed difference between vehicles (mph)

The Utah Department of Transportation [33] showed the effects of vehicle lengths and speed differences on passing time (based on Equation (2)) as illustrated in Table 6.3, and also showed the effect of various combination lengths, speeds, and speed differences on passing distance as illustrated in Figure 6.3. It is found that the increase in passed vehicle length leads to the requirement of the longer passing distance and time. This finding is more pronounced when

Table 6.3 Passing time requirements as a function of speed differences and truck lengths for two-lane highways

Speed Diff. (mph)	55 Ft. Comb. (single)	65 Ft. Comb. (double)	Added Time Single to Double	95 Ft. Comb. (Triple)	Added Time Single to Triple	Added Time Double to Triple
5	30.34	31.70	1.36	35.78	5.44	4.08
10	15.17	15.85	0.68	17.89	2.72	2.04
15	10.11	10.57	0.46	11.93	1.82	1.36

(SOURCE: Reference [33], pp. 35)

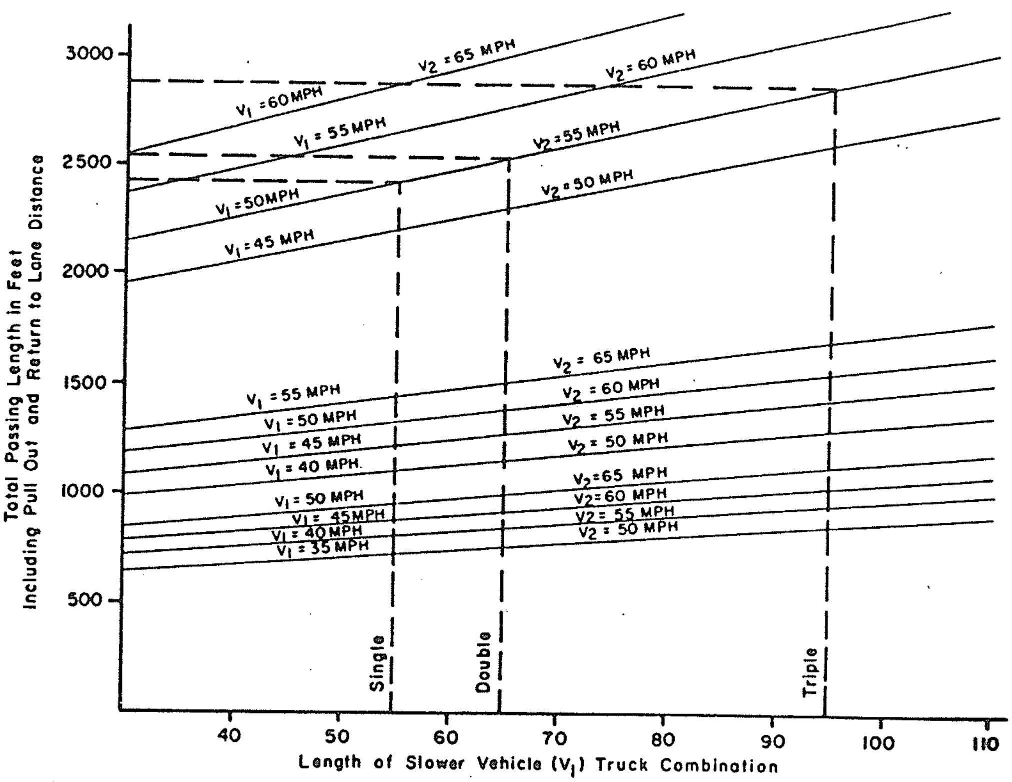


Figure 6.3 Passing distance requirements as a function of speeds, speed differences, and truck lengths for two-lane highways
(Source: Reference [33], pp. 36)

the passing manoeuvre occurs either at high speed, or at a lower speed difference. For example, for a speed difference of 5 miles per hour (mph), a car travelling at a speed to 55 mph requires a passing time of 30.34 secs and a passing distance of 2,448 ft to pass a 55-foot tractor-semitrailer unit. Under the same running speed and the same speed difference conditions, the same car needs the additional passing time of 1.36 and 5.44 secs and the additional passing distance of 110 and 439 ft to pass a 65-foot double-trailer unit and a 95-foot triple trailer unit, respectively [33].

Alberta Transportation [43] reported that a longer passing time and distance were required for a car to pass a longer truck combination, and that the additional time and distance were proportional to the additional length of the longer truck combination. For example, a passing time of 15 secs and a passing distance of 480 m are required for a car travelling at 115 km/h to pass a 23-m-long truck combination running at 100 km/h on a two-lane, undivided highway. The additional passing times and distances would be 10% more to pass a Rocky Mountain Double (29 m long), 13% for a triple (34 m long), and 20% for the turnpike (35 m long). One study [41] concluded that the truck combination length does have an impact on the passing time and distance, but the truck configuration type has little or no impact on the passing performance. This means, the impact of a tractor-semitrailer unit and that of a double-trailer unit on passing manoeuvres are the same, if both units have the same combination length.

Truck width also has an effect on passing manoeuvres on two-lane undivided highways, because a wider truck can reduce the sight distance of following vehicles, reduce lateral clearance between passing and passed vehicles, decrease lateral distance between passing vehicles and roadway shoulder and edge, and reduce suitable justment of safe or unsafe gaps to opposing vehicles [41]. However, the widths of various types of truck configurations are generally constant, and little change in width occurred over time. Therefore, the effect of truck width on passing manoeuvres is the same for a number of truck types and is considerably less important than truck combination length.

6.4 PASSENGER CAR EQUIVALENCE

Trucks can decrease highway capacity and level of service because of their significantly greater sizes and weights, and therefore, lower operational performance in comparison to passenger cars [26, 39, 41]. Passenger-car-equivalence (PCE) is used to monitor a truck's operational performance compared to that of a passenger car. PCE was defined in the Highway Capacity Manual [44] as "the number of passenger cars displaced in the traffic flow by a truck or bus, under the prevailing roadway and traffic conditions." There are a number of factors influencing PCE: roadway type, geographic condition, gradient, percent of trucks in the traffic flow, traffic volume, running speed, weight-to-power ratio, truck characteristics, etc. The situations leading to lower operational performance of a given truck combination can potentially increase PCE. Such situations occur when the truck combination is running on two-lane versus multilane highways, under difficult terrain (mountainous versus level), at a high gradient portion of highway, and a low running speed. For example, based on its effects on the capacity of freeway, a truck operating on level terrain has a PCE of 2, but the same truck operating on extended grades of 6 percent may be over 20 PCE [39]. For a low percentage of trucks (18-21%), a truck operating on a two-lane upgrade highway is equivalent to 3.0 PCE at a running speed of 50 mph, and 32 PCE at a speed of 20 mph [41].

The bigger (higher, wider, and longer) and heavier truck combinations can lead to higher PCE values because such combinations may have low accelerating and speed maintaining capabilities [41]. The most important factors affecting the performance of the bigger and heavier truck combinations is their weight-to-horsepower ratios. The higher weight-to-horsepower ratio of a given truck combination can decrease the operational performance and therefore, increase the PCE of that truck. However, this strongly depends on many other factors as previously described. For example, for an extended four-lane freeway with 15 percent trucks, a light truck with a weight-to-horsepower ratio of 100 lb/hp and a heavy truck with a 300 lb/hp ratio are equally equivalent to 2.0 PCE at 0% grade. However, the light truck is equivalent to 5.0 PCE, while the heavy truck is equivalent to 18.0 PCE at 6% grade [45]. This example shows that the effects of weight-to-horsepower on PCE for a given truck are more severe on high gradient highways.

The degree of greater size and weight of a truck can be represented by number of axles. Cunagin et al. [46] found that the PCE's increased as the number of axles on any truck combination increased, and as the gradient of the highway becomes steeper.

6.5 SPLASH AND SPRAY

Splash and spray can be a safety concern during wet conditions involving water, slush, and snow. The visibility of passenger cars is reduced by splash and spray from passing and passed trucks. Weir [47] defined splash and spray as: "Splash tends to be relatively large droplets which more in ballistic trajectories. Spray is composed of the smaller droplets, which tend to be suspended in the air and move with the air flow." Splash and spray vary with a number of factors, such as weather elements (water, slush, snow, and air), highway characteristics (surface type, grade, covering of pavement surface, etc.), driver behaviour, truck running speed, and vehicle characteristics (type of axle, total truck weight, length of truck, type of configuration, etc.) [31].

A number of observations concerning the effects of splash and spray produced by trucks can be noted:

> Visibility can be reduced to the point where it is dangerous to pass a truck, and since it would take longer to pass a longer truck, a motorist would be exposed to the danger for a greater length of time. [48].
>
> Large trucks create more critical splash and spray conditions than small vehicles, because they displace more moisture from the road surface ... and release the moisture cloud at higher elevation above the road surface. [41]

However, the contribution of splash and spray to accidents on highways have been rarely studied [31]. The major findings relating truck characteristics to splash and spray considerations are:

(a) Tandem axles usually cause larger and denser spray than single axles [41].

(b) In spite of having longer length and more axles, double and triple trailer combinations with single axles only create less splash and spray than a tractor-semitrailer does [33, 41].

(c) For the same configuration type, the longer unit did increase the splash and spray effects, but the degree of increment is not significant. For example, "longer tractor-semitrailers are likely to slightly aggravate the splash and spray problem... However, these differences are not large and are likely to be inconsequential for the replacement of 45-ft by 48-ft semitrailers." [41].

These points indicate that it would be more rational to concentrate on axle types (single versus tandem axle) rather than truck combination lengths when considering the effect of splash-spray on highway safety. The utilization of splash and spray suppression devices can reduce the problems. Properly designed spray protectors, for example, may reduce the visibility problem caused by trucks to other road users by 25-30% [7].

6.6 STABILITY AND CONTROL

The most systematic study, examining and testing the stability and control characteristics of heavy truck combinations employed for interprovincial freight transport in Canada, was conducted by the Vehicle Weight and Dimension study of the Roads and Transportation Association of Canada (RTAC) [8]. The main purpose of this study was to address the stability and control behaviour of considered vehicles in response to steering and braking manoeuvres, and to relate those findings expressing operational safety measures to the direction of changes in VWD regulations in Canada. The study determined a number of different truck combinations which were classified into six categories, as illustrated in Figure 6.4. Computer simulations and full-scale track tests of baseline vehicles from each of six categories and other configurations were carried out.

6.6.1 Performance Measures

The seven parametric measures used to compare the manoeuvring performances of all vehicles were defined according to the definitions in [8, 49, 50] as follows:

(i) Static Rollover Threshold is the lateral acceleration at which a vehicle can sustain a steady turn without rolling over. This measure has strong correlation with truck rollover accidents.

(ii) Dynamic Rollover Stability is the fractional change in tire loads between the left- and the right-side tire in avoiding an obstacle. This measure, called "load transfer ratio", indicates the point at which the vehicle lifts off all of its tires on one side, and starts rolling over, as shown in Figure 6.5.

(iii) Friction Demand in a Tight Turn is the minimum level of pavement friction on which a vehicle can negotiate a tight turn, such as at an intersection, without suffering from loss of controlling capability. Whenever the friction between the tires and pavement for a given vehicle is less than the friction demand, the vehicle will produce a "jack-knife" response, as shown in Figure 6.6. This situation is highly critical for semitrailers having widely spread axles and/or belly axles.

(iv) Braking efficiency is the highest percentage of tire/pavement friction that can be utilized in an emergency stop without suffering from wheel lockup.

(v) Low Speed Offtracking is the maximum offset in wheel paths between the outside of the frontmost wheel on the tractor and the inside of the rearmost wheel of the last trailer at a 90 degree right-hand turn at a 11-m radius intersection, as shown in Figure 6.7.

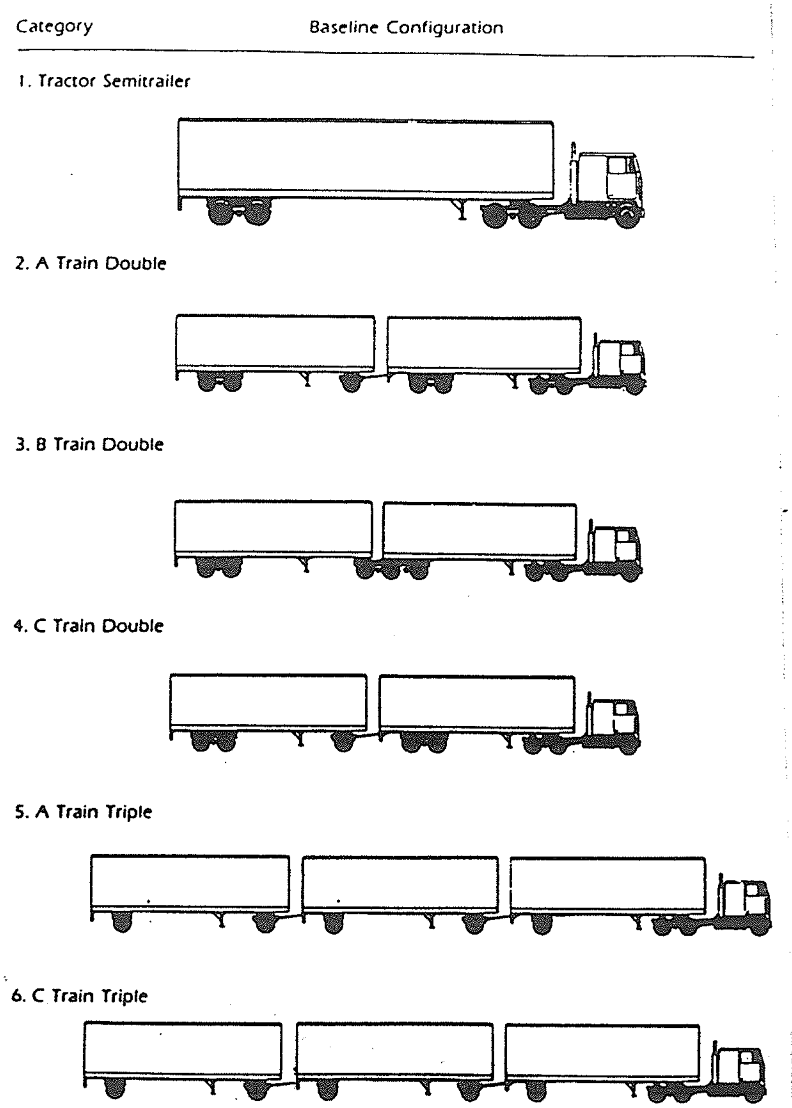


Figure 6.4 Vehicle classification framework
(Source: Reference [8], pp. 5)

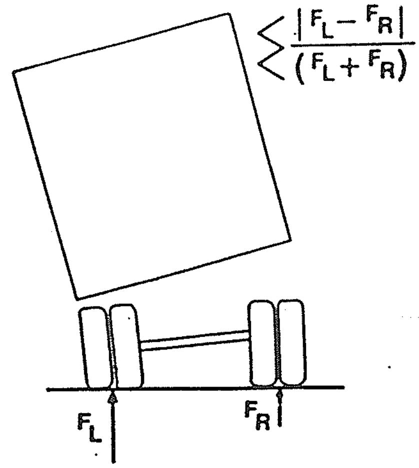


Figure 6.5 Dynamic rollover performance
(Source: Reference [50], pp. 13)

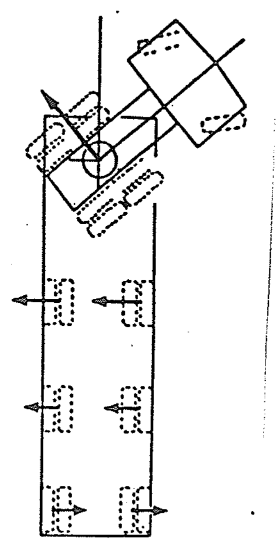


Figure 6.6 Friction demand performance
(Source: Reference [50], pp. 15)

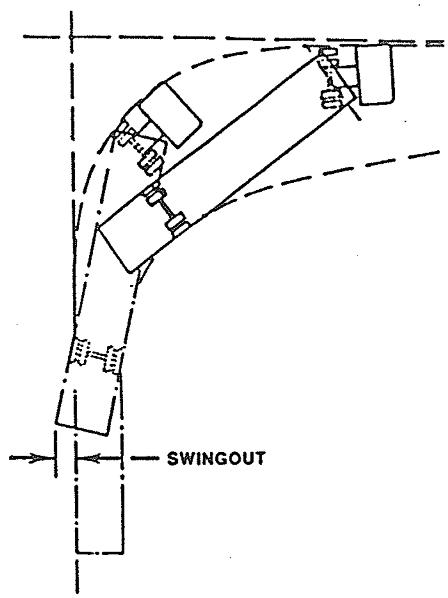


Figure 6.7 Low speed offtracking performance
(Source: Reference [50], pp. 14)

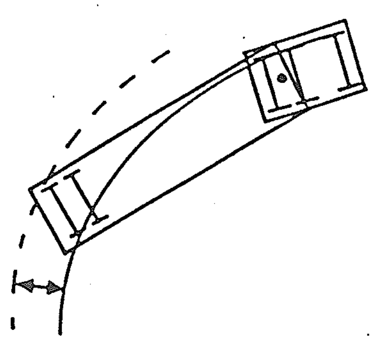


Figure 6.8 High speed offtracking performance
(Source: Reference [50], pp. 13)

Figure 6.9 Transient high speed offtracking performance
(Source: Reference [50], pp. 14)

(vi) High Speed Offtracking is the lateral offset in wheel paths between the outside of the frontmost wheel on the tractor and the outside of the rearmost wheel in a moderate steady turn, as shown in Figure 6.8.

(vii) Transient High-Speed Offtracking is the maximum value of offset in wheel paths between the outside of the frontmost wheel on the tractor and the most outward of the rearmost axle of the last trailer, as shown in Figure 6.9

6.6.2 Major Findings

The following notes summarize the major findings of the R.T.A.C. study concerning stability and control [8, 49, 50]:

Tractor-Semitrailer: The tractor-semitrailer was the most stable vehicle configuration investigated. It was found that its stability can be improved by reducing the spread of semitrailer axles (particularly in the case of triple, tri- and quad axles) and increasing semitrailer length (wheelbase) [8]. However, the maximum semitrailer length (wheelbase) is restricted by the offtracking consideration. Billing [50] stated that "Maximum wheelbase must be limited to control offtracking, and minimum wheelbase must be limited in conjunction with axle spread to control friction demand."

A-Train Double Trailer Combination: The typical A-train double units up to 23 metres in total length have a poor stability performance in response to rapid steering manoeuvres [50]. A-train double trailer units of 28 to 35 metres in total length are recommended to operate under special permits where there are no geometric problems because the longer combinations can improve high speed offtracking, dynamic rollover stability, and transient high speed offtracking performances [8, 50]. It should be noted that low speed offtracking must be determined in the case of lengthening A-train doubles.

B-Train Double Trailer Combinations: The B-train double unit has the highest stability and control capability compared to A- and C-train double trailer units.

C-Train Double Trailer Combination: The C-train double unit has better dynamic stability and control performances than A-train double units. However, the high-speed and transient high-speed offtracking of C-train double units is slightly worse than A-train doubles because of the steering characteristics of its dolly axles [50].

Triple Trailer Combination: Both A- and C-train triple trailer combinations have a considerably lower stability and control performance than doubles and tractor-semitrailers.

Table 6.4 [8] summarizes and compares the payload considerations, stability and control performances, and offtracking performances of 22 different vehicle configurations, including the 6 baseline vehicles. It should be noted that, based on productivity (volume and weight payload) considerations, the triple trailer combination is one of the most productive vehicle configurations. This is not the case when determining stability and control and offtracking performance. In particular, A-train triple trailer combinations (baseline 8-axle) have the worst stability and control and offtracking performance when compared to all other vehicles. B-train double trailer combinations (baseline 8-axle) rank as the superior configuration, in terms of productivity and safety aspects.

6.7 HISTORICAL ON-ROAD SAFETY

Although truck operational and stability and control performances of a number of different truck configurations have been determined, another important consideration is the examination of on-road truck accident history. The historical truck accident performance can reflect the effects of sizes, weights, and types of truck combinations actually operating on highway systems on their safety characteristics. The truck accident rate (number of accidents per mile or tonne-mile) and severity (fatality-, injury-, and property-damage-related accidents) are the indication of truck safety performance.

Table 6.4 Comparison of payload, stability and control, and offtracking performance for various types of truck combinations

CONFIGURATION	PAYLOAD		STABILITY AND CONTROL MEASURES				OFFTRACKING MEASURES		
	Volume	Weight	Static Rollover	Dynamic Rollover	Friction Demand	Braking Efficiency	Low Speed	High Speed	Transient High Speed
Reference Levels	104 m	25 t	0.5 g	0.60	0.10	70%	6 m	0.46 m	0.80 m
TRACTOR SEMITRAILERS									
Baseline 5 Axle	-	-	○	○	○	○	○	○	○
Close Spread Tridem	-	+	○	○	○	N/A	○	○	○
Wide Spread Tandem	-	++	◐	○	●	N/A	○	◐	○
Quad Axle	-	++	◐	◐	●	N/A	○	○	○
Belly Axle with Tandem	-	++	○	○	●	N/A	○	○	○
A TRAIN DOUBLES									
Baseline 8 Axle	+	++	○	●	○	○	○	○	○
7 Axle	+	++	◐	●	○	○	○	◐	●
6 Axle	+	+	○	●	○	○	○	◐	◐
Turnpike Doubles	++	++	○	○	○	○	●	○	○
Rocky Mountain	++	++	○	◐	○	○	●	○	○
C TRAIN DOUBLES									
Baseline 8 Axle	+	++	○	○	◐	○	○	◐	○
7 Axle	+	++	◐	○	○	○	○	◐	◐
6 Axle	+	+	○	○	○	○	○	●	○
Rocky Mountain	++	++	○	○	○	○	●	●	○
B TRAIN DOUBLES									
Baseline 8 Axle	+	++	○	○	○	N/A	○	○	○
7 Axle	+	++	○	○	○	○	○	○	○
6 Axle	+	-	○	○	○	○	○	○	○
Belly Axle	++	++	○	○	○	N/A	○	◐	○
A TRAIN TRIPLES									
Baseline 8 Axle	++	++	N/A	●	○	◐	◐	●	●
11 Axle	++	++	N/A	●	○	◐	◐	◐	●
C TRAIN TRIPLES									
Baseline 8 Axle	++	++	N/A	○	○	◐	◐	●	●
11 Axle	++	++	N/A	○	◐	◐	○	●	●

LEGEND:

Payload Measures:

- = Equal to Reference
+ = up to 20% better
++ = More than 20% better

Stability, Control & Offtracking Measures:

○ = Meets or exceeds reference performance
○ = less than 20% below reference performance
● = more than 20% below reference performance
N/A = Performance not available

(Source: Reference [8], pp. 13)

6.7.1 Effect of GVW on Truck Accident Characteristics

There is a concern that the use of bigger and heavier truck combinations would cause a reduction in highway safety and an increase in severity of truck accidents. It is generally known that truck weight is a significant factor in the severity of accidents, because of the effect of mass and speed change on any vehicle hit by that truck [52].

In terms of truck accident rate, Vallette et al. [51] conducted a truck accident study based on exposure and accident data collected on selected roadway segments in six states in the United States. They found that: (i) for straight trucks, the accident rate (number of accidents per 100 million vehicles miles) increases as GVW increases; (ii) for tractor-semitrailers, the accident rate decreases as GVW increases (the rate of decrease is high at low GVW and then gradually lower at high GVW); and (iii) for doubles, the accident rate gradually decreases as GVW increases, but after reaching the minimum accident rate at certain GVW, the accident rate increases moderately as GVW increases, as shown in Figure 6.10. However, it should be noted that the accident rate for doubles is higher than that for tractor-semitrailers.

Polus et al. [52] examined the road-accident involvement of various weight groups of trucks in Israel. The study was based on two sources of information: the police accident records, and the vehicle registration file. Polus et al. found that there exists a decreasing trend of accident rate (number of accidents per million vehicle km) as GVW increases, and that the involvement rate for trucks in highway accidents is lower than that for passenger cars and buses (Figure 6.11).

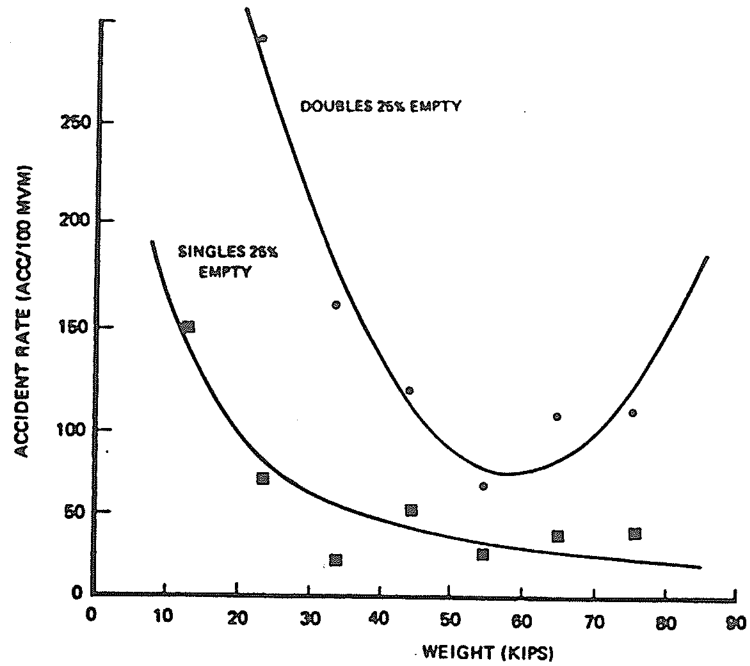


Figure 6.10 Truck accident rates as a function of gross vehicle weight for two states, California and Nevada
(Source: Reference [51], pp. 413)

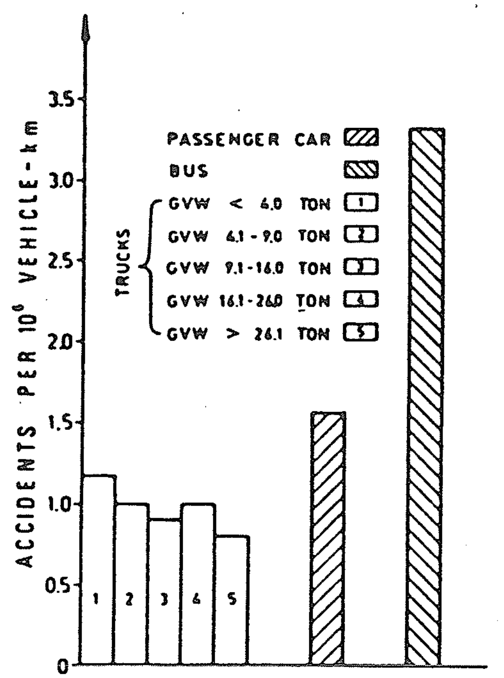


Figure 6.11 Truck accident rates as a function of gross vehicle weight in Israel
(Source: Reference [52], pp. 67)

In terms of severity, Vallette et al. [51] found that for tractor-semitrailer units, severity seems to be independent of GVW and for doubles, no conclusion could be drawn from the results obtained. Alassur [53] also found that "Increasing the current car/truck size disparity and mass ratio may have no significant adverse effect on the severity of car/truck accidents." Polus et al. [52], however, found that there is a tendency of increasing risk of a fatal accident as GVW increases. This was expressed in terms of percentage, and rate of fatal accidents involving trucks.

As discussed previously, the truck accident rate, in terms of the number of truck accidents per vehicle-distance (miles or kilometres), tends to decrease with the increase of GVW. However, Polus et al. [52] did not classify truck accident data by truck type (straight, single-trailer, or double-trailer units). This, therefore, could lead to the wrong conclusion, because tractor-semitrailers, for example, may cause different accident rates from doubles. The conclusion for truck accident severity relating to GVW is inconclusive.

6.7.2 Effects of the Number of Trailers on Truck Accident Characteristics

It was shown in Section 6.6 that different truck configurations had different operational performances which could possibly lead to different accident records actually experienced on highway operations. The following descriptions focus on the accident characteristics for tractor-semitrailer and double trailer units, because there is a lack of truck accident records for triples [41, 54].

In terms of truck accident rate, Carsten [55] conducted a study of truck accidents in the United States, and found that there is no difference in the rate of either fatality- or injury-related accidents between tractor-semitrailer and double trailer units. Vallette et al. [51] found that doubles experienced a higher accident rate than tractor-semitrailers at the same GVW as shown in Figure 6.10. Vallette et al. [51] also found that based on truck accident rate per ton-miles, doubles showed a considerably higher accident rate than tractor-semitrailers when operating on rural non-freeways and urban freeways. However, for rural freeways and urban non-freeways, the differences of that rate between doubles and tractor-semitrailers are not significant. In the TRB special report entitled "Twin Trailer Trucks" [41] based on a number of reviewed literatures, it was found that "twins have slightly more accident involvements per mile travelled than tractor-semitrailers operated under identical conditions at highway speeds." It should be noted that the most apparent difference between accidents experienced by doubles and those experienced by tractor-semitrailers was that a significantly higher proportion of doubles accidents were single vehicle accidents [41]. This indicates operating difficulties in the control of doubles.

In terms of truck accident severity, Carsten [55] found that double accidents showed somewhat more serious injuries than tractor-semitrailer ones, particularly in the case of noncollision accidents caused by rollovers and jack-knifing. This can be attributed to handling-related problems with double trailer combinations. The TRB special report [41] found that under reasonably similar conditions, the ratios between the accident involvement rate of doubles and that of tractor-semitrailers for fatal accidents were 0.93, 1.05, and 1.20 in the three selected studies. However, the conclusion was that "differences in the severity of twins and tractor-semitrailer accidents are small, and neither configuration is consistently associated with a more severe accident pattern." [41]. Vallette et al. [51] found that there was no difference in severity levels for tractor-semitrailers and doubles.

As discussed previously, the truck accident rate experienced by doubles tended to be higher than that experienced by tractor-semitrailers. It was found that doubles possibly have handling problems compared to tractor-semitrailers, because doubles showed a higher proportion of single-vehicle accidents such as jack-knifing and rollovers. There is no consistent conclusion for truck accident severity with respect to number of trailers. One should realize that the following factors can have some impact on the findings obtained:

(i) data considerations, such as sources of data, data-collection, method, quality and quantity of data, etc.

(ii) differences in definition and classification of accident types, analytical approaches, interpretation and evaluation approach.

(iii) differences in operating environments such as weather (dry, wet), highway type, highway location, time of day, traffic volume, speed, roadside features, geometric features, etc. [63].

An appropriate truck accident study should be conducted at a disaggregate level; for example, truck accident rate and severity should be determined separately for truck configuration types, truck weights, and truck sizes. Truck accident rate and severity should also be considered separately by highway types under the acceptably similar operating environments, and by accident types.

CHAPTER 7

SUGGESTED RESEARCH PROJECTS CONCERNING LARGE TRUCK OPERATIONS IN THE NORTHEAST REGION OF THAILAND

The utilization of large trucks in the Northeast Region of Thailand is increasing due to economic pressures. This increase has important effects for traffic, highways, and bridges. Although use of large trucks will result in a reduction in fuel consumption and truck operating cost, leading to an improvement of the region's economy, a better standard of living, and various other benefits, it can also lead to an increase in highway pavement and bridge costs, a reduction in highway capacity and level of service, and an increase in the number and severity of accidents involving those large trucks.

It is known that vehicle weight and dimension (VWD) regulations have an important effect on truck fleets and their operating characteristics. Highway and bridge engineers therefore require a clear understanding of the structure of VWD regulations, the influences of those regulations on the physical and operating characteristics of different truck configurations, and the effect of proposed changes in these regulations. This understanding would help those engineers to link the effects of VWD regulations to pavement and bridge damage, highway capacity and level of service reductions, and on-road truck accident performance, etc.

This chapter presents recommendations for relevant research relating to truck weight and dimension issues of apparent import to regulatory development opportunities concerning large truck transport in the Northeast region of Thailand.

The recommendations for relevant research are as follows:

1. In order to develop a clear understanding of the nature of truck transportation systems in the northeast region, the three main components--activity system relating to truck transport, truck transportation system, and commodity flow carried by trucks--must be studied. The activity system relating to truck transport needs is the pattern of social and economic activities, such as farm population, planted area, agricultural production and related industry, etc. The truck transportation system consists of roadway networks, roadway characteristics (i.e., primary, secondary or provincial highways, length of each highway, number of lanes, characteristics of curves, grades, and turns, etc.), vehicle characteristics (truck fleet composition, number of axles in each truck type, truck empty weight, axle load, GVW, truck overall length, etc.), and other elements. Truck transport flow pattern is determined based on commodity type, truck type, length of trip, origin-destination consideration, operating characteristics ("cube-out", "weight-out", overweight and overdimension operations, rate charged, one- or two-way hauling, etc.), and other elements.

   These three truck transport components are mutually interactive. The characteristics of truck transportation in the region would be more clearly understood at the end of this research. The answers for such questions as why the traffic of a given commodity on a particular highway portion is so heavy, why large trucks are used in long trips rather than short trips, why the use of large trucks is generally greater than small ones, why the empty trucks running on highways are so numerous, etc., would be revealed. This research would mainly be based on case studies, interviews with truck operators and users and farmers, and field data collection.

2. In order to develop a clear understanding of how VWD regulations influence truck fleet and operating characteristics in the northeast region of Thailand, five studies must be conducted. They are outlined as follows:

(i) To develop an understanding of the structure of VWD regulations, conceptual criteria (technical, operational or political aspects) in setting each element included in VWD regulations currently governing in the northeast region. It would be recommended that the comparison of VWD regulations currently governing in Thailand to those regulations currently governing in other countries in Southeast Asia, Europe, and Canada and the U.S.A., etc., should be considered. The changes in the VWD regulations in these countries should be compared to those in Thailand as well. The purpose is to discover the effects of international freight transportation (i.e., container transport) on the VWD regulatory changes in Northeast Thailand. This research would be based on interviews with government officers responsible for the setting VWD regulatory in the Department of Highways and Department of Land Transportation.

(ii) To develop an understanding of the effects of VWD regulations on truck fleet and operating characteristics (truck fleet selection, truck fleet mix, truck tare weight, truck GVW distribution, axle load distribution, etc.) based on currently governing VWD regulations and recently passed VWD regulations (VWD regulatory changes) in the region. The pattern of changes in truck fleet and operating characteristics over time will represent the influences of VWD regulatory changes. This research would be based on field data collection conducted by Khon Kaen University (KKU) staff and truck survey data conducted by DOH in the northeast region. In addition, truck data collection at weighing scales in processing plants in the region would be performed mainly to obtain truck tare weight and GVW distribution data. Truck operators would also be interviewed.

(iii) To develop an understanding of overweight/overdimension operations, reflecting the efficiency of enforcement programs actually performed and enforcement programs such as fine and penalty structure and overweight/overdimension detection conducted by government officers and policemen. This research would be based on interviews with government officers and policemen at detecting scales, and interviews with truck operators and truck drivers. The true overweight/overdimension information would also be collected at those scales.

(iv) To develop an understanding of the effects of non-VWD regulatory factors (i.e., commodity, route, operational, terminal characteristics, etc.) on truck fleet and operating characteristics. This research would reflect the influences of those factors on the relationship between VWD regulations and truck fleet and operating characteristics, and would be based on truck operator and user interviews, and case studies.

(v) According to the first four researches discussed in this section, another study should be conducted to develop an understanding of the implications of VWD regulations to the range of several truck configuration types potentially and actually operating in the northeast region. This research should be formulated at a disaggregate level to take into account commodity differences (i.e., liquid, bulk dry, general freight, as well as commodity density), route differences (i.e., primary highways, unpaved rural roads, etc.), regional differences (i.e., rural, urban, etc.), and operational differences ("weight-out", "cube-out", "empty", or "less-than-truckload" (LTL) operations). This research would identify "what went wrong in governing VWD regulations", and recommend possible VWD regulatory improvements.

3. It is necessary to analyze the theoretical and actual productivity in terms of truck operating cost per output (baht per tonne-km) with respect to governing VWD regulations and potential change to those regulations. The theoretical considerations of this analysis would consider payload-handling capabilities (by freight type), annual utilization levels, cost structure and energy consumption of a number of feasible truck types operating in the region. The following steps would be performed:

(i) Based on the research described in "2" above, scenarios of VWD regulations and truck types would be established. Therefore, tare weights, cubic payload and weight payload capacities for each of those truck types would also be determined.

(ii) The typical range of vehicle utilization (distance travelled) and typical operating performance (long trips between cities, short trips in urban areas, etc.) for different vehicle types and different commodities handled would be considered.

(iii) Suitable input cost data would be developed based on typical operational situations by truck types, commodity types, and route types.

(iv) The data in (iii) would be input into a selected cost model. The results of theoretical productivity (baht per tonne-km) for each truck and VWD regulation scenario would then be obtained. It should be noted that the cost model used in this research should be appropriate to the developing country situation and should be a deterministic cost model. It is recommended that based on this deterministic model, the sensitivity analysis would be performed to identify which input parameters (sensitivity parameters) have strong influences on truck operating costs.

The actual considerations of this analysis would focus on development of an understanding of actual payloads handled, operating circumstances, utilization levels, fuel consumption, and cost experiences. This analysis would be based on case studies and interview programs conducted in the northeast region.

4. An understanding of the effects of VWD regulations and their changes on highway pavements and bridges in terms of reconstruction and maintenance costs is needed. The VWD regulation and truck type scenarios providing high theoretical and (possibly) actual productivity (high truck operating cost saving) would be considered as the VWD regulation and truck type scenarios input in this research. This would be based on the study mentioned in "3" above. These scenarios would be considered separately for commodity types, operation types, and route types.

   For pavement costs, the damaging effects of a particular truck type operating under a given VWD regulation scenario would be mainly varied according to axle types, axle loads, axle spreads, and suspension systems allowed by that VWD regulatory scenario. The pavement damage caused by a given truck configurations is determined by the increases in the equivalent (18-kip) single axle load applications. Therefore, research involving the effects of each truck type operating under a given VWD regulation scenario on highway pavements (both rigid and flexible) in terms of the equivalent (18-kip) single axle load would be conducted.

   For bridge costs, the damaging effects of a particular truck type operating under a given VWD regulation scenario on bridges are varied according to GVW and axle spacing. The main effect of those trucks on bridges is the magnitude of bending moment created on those bridges compared to the bending moment caused by design vehicles (i.e., HS-20). Therefore, the research involving the effects (bending moment) of each truck type operating under a given VWD regulation scenario on different kinds of bridges (i.e., short, medium, or long span bridges) in the northeast region would be conducted.

A highway rehabilitation and maintenance cost model would be developed or adapted from other studies in order to calculate those costs. It should be noted that data input into the model must be carefully determined because those data will reflect truck configuration types for each VWD regulation scenario, and also represent highway and bridge characteristics, and typical truck operational characteristics in the region. This can lead to more realistic results. The benefit cost ratio analysis should then be conducted to evaluate the economic feasibility for each VWD regulation scenario.

5. Developing an understanding of operating performance in terms of stability and control characteristics (i.e., braking efficiency, offtracking, rollover, jackknife, etc.), of feasible truck types operating under each VWD regulation scenario and actual truck types currently operating in the region is essential. This research would be conducted using computer simulations of all feasible and actual truck types, as well as full-scale tests of some popular truck types. The computer simulation model would be adapted from one available from a developed country, such as the model used in the RTAC Study [57] conducted in Canada. While some truck configuration types are feasible in economic terms, this research would identify which of them have operating problems on highway environments in the northeast region. This research is very important, because it would help to indicate the direction of appropriate, productive and safe changes in VWD regulations.

6. Evidence of actual operation problems of truck types operating on highway networks in the northeast region based on historical on-road truck accident records should be collected. This research would attempt to correlate problems with certain truck configurations indicated in research (5) to problems in actual on-road operation. The

main source of this research would be police accident records. Although the reliability of this source is questionable, it is the best of the actual on-road accident data. The research should be formulated (if possible) to present accident rate and severity for different truck characteristics such as GVW, number of trailers, and truck types. It would also be important to control operating environments such as weather (dry or wet), highway types (divided or undivided, number of lanes), highway location (turns, intersection, curves, etc.), driver condition, etc. In addition, the definition and classification of accident types, analytical approaches, interpretation and evaluation should be carefully set to match the in-hand data and truck operating conditions in the region.

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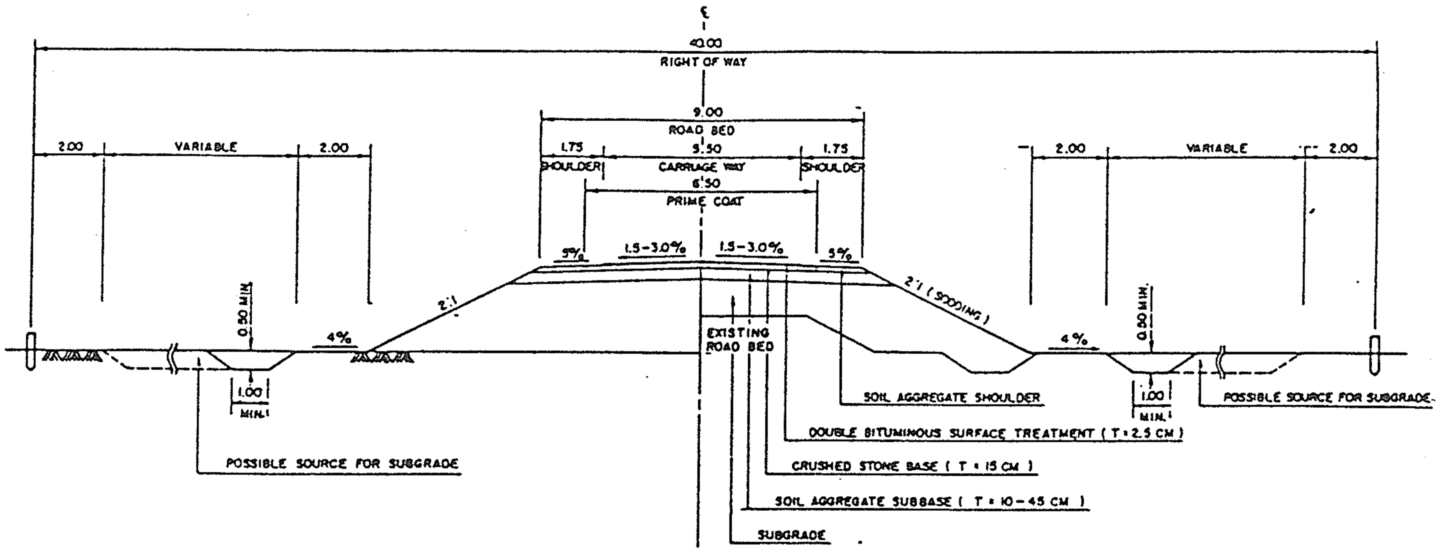
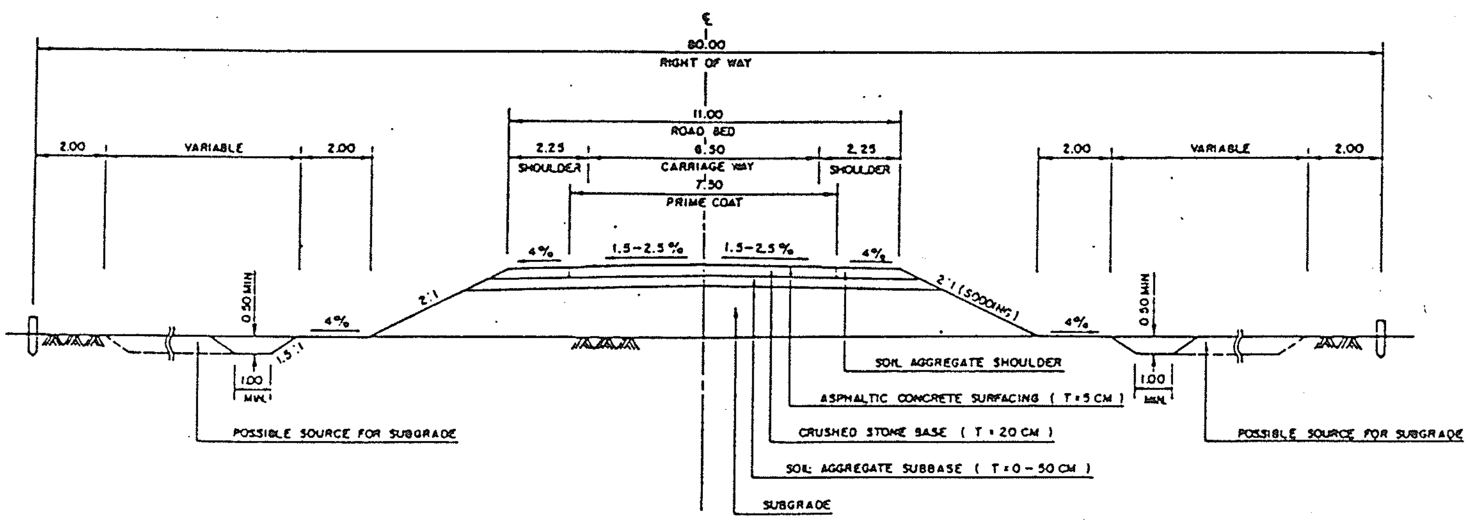
Appendix A-1 Typical cross sections of primary and provincial highways in Northeast Region (Source: Reference [1])

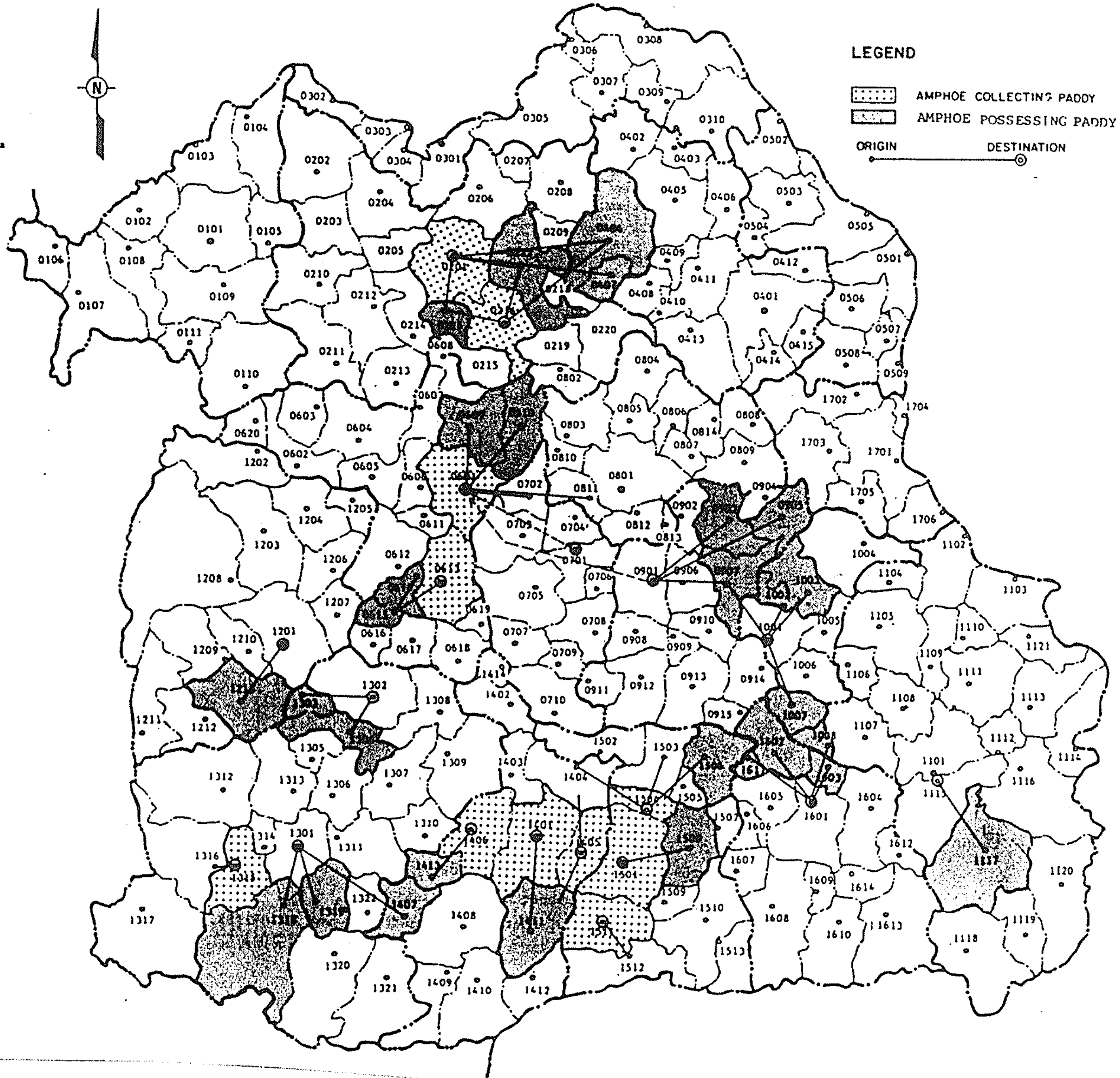


PROVINCIAL HIGHWAY (CLASS F4)

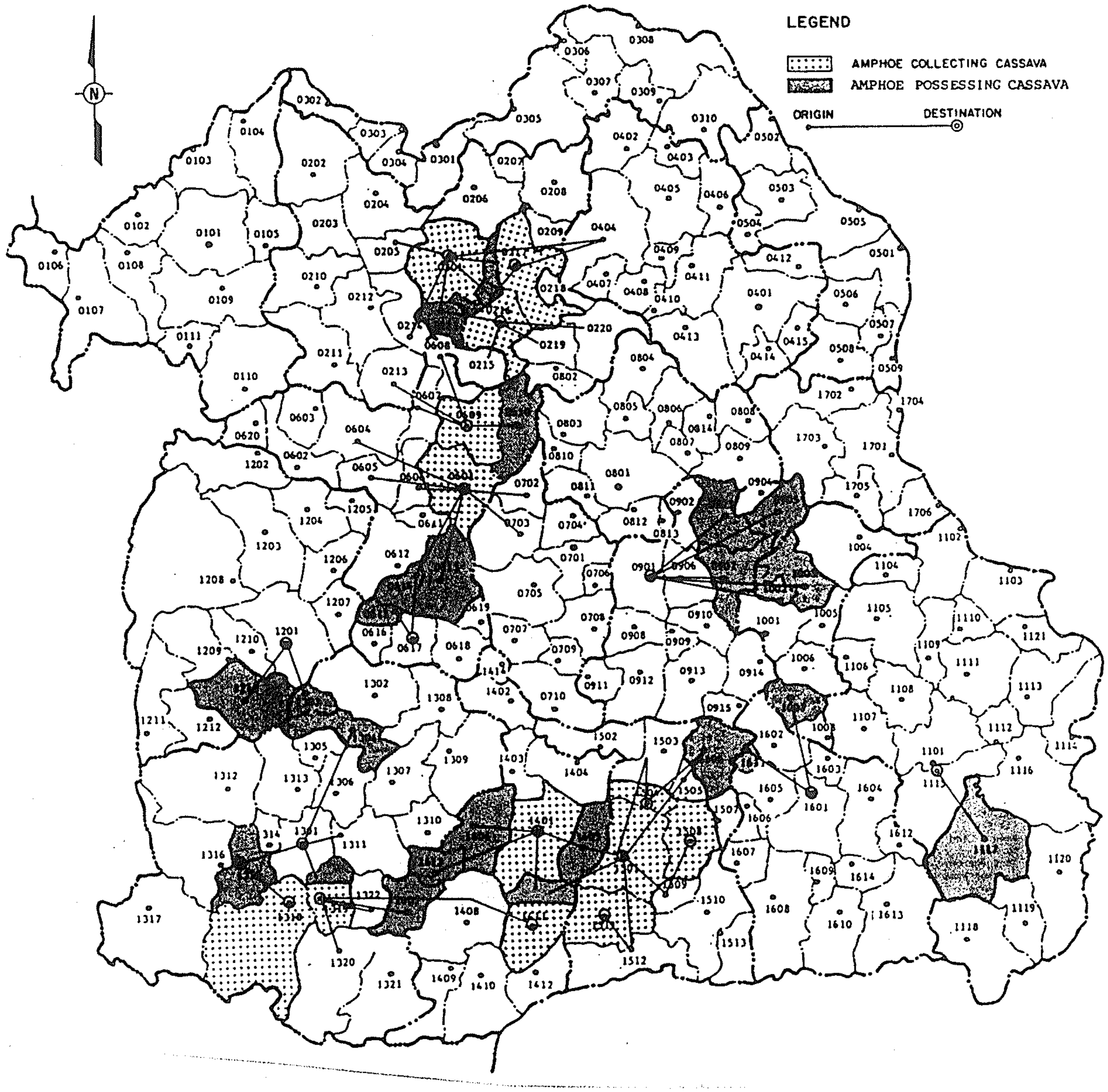


PRIMARY HIGHWAY (CLASS P2)

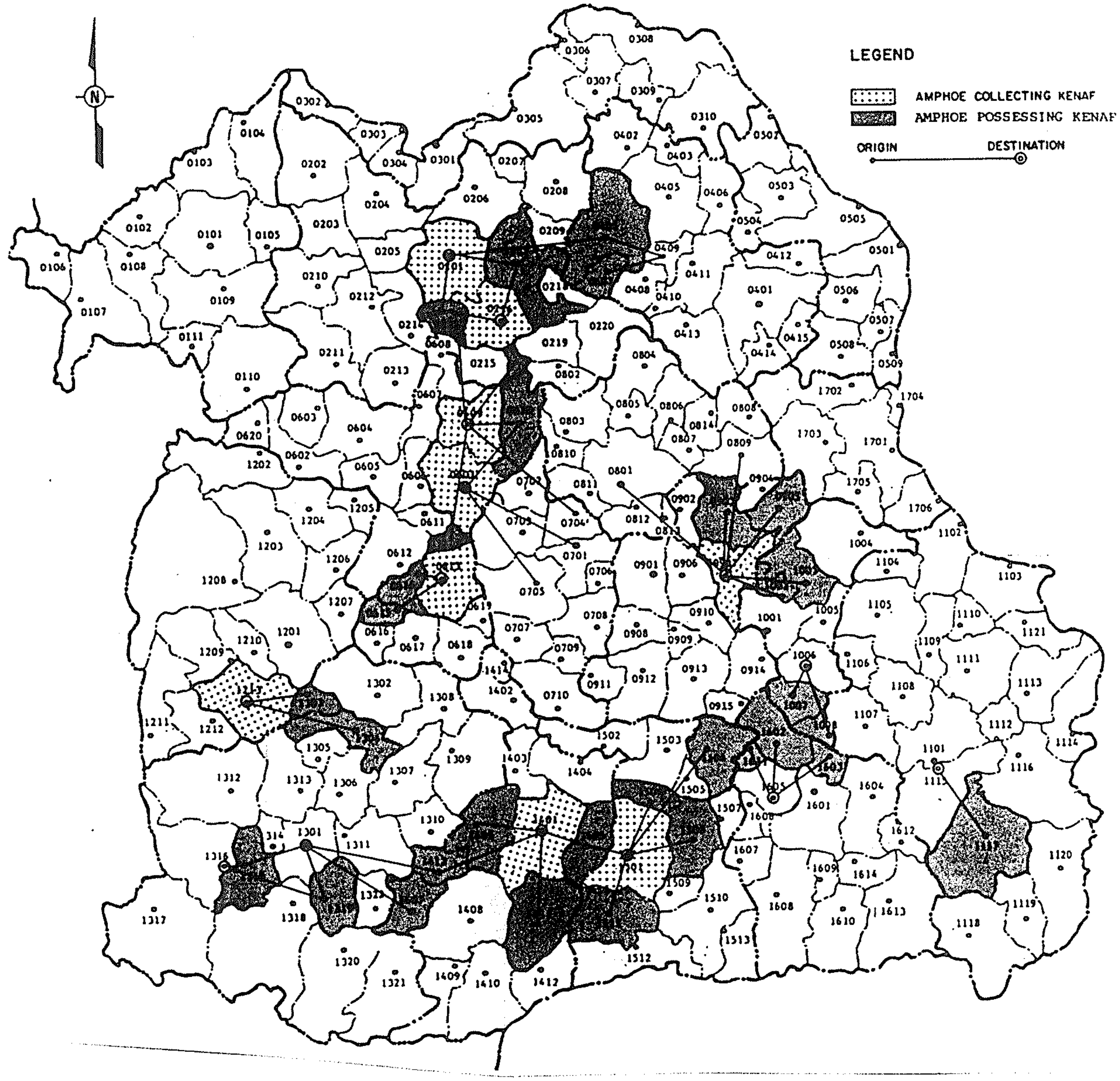
0101 M. Loei
0102 Tha Li
0103 Chiang Khan
0104 Pak Chom
0105 Na Duang
0106 Na Haeo
0107 Dan Sai
0108 Phu Rue
0109 Wang Saphung
0110 Phu Kradung
0111 Phu Luang
0201 M. Udon Thani
0202 Nam Som
0203 Suwannakhuha
0204 Ban Phu
0205 Kut Chap
0206 Phen
0207 Sang Khom
0208 Ban Dung
0209 Thung Fon
0210 Na Klang
0211 Si Bun Ruang
0212 Nong Bua Lam Phu
0213 Non Sang
0214 Nong Wua So
0215 Non Sa-At
0216 Kumphawapi
0217 Nong Han
0218 Chaiwan
0219 Si That
0220 Wang Sam Mo
0221 Nong Saeng
0301 M. Nong Khai
0302 Sangkhom
0303 Si Chiang Mai
0304 Tha Bo
0305 Phon Phisai
0306 Pak Kad
0307 So Phisai
0308 Bung Kan
0309 Phon Charoen
0310 Seka
0401 M. Sakhon Nakhon
0402 Ban Muang
0403 Kham Ta Kla
0404 Savang Daen Din
0405 Wanon Niwat
0406 Akat Amnuai
0407 Song Dao
0408 Waritchaphum
0409 Phang Khon
0410 Nikhom Nam Un
0411 Phanna Nikhom
0412 Kusuman
0413 Kut Bak
0414 Tao Koi
0415 Kok Sri Supan
0501 M. Nakhon Phanom
0502 Ban Phaeng
0503 Si Songkhram
0504 Na Wa
0505 Tha Uthen
0506 Pla Pak
0507 Renu Nakhon
0508 Na Kae
0509 That Phanom
0601 M. Khon Kaen
0602 Chumphae
0603 Si Chomphu
0604 Phu Wiang
0605 Nong Rua
0606 Ban Fang
0607 Ubolratana
0608 Kaosuankwang
0609 Nam Phong
0610 Kranuan
0611 Phra Yun
0612 Mancha Khiri
0613 Ban Phai
0614 Chonnabot
0615 Waeng Yai
0616 Waeng Noi
0617 Phon
0618 Nong Song Hon
0619 Phouy Noi
0620 Phu Pha Man
0701 M. Maha Satakham
0702 Chiang Yun
0703 Kosum Phisai
0704 Kantharawichai
0705 Borabu
0706 Kae Dam
0707 Na Chuak
0708 Wapi Pathum
0709 Na Dum
0710 Phayakkhaphum Pisai
0801 M. Kalasin
0802 Tha Khantho
0803 Nong Kung Si
0804 Khom Muang
0805 Sahatsakhan
0806 Somdet
0807 Na Mon
0808 Khao Wong
0809 Kuchinarai
0810 Huai Mek
0811 Yang Talat
0812 Kamalasai
0813 Rong Kham
0814 Huay Pung
0901 M. Roi Et
0902 Pho Chai
0903 Phon Thong
0904 Muayawadee
0905 Nong Phok
0906 Thawatchaburi
0907 Selaphum
0908 Chaturapak Pimun
0909 Muang Suang
0910 At Samat
0911 Pathum Rat
0912 Kaset Wisai
0913 Suwannaphum
0914 Phanom Phrai
0915 Phon Sai
1001 M. Yasothon
1002 Sai Mun
1003 Kut Chum
1004 Loeng Nok Tha
1005 Pa Tiu
1006 Kham Khuan Kaeo
1007 Maha Chana Chai
1008 Kho Wang
1101 M. Ubon Ratchathani
1102 Chanuman
1103 Khemaraj
1104 Senang Khanikhom
1105 Amnat Charoen
1106 Hua Thaphan
1107 Khuang Nai
1108 Muang Samsip
1109 Phana
1110 Kut Kaopun
1111 Trakan Phutphon
1112 Taleum
1113 Si Muang Mai
1114 Khong Chiam
1115 Warin Chamrap
1116 Pibun Mungsahan
1117 Det Udom
1118 Nam Yun
1119 Na Chaluai
1120 Buntharik
1121 Pho Sai
1201 M. Chaiyaphum
1202 Khon San
1203 Kaset Sombun
1204 Phu Khieo
1205 Ban Thaen
1206 Kaeng Khlo
1207 Khon Savan
1208 Nong Bua Daeng
1209 Nong Bua Rahuao
1210 Ban Khwao
1211 Thep Satit
1212 Bamnet Narong
1213 Chatturat
1301 M. Nakhon Ratchasima
1302 Bua Yai
1303 Ban Luam
1304 Khong
1305 Kham Sakae Saeng
1306 Nong Sung
1307 Phimai
1308 Prathai
1309 Chum Phuang
1310 Huai Thalaeng
1311 Chakkaraj
1312 Dan Khun Thot
1313 Non Thai
1314 Kham Thalae So
1315 Sung Noen
1316 Sikhiu
1317 Pak Chong
1318 Pak Thong Chai
1319 Chok Chai
1320 Khon Buri
1321 Soeng Sang
1322 Nong Bunnak
1401 M. Buri Ram
1402 Phutthaisong
1403 Khu Muang
1404 Satuk
1405 Krasang
1406 Lam Plai Mat
1407 Nong Ki
1408 Nang Rong
1409 Pa khom
1410 Lahan Sai
1411 Prakhon Chai
1412 Ban Kruat
1413 Nong Hong
1414 Na Pho
1501 M. Surin
1502 Chumphon Buri
1503 Tha Tum
1504 Chom Phra
1505 Sanom
1506 Rattanaburi
1507 Samrong Thap
1508 Sikhoraphum
1509 Lamduan
1510 Sangkha
1511 Prasat
1512 Kap Choeng
1513 Bua Chet
1601 M. Si Sa Ket
1602 Rasi Salai
1603 Yang Chum Noi
1604 Kanthararom
1605 Uthumpon Phisai
1606 Huai Thap Than
1607 Prang Ku
1608 Khukhan
1609 Phrai Bung
1610 Khun Han
1611 Bung Boon
1612 Non Koon
1613 Kanthararak
1614 Sri Pattana
1701 Mukdahan
1702 Dong Luang
1703 Khamcha-I
1704 Wan Yai
1705 Nikhom Kham Soi
1706 Don Tan



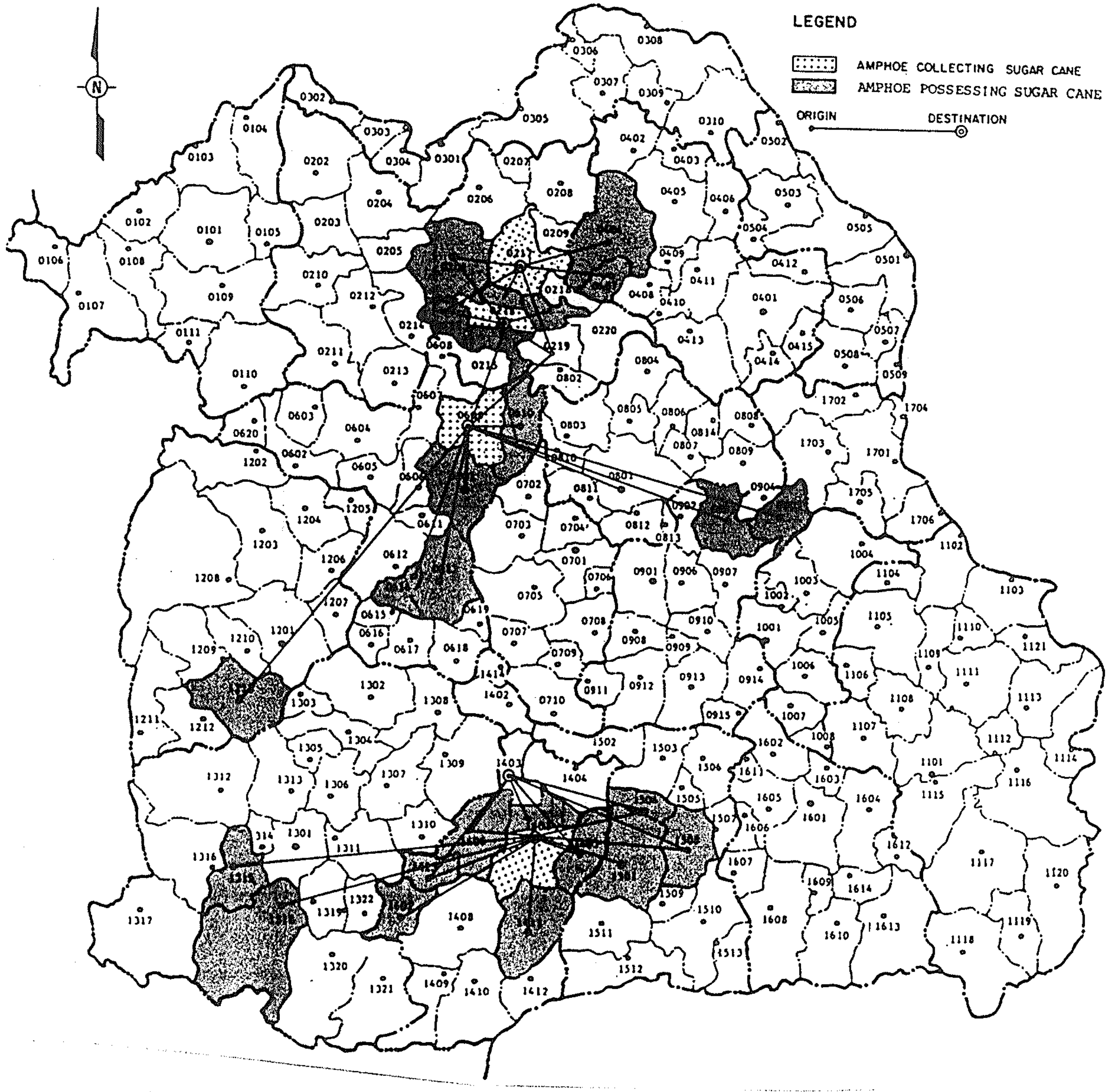
Appendix A-2 Commodity flow of rice (Source: Reference [21])



Appendix A-3 Commodity flow of cassava (Source: Reference [2])



Appendix A-4 Commodity flow of kenaf (Source: Reference [2])



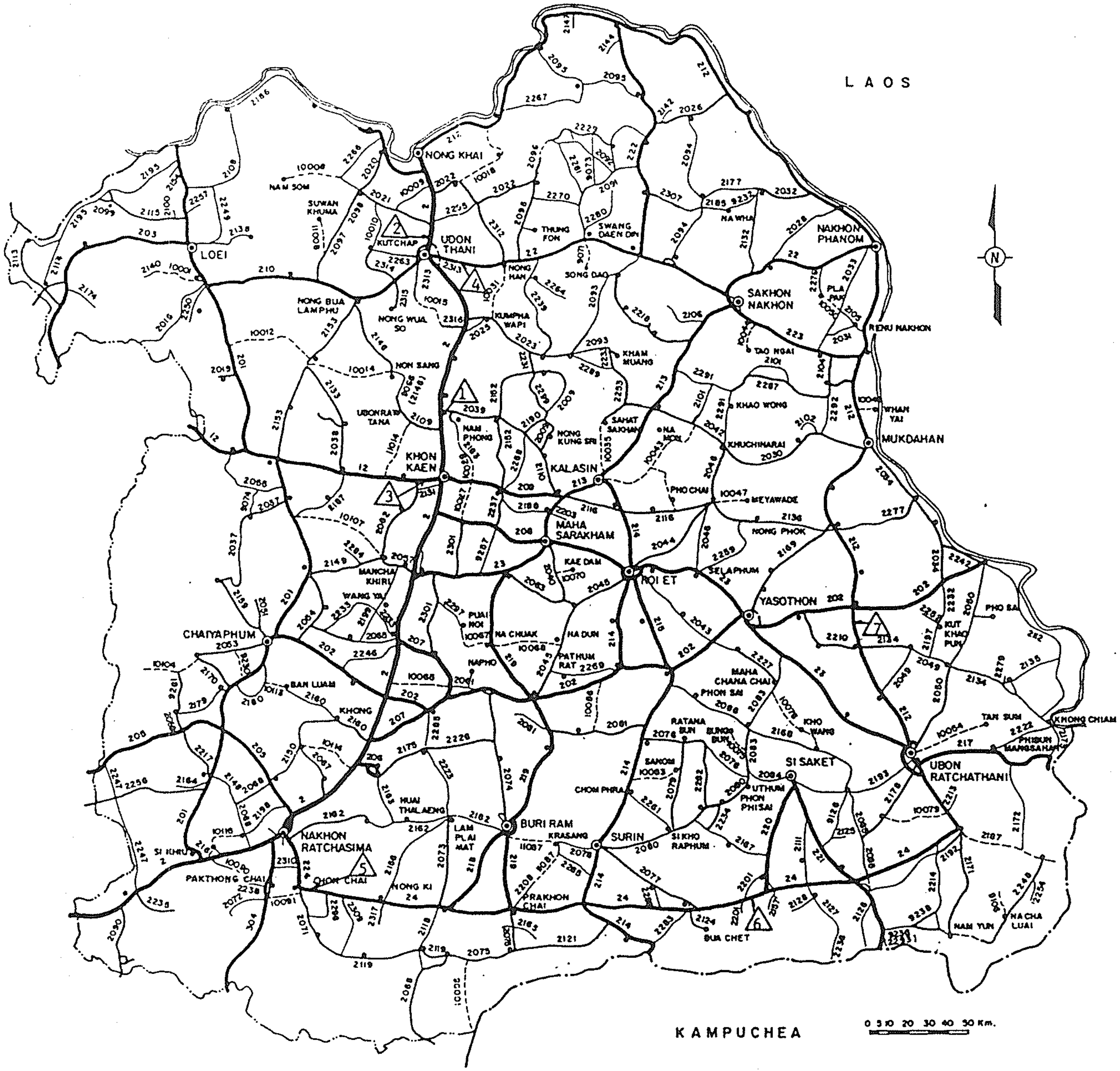
Appendix A-5 Commodity flow of sugarcane (Source: Reference [2])

Appendix A-6 Location of vehicle gross weight surveys by DOH (1980)

Location	No.	Route	Origin-Destination	Km. Post
1	(D1)	2	Khon Kaen (C) - Udon Thani (C)	479 + 000
2	(D2)	2	Udon Thani (C) - Nong Khai (C)	572 + 200
3	(D3)	2	Khon Kaen (C) - Chumphae (A)	8 + 000
4	(D4)	22	Udon Thani (C) - Swang Daen Din (A)	10 + 800
5	(D5)	24	Chok Chai (A) - Nang Rong (A)	6 + 500
6	(D6)	24	Sangkha (A) - Det Udom (A)	222 + 800
7	(D7)	212	Ubon Ratchathani (C) - Amnat Charoen (A)	68 + 800

Note: (C): Changwat, (A): Amphoe

Appendix A-7 Location of vehicle gross weight surveys (Source: Reference [2])



LEGEND

- NATIONAL HIGHWAYS (Paved)
- PROVINCIAL ROADS (Paved)
- PROVINCIAL ROADS (Unpaved)
- RURAL ROADS (Unpaved)
- CHANGWAT
- AMPHOE
- BOUNDARY OF COUNTRY
- BOUNDARY OF PROVINCE
- 2, 2096 HIGHWAYS, ROAD NUMBERS
- △ : Surveyed by DOH (1980)

Location No.	Route	Km Post
1	2	479 + 0
2	2	572 + 200
3	12	8 + 0
4	22	10 + 800
5	24	6 + 500
6	24	222 + 800
7	212	68 + 800

Appendix A-8 Gross vehicle weight (GVW) distributions for loaded and 10-wheel trucks

GVW (tonnes)	GVW Midpoint (tonnes)	6-Wheel			10-Wheel		
		No. of Trucks	%	Cumulative %	No. of Trucks	%	Cumulative %
3.5-4.5	4	1	0.29	0.29			
4.5-5.5	5	9	2.62	2.92			
5.5-6.5	6	17	4.96	7.87			
6.5-7.5	7	30	8.75	16.62			
7.5-8.5	8	41	11.95	28.57	1	0.08	0.08
8.5-9.5	9	43	12.54	41.11	3	0.25	0.33
9.5-10.5	10	54	15.74	56.85	6	0.50	0.83
10.5-11.5	11	38	11.08	67.93	11	0.92	1.75
11.5-12.5	12	31	9.04	76.97	14	1.17	2.92
12.5-13.5	13	21	6.12	83.09	17	1.42	4.33
13.5-14.5	14	36	10.50	93.59	20	1.67	6.00
14.5-15.5	15	12	3.50	97.08	29	2.42	8.42
15.5-16.5	16	8	2.33	99.42	39	3.25	11.67
16.5-17.5	17	2	0.58	100.00	73	6.08	17.75
17.5-18.5	18				144	12.00	29.75
18.5-19.5	19				233	19.42	49.17
19.5-20.5	20				238	19.83	69.00
20.5-21.5	21				100	8.33	77.33
21.5-22.5	22				36	3.00	80.33
22.5-23.5	23				42	3.50	83.83
23.5-24.5	24				37	3.08	86.92
24.5-25.5	25				42	3.50	90.42
25.5-26.5	26				49	4.08	90.50
26.5-27.5	27				35	2.92	97.42
27.5-28.5	28				18	1.50	98.92
28.5-29.5	29				8	0.67	99.58
29.5-30.5	30				4	0.33	99.92
30.5-31.5	31				1	0.08	100.00
		343	100		1200	100	

Source: Reference [3]

Appendix A-9 Small truck, "Eatan", for rural areas

Because of the improvement of production technology and other factors, the processing plants require large amounts of raw material from the farms. As a result, the farmers are forced to buy trucks to transport their product to the plants.

Since the existing trucks, usually manufactured in Japan, are very expensive, the cheaper and smaller trucks, called "Eatans" are produced and widely used in all regions of Thailand. The engine of this truck is usually a diesel engine, and has low fuel consumption. In addition, the engine can be removed for use as a water pump or a power unit for farm machines (a plowing machine, for example). The engine is quite easy to maintain. These factors make the "Eatan" a very popular choice for farmers in rural areas of Thailand.

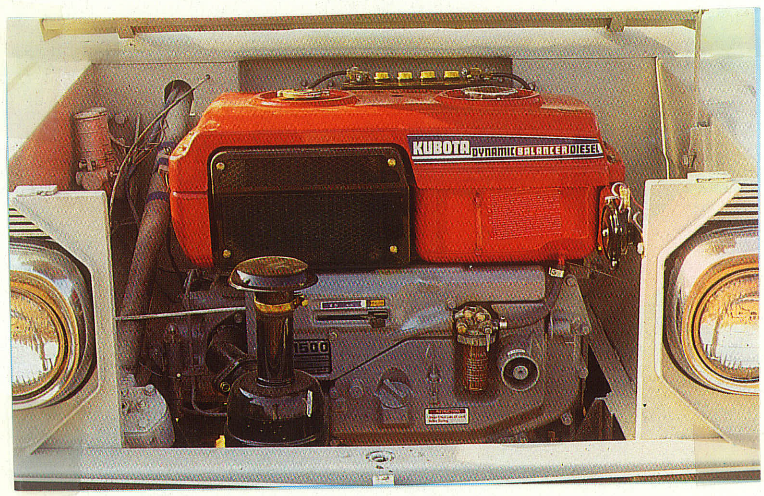


Figure A-9.1 The engine

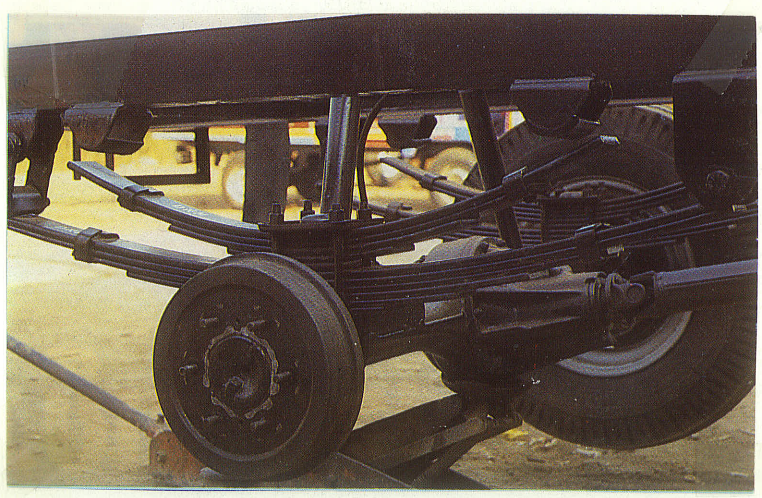


Figure A-9.2 The suspension system

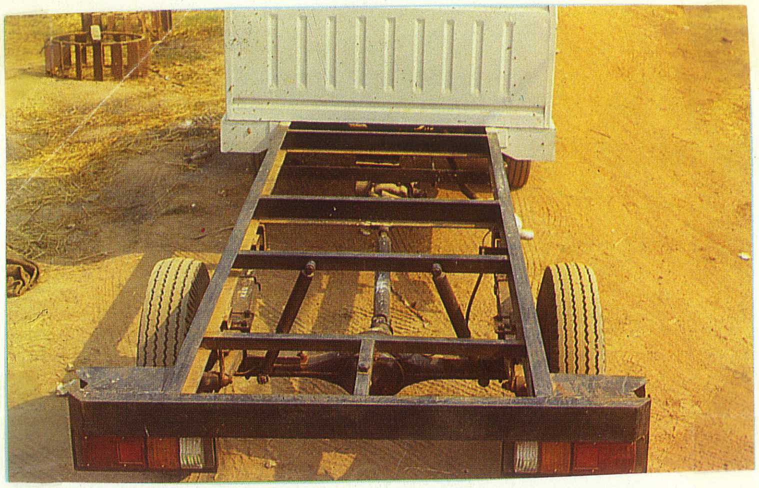


Figure A-9.3 Chassis structure

Maximum payload capacity of 2 tonnes

Maximum payload capacity of 3 tonnes

Maximum payload capacity of 3 tonnes

Maximum payload capacity of 4 tonnes

Figure A-9.4 The typical four models of "Eatan" trucks

Appendix A-10 Truck characteristics for Case Study I

All three trucks are the old model of ISUZU, as shown in Figure 2.10.1 below.

Figure A-10.1 3-axle, 10-wheel single unit truck (Vehicle Type II)

Truck Characteristics:

- fuel type: diesel
- power: 120 horsepower (HP)
- configuration: 3-axle, 10-wheel single unit truck
- tare weight: 7.0-8.0 tonnes
- maximum GVW limit: 21.0 tonnes
- payload capacity: 14.0-14.5 tonnes

Appendix A-11 Truck characteristics for Case Study II

All trucks are the old model of ISUZU as shown in Figure 2.11.1 and 2.11.2 below.

Figure A-11.1 3-axle, 10-wheel single unit truck (Vehicle Type II)

Figure A-11.2 10-wheel truck, plus 2-axle full-trailer combination (Vehicle Type IV)

Truck Characteristics:

- fuel type: diesel
- power: 120 hp
- configuration: 3-axle, 10-wheel single unit truck
- payload capacity: 12,000 litres

Only one 10-wheel truck plus full-trailer combination (vehicle type IV) is operated. The combination has a payload capacity of 30,000 litres, and a power of approximately 170 HP.

Appendix B-1

STRUCTURE OF THE TRIMAC TRUCK COST MODEL

1. **Tractor Variable Costs:**

DRIVER:	based on driver wage rates
FUEL:	based on unit price x consumption rate
REPAIRS:	fleet average costs of parts, lubricants, based on 3-year-old tractors
CLEANING:	fleet average cost experience
TRANSPORT:	fleet average costs of "extra" equipment (i.e., pumps, hoses, safety equipment, but excluding tarps, refrigeration)
TIRES:	fleet average cost experience

2. **Tractor Fixed Costs:**

DEPRECIATION:	based on new 1986 capital cost straight-line depreciated at 79.21/year for 5 years, and then replaced
LICENCE:	annual licence fee varying by registered g.v.w.

3. **Trailer Variable Costs:**

REPAIRS:	same as for tractor, except 5-year old trailer is assumed
CLEANING:	same as for tractor, except as experienced with trailers
TRANSPORT:	same as for tractor, except as experienced with trailers
TIRES:	same as for tractor, except as experienced with trailers

4. **Trailer Fixed Costs:**

DEPRECIATION:	based on new 1986 capital cost straight-line depreciated at 1%/month for 8 years, to scrap value
LICENCE:	annual fee

5. **Insurance Costs**

- based on 3% of "total cost", being a fleet average experience

6. **Administration and Interest**

- based on 14% of "total cost", being a fleet average experience

7. **"Profit"**

- successful Canadian trucking operating are expected to achieve an "operating ratio" (i.e., total expense: total revenue) of 0.90, implying an "operating profit" (not a return on investment) of 10%

(Source: Reference [25], pp. 7.16)

Appendix B-2. 1986 Truck Operating Cost Characteristics: Manitoba-Bulk Commodity by Annual Truck Utilization (2-axle Straight Truck)

Configuration -- 2 axle straight truck (diesel) Manitoba

Commodity -- Bulk

Annual distance -- 40000 km.

		Paved Road	Gravel Road
A.	Vehicle Utilization		
	Gross Vehicle Weight	14600 kg.	14600 kg.
	Average Payload	6570 kg.	6570 kg.
	Estimated Annual Quantity	2628 tonnes	2628 tonnes
	Trip Running Time	3.1 hrs.	3.1 hrs.
	Annual Running Hours	1243 hrs.	1243 hrs.
B.	Driver Costs		
	Load - unload time cost	$ 716	$ 716
	Distance wage	$ 0	$ 0
	Hourly wage	$ 11500	$ 11500
	Wage burden	$ 2567	$ 2567

C. Total Operating Costs

Paved Roads Total Cost $	Paved Roads Cost per Running Hour $	Paved Roads Cost per km.		Gravel Roads Total Cost $	Gravel Roads Cost per Running Hour $	Gravel Roads Cost per km.
			Tractor variable costs			
14,791	11.90	37.0	Driver	14,791	11.90	37.0
4,457	3.59	11.1	Fuel	4,457	3.59	11.1
4,226	3.40	10.6	Repairs	5,071	4.08	12.7
295	0.24	0.7	Cleaning	295	0.24	0.7
447	0.36	1.1	Transport	447	0.36	1.1
1,263	1.02	3.2	Tires	1,806	1.45	4.5
25,479	20.51	63.7	Total tractor variable	26,867	21.62	67.1
			Tractor fixed costs			
12,929	10.40	32.3	Depreciation	12,929	10.40	32.3
482	0.39	1.2	Licences	482	0.39	1.2
13,411	10.79	33.5	Total tractor fixed	13,411	10.79	33.5
38,890	31.30	97.2	Tractor total	40,278	32.41	100.6
			Trailer variable costs			
			Repairs			
			Cleaning			
			Transport			
			Tires			
			Total trailer variable			
			Trailer fixed costs			
			Depreciation			
			Licences			
			Total trailer fixed			
			Trailer total			
38,890	31.30	97.2	Total vehicle costs	40,278	32.41	100.6
1,598	1.29	4.0	Insurance costs	1,655	1.33	4.1
7,458	6.00	18.6	Admin. and interest	7,724	6.22	19.3
			Pickup and delivery			
5,327	4.29	13.3	Profit	5,517	4.44	13.8
53,273	42.88	133.1	Total operating cost	55,174	44.40	137.8

Imperial Equivalent Summary

A.	Annual distance travelled	--	24,856 mi.
	Gross vehicle weight	--	32,187 lbs.
	Average payload	--	14,484 lbs.
	Estimated annual quantity	--	2,897 tons

B. Total Operating Cost per mile (cents/mile)

Paved roads		Gravel roads
214.2	Total Operating Cost	221.8

Configuration -- 2 axle straight truck (diesel) Manitoba

Commodity -- Bulk

Annual distance -- 80000 km.

		Paved Road	Gravel Road
A.	Vehicle Utilization		
	Gross Vehicle Weight	14600 kg.	14600 kg.
	Average Payload	6570 kg.	6570 kg.
	Estimated Annual Quantity	5256 tonnes	5256 tonnes
	Trip Running Time	3.1 hrs.	3.1 hrs.
	Annual Running Hours	2486 hrs.	2486 hrs.
B.	Driver Costs		
	Load - unload time cost	$ 1431	$ 1431
	Distance wage	$ 0	$ 0
	Hourly wage	$ 23016	$ 23016
	Wage burden	$ 5134	$ 5134

C. Total Operating Costs

Paved Roads Total Cost $	Paved Roads Cost per Running Hour $	Paved Roads Cost per km.		Gravel Roads Total Cost $	Gravel Roads Cost per Running Hour $	Gravel Roads Cost per km.
			Tractor variable costs			
29,581	11.90	37.0	Driver	29,581	11.90	37.0
8,914	3.59	11.1	Fuel	8,914	3.59	11.1
8,451	3.40	10.6	Repairs	10,141	4.08	12.7
591	0.24	0.7	Cleaning	591	0.24	0.7
447	0.18	0.6	Transport	447	0.18	0.6
2,525	1.02	3.2	Tires	3,611	1.45	4.5
50,509	20.33	63.2	Total tractor variable	53,285	21.44	66.6
			Tractor fixed costs			
12,929	5.20	16.2	Depreciation	12,929	5.20	16.2
482	0.19	0.6	Licences	482	0.19	0.6
13,411	5.39	16.8	Total tractor fixed	13,411	5.39	16.8
63,920	25.72	80.0	Tractor total	66,696	26.83	83.4
			Trailer variable costs			
			Repairs			
			Cleaning			
			Transport			
			Tires			
			Total trailer variable			
			Trailer fixed costs			
			Depreciation			
			Licences			
			Total trailer fixed			
			Trailer total			
63,920	25.72	80.0	Total vehicle costs	66,696	26.83	83.4
2,627	1.06	3.3	Insurance costs	2,741	1.10	3.4
12,259	4.93	15.3	Admin. and interest	12,791	5.15	16.0
			Pickup and delivery			
8,756	3.52	10.9	Profit	9,136	3.68	11.4
87,562	35.23	109.5	Total operating cost	91,364	36.76	114.2

Imperial Equivalent Summary

A.	Annual distance travelled	--	49,712 mi.
	Gross vehicle weight	--	32,187 lbs.
	Average payload	--	14,484 lbs.
	Estimated annual quantity	--	5,794 tons

B. Total Operating Cost per mile (cents/mile)

Paved roads		Gravel roads
176.2	Total Operating Cost	183.8

Configuration -- 2 axle straight truck (diesel) Manitoba

Commodity -- Bulk

Annual distance -- 120000 km.

		Paved Road	Gravel Road
A.	Vehicle Utilization		
	Gross Vehicle Weight	14600 kg.	14600 kg.
	Average Payload	6570 kg.	6570 kg.
	Estimated Annual Quantity	7884 tonnes	7884 tonnes
	Trip Running Time	3.1 hrs.	3.1 hrs.
	Annual Running Hours	3728 hrs.	3728 hrs.
B.	Driver Costs		
	Load - unload time cost	$ 2147	$ 2147
	Distance wage	$ 0	$ 0
	Hourly wage	$ 34524	$ 34524
	Wage burden	$ 7701	$ 7701

C. Total Operating Costs

Paved Roads Total Cost $	Paved Roads Cost per Running Hour $	Paved Roads Cost per km.		Gravel Roads Total Cost $	Gravel Roads Cost per Running Hour $	Gravel Roads Cost per km.
			Tractor variable costs			
44,372	11.90	37.0	Driver	44,372	11.90	37.0
13,371	3.59	11.1	Fuel	13,371	3.59	11.1
12,677	3.40	10.6	Repairs	15,212	4.08	12.7
886	0.24	0.7	Cleaning	886	0.24	0.7
447	0.12	0.4	Transport	447	0.12	0.4
3,788	1.02	3.2	Tires	5,417	1.45	4.5
75,541	20.27	63.0	Total tractor variable	79,705	21.38	66.4
			Tractor fixed costs			
12,929	3.47	10.8	Depreciation	12,929	3.47	10.8
482	0.13	0.4	Licences	482	0.13	0.4
13,411	3.60	11.2	Total tractor fixed	13,411	3.60	11.2
88,952	23.87	74.2	Tractor total	93,116	24.98	77.6
			Trailer variable costs			
			Repairs			
			Cleaning			
			Transport			
			Tires			
			Total trailer variable			
			Trailer fixed costs			
			Depreciation			
			Licences			
			Total trailer fixed.			
			Trailer total			
88,952	23.87	74.2	Total vehicle costs	93,116	24.98	77.6
3,656	0.98	3.0	Insurance costs	3,827	1.03	3.2
17,059	4.58	14.2	Admin. and interest	17,858	4.79	14.9
			Pickup and delivery			
12,185	3.27	10.2	Profit	12,756	3.42	10.6
121,852	32.70	101.6	Total operating cost	127,557	34.22	106.3

Imperial Equivalent Summary

A.	Annual distance travelled	--	74,568 mi.
	Gross vehicle weight	--	32,187 lbs.
	Average payload	--	14,484 lbs.
	Estimated annual quantity	--	8,691 tons

B. Total Operating Cost per mile (cents/mile)

Paved roads		Gravel roads
163.5	Total Operating Cost	171.1

(Source: Reference [28])

Appendix B-2 (Continued) (5-axle Tractor-Semitrailer unit)

Configuration -- 5 axle semi-trailer unit — Manitoba

Commodity -- Bulk — Annual distance -- 80000 km.

A.	Paved Road	Gravel Road
Vehicle Utilization		
Gross Vehicle Weight	37500 kg.	37500 kg.
Average Payload	22680 kg.	22680 kg.
Estimated Annual Quantity	5670 tonnes	5670 tonnes
Trip Running Time	5.7 hrs.	6.6 hrs.
Annual Running Hours	1420 hrs.	1657 hrs.

B. Driver Costs	Paved	Gravel
Load - unload time cost	$ 1544	$ 1544
Distance wage	$ 12560	$ 0
Hourly wage	$ 0	$ 15344
Wage burden	$ 2962	$ 3547

C. Total Operating Costs

Paved Roads Total Cost $	Paved Roads Cost per Running Hour $	Paved Roads Cost per km.		Gravel Roads Total Cost $	Gravel Roads Cost per Running Hour $	Gravel Roads Cost per km.
			Tractor variable costs			
17,066	12.02	21.3	Driver	20,435	12.33	25.5
14,811	10.43	18.5	Fuel	14,811	8.94	18.5
7,556	5.32	9.4	Repairs	9,067	5.47	11.3
919	0.65	1.1	Cleaning	919	0.55	1.1
2,486	1.75	3.1	Transport	2,486	1.50	3.1
2,007	1.41	2.5	Tires	3,412	2.06	4.3
44,845	31.58	55.9	Total tractor variable	51,130	30.85	63.8
			Tractor fixed costs			
15,294	10.77	19.1	Depreciation	15,294	9.23	19.1
1,983	1.40	2.5	Licences	1,983	1.20	2.5
17,277	12.17	21.6	Total tractor fixed	17,277	10.43	21.6
62,122	43.75	77.5	Tractor total	68,407	41.28	85.4
			Trailer variable costs			
3,897	2.74	4.9	Repairs	4,677	2.82	5.8
1,351	0.95	1.7	Cleaning	1,351	0.82	1.7
994	0.70	1.2	Transport	994	0.60	1.2
1,619	1.14	2.0	Tires	2,671	1.61	3.3
7,861	5.53	9.8	Total trailer variable	9,693	5.85	12.0
			Trailer fixed costs			
6,277	4.42	7.8	Depreciation	6,277	3.79	7.8
10	0.01		Licences	10	0.01	
6,287	4.43	7.8	Total trailer fixed	6,287	3.80	7.8
14,148	9.96	17.6	Trailer total	15,980	9.65	19.8
76,270	53.71	95.1	Total vehicle costs	84,387	50.93	105.2
3,134	2.21	3.9	Insurance costs	3,468	2.09	4.3
14,627	10.30	18.3	Admin. and interest	16,184	9.77	20.2
			Pickup and delivery			
10,448	7.36	13.1	Profit	11,560	6.98	14.5
104,479	73.58	130.4	Total operating cost	115,599	69.77	144.2

Imperial Equivalent Summary

A. Annual distance travelled -- 49,712 mi.
Gross vehicle weight -- 82,673 lbs.
Average payload -- 50,000 lbs.
Estimated annual quantity -- 6,250 tons

B. Total Operating Cost per mile (cents/mile)

Paved roads 209.9 — Total Operating Cost — Gravel roads 232.1

Configuration -- 5 axle semi-trailer unit — Manitoba

Commodity -- Bulk — Annual distance -- 160000 km.

A.	Paved Road	Gravel Road
Vehicle Utilization		
Gross Vehicle Weight	37500 kg.	37500 kg.
Average Payload	22680 kg.	22680 kg.
Estimated Annual Quantity	11340 tonnes	11340 tonnes
Trip Running Time	5.7 hrs.	6.6 hrs.
Annual Running Hours	2841 hrs.	3314 hrs.

B. Driver Costs	Paved	Gravel
Load - unload time cost	$ 3088	$ 3088
Distance wage	$ 25120	$ 0
Hourly wage	$ 0	$ 30688
Wage burden	$ 5924	$ 7093

C. Total Operating Costs

Paved Roads Total Cost $	Paved Roads Cost per Running Hour $	Paved Roads Cost per km.		Gravel Roads Total Cost $	Gravel Roads Cost per Running Hour $	Gravel Roads Cost per km.
			Tractor variable costs			
34,132	12.02	21.3	Driver	40,869	12.33	25.5
29,622	10.43	18.5	Fuel	29,622	8.94	18.5
15,112	5.32	9.4	Repairs	18,135	5.47	11.3
1,837	0.65	1.1	Cleaning	1,837	0.55	1.1
2,486	0.88	1.6	Transport	2,486	0.75	1.6
4,014	1.41	2.5	Tires	6,825	2.06	4.3
87,203	30.71	54.4	Total tractor variable	99,774	30.10	62.3
			Tractor fixed costs			
15,294	5.38	9.6	Depreciation	15,294	4.61	9.6
1,983	0.70	1.2	Licences	1,983	0.60	1.2
17,277	6.08	10.8	Total tractor fixed	17,277	5.21	10.8
104,480	36.79	65.2	Tractor total	117,051	35.31	73.1
			Trailer variable costs			
7,795	2.74	4.9	Repairs	9,354	2.82	5.8
2,701	0.95	1.7	Cleaning	2,701	0.82	1.7
994	0.35	0.6	Transport	994	0.30	0.6
3,237	1.14	2.0	Tires	5,342	1.61	3.3
14,727	5.18	9.2	Total trailer variable	18,391	5.55	11.4
			Trailer fixed costs			
6,277	2.21	3.9	Depreciation	6,277	1.89	3.9
10			Licences	10		
6,287	2.21	3.9	Total trailer fixed	6,287	1.89	3.9
21,014	7.39	13.1	Trailer total	24,678	7.44	15.3
125,494	44.18	78.3	Total vehicle costs	141,729	42.75	88.4
5,157	1.82	3.2	Insurance costs	5,824	1.76	3.6
24,066	8.47	15.0	Admin. and interest	27,181	8.20	17.0
			Pickup and delivery			
17,191	6.05	10.7	Profit	19,415	5.86	12.1
171,910	60.52	107.2	Total operating cost	194,149	58.57	121.1

Imperial Equivalent Summary

A. Annual distance travelled -- 99,424 mi.
Gross vehicle weight -- 82,673 lbs.
Average payload -- 50,000 lbs.
Estimated annual quantity -- 12,500 tons

B. Total Operating Cost per mile (cents/mile)

Paved roads 172.5 — Total Operating Cost — Gravel roads 194.9

Configuration -- 5 axle semi-trailer unit — Manitoba

Commodity -- Bulk — Annual distance -- 240000 km.

A.	Paved Road	Gravel Road
Vehicle Utilization		
Gross Vehicle Weight	37500 kg.	37500 kg.
Average Payload	22680 kg.	22680 kg.
Estimated Annual Quantity	17010 tonnes	17010 tonnes
Trip Running Time	5.7 hrs.	6.6 hrs.
Annual Running Hours	4261 hrs.	4971 hrs.

B. Driver Costs	Paved	Gravel
Load - unload time cost	$ 4633	$ 4633
Distance wage	$ 37680	$ 0
Hourly wage	$ 0	$ 46032
Wage burden	$ 8886	$ 10646

C. Total Operating Costs

Paved Roads Total Cost $	Paved Roads Cost per Running Hour $	Paved Roads Cost per km.		Gravel Roads Total Cost $	Gravel Roads Cost per Running Hour $	Gravel Roads Cost per km.
			Tractor variable costs			
51,199	12.02	21.3	Driver	61,305	12.33	25.5
44,433	10.43	18.5	Fuel	44,433	8.94	18.5
22,669	5.32	9.4	Repairs	27,202	5.47	11.3
2,756	0.65	1.1	Cleaning	2,756	0.55	1.1
2,486	0.58	1.0	Transport	2,486	0.50	1.0
6,022	1.41	2.5	Tires	10,237	2.06	4.3
129,565	30.41	53.8	Total tractor variable	148,419	29.85	61.7
			Tractor fixed costs			
15,294	3.59	6.4	Depreciation	15,294	3.08	6.4
1,983	0.47	0.8	Licences	1,983	0.40	0.8
17,277	4.06	7.2	Total tractor fixed	17,277	3.48	7.2
146,842	34.47	61.0	Tractor total	165,696	33.33	68.9
			Trailer variable costs			
11,692	2.74	4.9	Repairs	14,031	2.82	5.8
4,052	0.95	1.7	Cleaning	4,052	0.82	1.7
994	0.23	0.4	Transport	994	0.20	0.4
4,856	1.14	2.0	Tires	8,013	1.61	3.3
21,594	5.06	9.0	Total trailer variable	27,090	5.45	11.2
			Trailer fixed costs			
6,277	1.47	2.6	Depreciation	6,277	1.26	2.6
10			Licences	10		
6,287	1.47	2.6	Total trailer fixed	6,287	1.26	2.6
27,881	6.53	11.6	Trailer total	33,377	6.71	13.8
174,723	41.00	72.6	Total vehicle costs	199,073	40.04	82.7
7,180	1.69	3.0	Insurance costs	8,181	1.65	3.4
33,509	7.86	14.0	Admin. and interest	38,178	7.68	15.9
			Pickup and delivery			
23,935	5.62	10.0	Profit	27,270	5.49	11.4
239,347	56.17	99.6	Total operating cost	272,702	54.86	113.4

Imperial Equivalent Summary

A. Annual distance travelled -- 149,136 mi.
Gross vehicle weight -- 82,673 lbs.
Average payload -- 50,000 lbs.
Estimated annual quantity -- 18,750 tons

B. Total Operating Cost per mile (cents/mile)

Paved roads 160.3 — Total Operating Cost — Gravel roads 182.5

(Source: Reference [28])

Appendix B-2 (Continued) (7/8-axle Double-Trailer Combination)

Configuration -- semi-trailer and pup 7 axles — Manitoba

Commodity -- Bulk — Annual distance -- 80000 km.

A. Vehicle Utilization	Paved Road	Gravel Road
Gross Vehicle Weight	56500 kg.	56500 kg.
Average Payload	37450 kg.	37450 kg.
Estimated Annual Quantity	9363 tonnes	9363 tonnes
Trip Running Time	5.7 hrs.	6.6 hrs.
Annual Running Hours	1420 hrs.	1657 hrs.
B. Driver Costs		
Load - unload time cost	$ 2641	$ 2641
Distance wage	$ 13344	$ 0
Hourly wage	$ 0	$ 15891
Wage burden	$ 3357	$ 3892

C. Total Operating Costs

Paved Roads Total Cost $	Paved Roads Cost per Running Hour $	Paved Roads Cost per km.		Gravel Roads Total Cost $	Gravel Roads Cost per Running Hour $	Gravel Roads Cost per km.
			Tractor variable costs			
19,342	13.62	24.2	Driver	22,424	13.53	28.0
15,281	10.76	19.1	Fuel	15,281	9.22	19.1
8,202	5.77	10.3	Repairs	9,843	5.94	12.3
853	0.60	1.1	Cleaning	853	0.51	1.1
2,486	1.75	3.1	Transport	2,486	1.50	3.1
2,201	1.55	2.8	Tires	3,743	2.26	4.7
48,365	34.05	60.6	Total tractor variable	54,630	32.96	68.3
			Tractor fixed costs			
15,606	10.99	19.5	Depreciation	15,606	9.42	19.5
3,525	2.48	4.4	Licences	3,525	2.13	4.4
19,131	13.47	23.9	Total tractor fixed	19,131	11.55	23.9
67,496	47.52	84.5	Tractor total	73,761	44.51	92.2
			Trailer variable costs			
4,802	3.38	6.0	Repairs	5,763	3.48	7.2
995	0.70	1.2	Cleaning	995	0.60	1.2
994	0.70	1.2	Transport	994	0.60	1.2
2,525	1.78	3.2	Tires	4,167	2.51	5.2
9,316	6.56	11.6	Total trailer variable	11,919	7.19	14.8
			Trailer fixed costs			
12,140	8.55	15.2	Depreciation	12,140	7.33	15.2
20	0.01		Licences	20	0.01	
12,160	8.56	15.2	Total trailer fixed	12,160	7.34	15.2
21,476	15.12	26.8	Trailer total	24,079	14.53	30.0
88,972	62.64	111.3	Total vehicle costs	97,840	59.04	122.2
3,656	2.57	4.6	Insurance costs	4,021	2.43	5.0
17,063	12.01	21.3	Admin. and interest	18,764	11.32	23.5
			Pickup and delivery			
12,188	8.58	15.2	Profit	13,403	8.09	16.8
121,879	85.80	152.4	Total operating cost	134,028	80.88	167.5

Imperial Equivalent Summary

A. Annual distance travelled -- 49,712 mi.
Gross vehicle weight -- 124,560 lbs.
Average payload -- 82,562 lbs.
Estimated annual quantity -- 10,321 tons

B. Total Operating Cost per mile (cents/mile)

Paved roads		Gravel roads
245.3	Total Operating Cost	269.6

Configuration -- semi-trailer and pup 7 axles — Manitoba

Commodity -- Bulk — Annual distance -- 160000 km.

A. Vehicle Utilization	Paved Road	Gravel Road
Gross Vehicle Weight	56500 kg.	56500 kg.
Average Payload	37450 kg.	37450 kg.
Estimated Annual Quantity	18725 tonnes	18725 tonnes
Trip Running Time	5.7 hrs.	6.6 hrs.
Annual Running Hours	2841 hrs.	3314 hrs.
B. Driver Costs		
Load - unload time cost	$ 5282	$ 5282
Distance wage	$ 26688	$ 0
Hourly wage	$ 0	$ 31782
Wage burden	$ 6714	$ 7783

C. Total Operating Costs

Paved Roads Total Cost $	Paved Roads Cost per Running Hour $	Paved Roads Cost per km.		Gravel Roads Total Cost $	Gravel Roads Cost per Running Hour $	Gravel Roads Cost per km.
			Tractor variable costs			
38,684	13.62	24.2	Driver	44,847	13.53	28.0
30,563	10.76	19.1	Fuel	30,563	9.22	19.1
16,405	5.78	10.3	Repairs	19,686	5.94	12.3
1,706	0.60	1.1	Cleaning	1,706	0.51	1.1
2,486	0.88	1.6	Transport	2,486	0.75	1.6
4,403	1.55	2.8	Tires	7,485	2.26	4.7
94,247	33.19	59.1	Total tractor variable	106,773	32.21	66.8
			Tractor fixed costs			
15,606	5.49	9.8	Depreciation	15,606	4.71	9.8
3,525	1.24	2.2	Licences	3,525	1.06	2.2
19,131	6.73	12.0	Total tractor fixed	19,131	5.77	12.0
113,378	39.92	71.1	Tractor total	125,904	37.98	78.8
			Trailer variable costs			
9,604	3.38	6.0	Repairs	11,525	3.48	7.2
1,990	0.70	1.2	Cleaning	1,990	0.60	1.2
994	0.35	0.6	Transport	994	0.30	0.6
5,050	1.78	3.2	Tires	8,333	2.51	5.2
17,638	6.21	11.0	Total trailer variable	22,842	6.89	14.2
			Trailer fixed costs			
12,140	4.27	7.6	Depreciation	12,140	3.66	7.6
20	0.01		Licences	20	0.01	
12,160	4.28	7.6	Total trailer fixed	12,160	3.67	7.6
29,798	10.49	18.6	Trailer total	35,002	10.56	21.8
143,176	50.41	89.7	Total vehicle costs	160,906	48.54	100.6
5,884	2.07	3.7	Insurance costs	6,613	2.00	4.1
27,459	9.67	17.2	Admin. and interest	30,859	9.31	19.3
			Pickup and delivery			
19,613	6.90	12.3	Profit	22,042	6.65	13.8
196,132	69.05	122.9	Total operating cost	220,420	66.50	137.8

Imperial Equivalent Summary

A. Annual distance travelled -- 99,424 mi.
Gross vehicle weight -- 124,560 lbs.
Average payload -- 82,562 lbs.
Estimated annual quantity -- 20,641 tons

B. Total Operating Cost per mile (cents/mile)

Paved roads		Gravel roads
197.8	Total Operating Cost	221.8

Configuration -- semi-trailer and pup 7 axles — Manitoba

Commodity -- Bulk — Annual distance -- 240000 km.

A. Vehicle Utilization	Paved Road	Gravel Road
Gross Vehicle Weight	56500 kg.	56500 kg.
Average Payload	37450 kg.	37450 kg.
Estimated Annual Quantity	28088 tonnes	28088 tonnes
Trip Running Time	5.7 hrs.	6.6 hrs.
Annual Running Hours	4261 hrs.	4971 hrs.
B. Driver Costs		
Load - unload time cost	$ 7922	$ 7922
Distance wage	$ 40032	$ 0
Hourly wage	$ 0	$ 47673
Wage burden	$ 10070	$ 11675

C. Total Operating Costs

Paved Roads Total Cost $	Paved Roads Cost per Running Hour $	Paved Roads Cost per km.		Gravel Roads Total Cost $	Gravel Roads Cost per Running Hour $	Gravel Roads Cost per km.
			Tractor variable costs			
58,024	13.62	24.2	Driver	67,270	13.53	28.0
45,844	10.76	19.1	Fuel	45,844	9.22	19.1
24,607	5.78	10.3	Repairs	29,529	5.94	12.3
2,559	0.60	1.1	Cleaning	2,559	0.51	1.1
2,486	0.58	1.0	Transport	2,486	0.50	1.0
6,604	1.55	2.8	Tires	11,228	2.26	4.7
140,124	32.89	58.5	Total tractor variable	158,916	31.96	66.2
			Tractor fixed costs			
15,606	3.66	6.5	Depreciation	15,606	3.14	6.5
3,525	0.83	1.5	Licences	3,525	0.71	1.5
19,131	4.49	8.0	Total tractor fixed	19,131	3.85	8.0
159,255	37.38	66.5	Tractor total	178,047	35.81	74.2
			Trailer variable costs			
14,407	3.38	6.0	Repairs	17,288	3.48	7.2
2,986	0.70	1.2	Cleaning	2,986	0.60	1.2
994	0.23	0.4	Transport	994	0.20	0.4
7,576	1.78	3.2	Tires	12,500	2.51	5.2
25,963	6.09	10.8	Total trailer variable	33,768	6.79	14.0
			Trailer fixed costs			
12,140	2.85	5.1	Depreciation	12,140	2.44	5.1
20			Licences	20		
12,160	2.85	5.1	Total trailer fixed	12,160	2.44	5.1
38,123	8.94	15.9	Trailer total	45,928	9.23	19.1
197,378	46.32	82.4	Total vehicle costs	223,975	45.04	93.3
8,111	1.90	3.4	Insurance costs	9,204	1.85	3.8
37,853	8.88	15.8	Admin. and interest	42,954	8.64	17.9
			Pickup and delivery			
27,038	6.35	11.3	Profit	30,681	6.17	12.8
270,380	63.45	112.9	Total operating cost	306,814	61.70	127.8

Imperial Equivalent Summary

A. Annual distance travelled -- 149,136 mi.
Gross vehicle weight -- 124,560 lbs.
Average payload -- 82,562 lbs.
Estimated annual quantity -- 30,961 tons

B. Total Operating Cost per mile (cents/mile)

Paved roads		Gravel roads
181.7	Total Operating Cost	205.7

(Source: Reference [28])