RUNNING COSTS FOR MOTOR VEHICLES

by

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ABSTRACT

A review of the basic purposes for, and research work conducted on, estimates of running costs of motor vehicles is presented. An attempt at using available running cost data at the Ministry of Transportation and Communications (Ontario) to obtain acceptable estimates of running costs is also presented. The purpose of this report was to study, in detail, the purpose and research methods advocated for obtaining running cost estimates with inherent advantages and disadvantages, and includes an attempt at using available data in obtaining such estimates and the problems associated with it.

Several of the principal purposes and uses of running cost estimates are addressed. Each purpose is presented and discussed in detail and examples of data obtained to satisfy that purpose are given. In addition, the deficiencies of each data type are identified. Examples of use and application of different data types in obtaining economic assessment for individual organizational and governmental uses are included.

A review of literature on running costs for motor vehicles is given. The different data collection and research methods adopted by researchers all over the world are discussed. A discussion of the advantages and disadvantages of each method with respect to variables included, data collection method, level of data aggregation, impact of time-dependence, techniques and results is presented.

An investigation of running cost records available at the Ontario Ministry of Transportation and Communications was conducted. An effort at using such records to obtain reliable estimates of running costs was attempted but no conclusive results were obtained. The limitations of using these records to obtain running costs estimates are indicated.

The concluding chapter includes recommendations for future research efforts for both short term and long term consideration.

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1. INTRODUCTION

The cost of operating a motor vehicle is of particular interest to decision-makers ranging from individuals to local and national governmental authorities. Individuals need information concerning vehicle operating costs, for example, to make trade-off decisions between the use of private automobiles and public transportation. On the other hand, transportation authorities at various levels of government often use operating costs in the decision-making process dealing with the planning and improvement of transportation facilities. Within the range between individuals and large highway authorities, a large number of public and private businesses use or operate transportation services and are interested in vehicle operating costs because it constitutes an important element of total business costs.

Within this overall context, highway transportation engineers frequently require such information. In general, the goal of a highway engineer is to provide highway service that is rapid, safe, comfortable, convenient, and economical for motor vehicle users. When specifically studying the economics of road transportation, three major components of road cost are usually considered: road construction cost, road maintenance cost and motor vehicle operating cost. According to Winfery (31), motor vehicle operating costs (during the late 1960's) represent about 88% of the total highway transport cost; the highway cost accounts for the remaining 12%. The task of the highway engineer is usually interpreted as to determine the best combination of these three costs to accommodate various levels of traffic volume. Although the highway engineer has at hand sufficient data, knowledge, and experience which permit him to make reliable estimates of the first two cost components, further research is required to provide information requisite to obtaining reliable operating cost estimates.

Since definitions of motor vehicle cost vary somewhat between authors, it is perhaps useful at this juncture to outline the various definitions as they are referred to throughout this report. In particular, it is important to note the distinction between vehicle operating and running costs:

General road user cost: the cost of fuel consumption, oil consumption, tire wear and the portion of maintenance, depreciation and accident costs related to vehicle use.

Direct running cost: the cost of gasoline consumption, oil consumption, tire wear and maintenance (note that accident cost is not included).

Direct operating cost: the direct running costs plus the motor vehicle occupants time cost.

Total running cost: the direct running costs plus depreciation due to running (mileage). Throughout, this will be referred to simply as running cost.

Other motor vehicle costs include the fixed costs of registration, parking, garaging, taxes, insurance and so on. Since these costs do not vary significantly with vehicle use, only total running costs will be discussed and analyzed in detail in this report. To this end, one should also note that total running cost is a function of such factors as road characteristics, traffic conditions, vehicle characteristics, environmental factors and operator characteristics. These factors are often referred to as the principal independent variables and are described below:

Road characteristics: include grades (vertical alignment), curvature (horizontal alignment), surface type and condition, entry-exit points and surface width.

Traffic conditions: include traffic speed, traffic volumes, level of service, traffic control features and so on.

Vehicle characteristics: represent vehicle class, weight, age, purchase price, engine power, transmission type, and so on.

Environmental Factors: include topography, altitude, wind, temperature and precipitation.

Operator Factors: include the manner in which the driver cares for and uses the vehicle.

Obviously it is not an easy task to determine aggregate motor vehicle running cost due to the large number of dependent and independent variables involved. Nevertheless, good highway design and improvement strategies call for making the best possible estimate of running costs as influenced by each of the road design features. In addition, running cost data should be arranged in an appropriate format to meet the diversified purposes of individuals, private organizations and governments. Since highway design and planning is the most demanding, the objective of past research has tended to relate each of the dependent variables (fuel, oil, tire wear, maintenance, and depreciation) to each of the highway design, traffic, vehicle and environmental factors.

Running cost estimates as reported in various studies sometimes appear to be incompatible. The reason(s) for such differences are not always clearly indicated in each study, which leads to some confusion in their use. The purpose of this report is to identify these differences, the reason(s) for their presence, and how such a problem can be treated. Accordingly a review, discussion and analysis of running cost estimates was carried out. Chapter 2 deals with the different purposes for which running cost estimates might be used. Also included are discussions concerning methods of running cost estimates which are suitable for each purpose as well as illustrative examples which are intended to explain the use and application of such data. Chapter 3 includes a detailed review of available literature; research approaches and methods are evaluated with respect to a specific set of criteria. Chapter 4 describes an empirical investigation of Ministry data available regarding some of the running cost dependent variables. Also included is a discussion of research work that has been conducted as an attempt at using this information to obtain reliable running cost estimates. Comments on problems associated with use of running cost estimates and recommendations for future research efforts are included in Chapter 5.

2. APPLICATION OF RUNNING COST ESTIMATES

The purpose of this chapter is to describe in detail potential uses and applications of running cost estimates for various design and operational purposes. In the first section, a brief summary of world-wide research efforts on running, operating and road user costs is given. It is interesting to note that, even though research in the United States has been underway for more than fifty years, published research has been available from other countries only during the past twenty years. This is due, undoubtedly, to the fact that the United States is not only the birth place of the motor vehicle, but it is also the world's leader in the utilization of the motor vehicle whether measured in terms of the number of vehicles per person or in terms of annual mileage per vehicle. In the second section, seven different purposes for which running cost estimates are used are given. Examples, in the form of tables and graphs of the different types of running cost data as they apply to the seven different purposes are displayed. The comprehensiveness and level of detail involved in each data type depends a great deal on the purpose for which it is used. Furthermore, illustrative examples on the use of running cost data for economic evaluation of the purpose at hand are included.

2.1 A BRIEF HISTORY

The extraction and accumulation of motor vehicle running costs have recieved the attention of researchers from around the world. Over the years, private and public organizations have carried out research on some or all of the running cost variables (fuel, oil, tire, maintenance and depreciation). In the United States, research on the performance of motor vehicles with respect to highway design started in the 1920's. This early effort was concerned with fuel comsumption, tractive resistance, tire wear, and roadway surfaces. During those pioneer days, the research objective was to establish monetary values for the factors involved in the relative economy of surfaced roads (30). Although a lapse in research effort occurred between 1940 and 1950, partly due to intrusion of the second world war, interest in running cost estimates for certain highway design features was again initiated by 1950 and was later stimulated by the expansion of highway construction. Since that time the principal objective has been to determine the most economical method of serving large volumes of traffic with the lowest highway cost.

In England, the Transport and Road Research Laboratory (TRRL), Department of the Environment, has been publishing reports on vehicle operating costs for the past twenty years. The results contained in these reports were intended for use in the assessment of road and traffic improvement schemes. The statistics are updated almost annually to reflect current changes in prices and treatment methods for variables such as fuel taxes.

In New Zealand, The Ministry of Transport, Economic Division, has become aware that only very few automobile owners precisely know the costs incurred while operating a motor vehicle. This is partially due to the fact that during the 1960's there were approximately three people for every private motor vehicle which lead to the tendency of regarding operating costs as just another household expense. Thus, for purposes of educating the public, bulletins describing operating costs of motor vehicles have been published since 1965.

In Australia, a small committee was established in 1968 to prepare a report on road user costs. The overall objective has been to reach a consensus of opinion on the economic concepts to be used in the collection and application of road user cost data (3). In approaching this objective, the committee identified several possible uses of road-user cost data to guide future research efforts. Several reports on running costs of motor vehicles have been prepared by the committee during the past nine years and contain quite comprehensive information.

During the past decade or so massive injections of financial resources into road building programs in developing countries has focused attention on the need to gather basic data on vehicle operating characteristics and costs, road construction, maintenance and deterioration patterns, and other costs which are relevant and specific to the environment of the these countries (1). This has resulted in efforts by many researchers, both from within and outside the developing countries, to investigate the running cost of motor vehicles in those countries. Results to date have provided many methodologies that differ both in the basic research method employed and the techniques applied to obtain data necessary for running cost estimation.

2.2 PURPOSE AND USE

The purpose or objective of research on running cost has varied from time to time and from country to country, depending on factors such as environmental and economic conditions. These purposes have tended to control the nature of the data collected and its alternate application. If, for example, the purpose of running cost estimates is merely to inform the public as to how much it costs to drive their private motor vehicles, then data need not be as detailed or comprehensive as that required to assess the impact of roadway improvements. In this section, the seven following purposes are identified and discussed in detail: public information, business assessment, modal costs, road planning and design, road improvement programs, traffic control systems, and special road services. The use and application of the appropriate running cost data type for each of these purposes is also described.

2.2.1 Public Information

The objective here is to aid private motor vehicle owners in the identification and subsequent reduction of running costs and in determining how long each owner should keep a private vehicle. Several reports were published to specifically satisfy this purpose. In New Zealand, the Ministry of Transport has been publishing periodical bulletins with tables on running cost to be used as a general guide by private automobile owners (19,20,21). The tables give the magnitude of each of the running cost items for four different classes of vehicles (given by the range of engine-size) on a cost/km basis. Also included is a brief discussion on each item to help individuals understand the nature of these costs. Table 2.1 (21, p.13) is an example of the information published in these bulletins (for vehicles with engine size between 2000 cc and 3500 cc), where single and total running cost items are given.

Cope and Gauthier's report (9) is one of several Federal Highway Administration (FHWA) reports on operating costs of motor vehicles. In general, they are published when a need for the information and/or change in costs seems to warrant. Discussions are contained on each of the running cost variables as affected by some of the independent variables, especially those which are related to vehicle characteristics. One of the main purposes of the FHWA research is to determine the relative cost of depreciation compared with other operating cost items, specifically in the first two years of vehicle life, and consequently help individuals determine how long they should keep their vehicles. To enhance this purpose, a table for the value of operating cost variables for each year of a 10-year lifetime of a vehicle is included. Table 2.2 (9, p.11) presents an example of only those values that are pertinent to this report; namely the running cost variables.

To conclude, it would appear that for purposes of public information, running cost data need not be very comprehensive. For instance, it is of no interest to individuals to have information regarding the total running cost as it varies with grade or curvature since they have no means of estimating grade or curvature encountered in driving, whether it be per trip or per year. Likewise, the effect of road surface condition, traffic volume, or level of service on running cost is of little value to individuals. The more important variables should be those for which the average individual has some knowledge or can reasonably assess, such as vehicle age in kilometers (miles) and years, vehicle weight, vehicle engine-size, vehicle price, average operating speed and weather conditions. Obviously, not all of these variables are explicit in Tables 2.1 and 2.2. For instance, in Table 2.1, operating speeds can be considered as "typical" speeds of a passenger vehicle operating in New Zealand, since data is given for "typical" passenger vehicles. In addition, weather condition is implicitly incorporated in the prevailing operating speeds at the location under consideration. Therefore, in using these values for more detailed purposes, particular attention must be given to the incorporated variables and inherent consequences.

Table 2.1 Estimated Running Cost of a Typical Private Motor Vehicle* in New Zealand; Engine Size between 2000 cc and 3500 cc, 1974.

Item of Expenditure	Cost/km (cents)	10,000 km $	15,000 km $	20,000 km $
Fuel	1.8448	184.48	276.72	368.96
Oil	0.0315	3.15	4.72	6.30
Tires and Tubes	0.4148	41.48	62.22	82.96
Repairs and Maintenance	2.6510	265.10	397.65	530.20
Depreciation	2.6984	269.84	404.76	539.68
Total Cost	7.6405	764.05	1146.07	1528.10

* Vehicle represented here has the following:

Capital Cost $5,293

Less tires $ 112

Net Capital Cost $5,181

TABLE 2.2 ESTIMATED COST OF OPERATING AN AUTOMOBILE, BALTIMORE, 1974

Item	First Year 14,500 miles		Second Year 13,00 miles		Third Year 11,500 miles		Fourth Year 10,000 miles		Fifth Year 9,900 miles	
	Total Cost $	Cost c/mile	Total Cost $	Cost c/mile	Total Cost $	Cost c/mile	Total Cost $	Cost c/mile	Total Cost $	Cost c/mile
Depreciation	955.00	6.59	558.00	4.29	451.00	3.92	366.00	3.66	257.00	2.60
Repairs/Maintenance	72.51	0.50	94.58	0.73	182.94	1.59	166.62	1.67	172.54	1.74
Replacement Tires	17.23	0.12	15.45	0.12	13.66	0.12	38.61	0.39	38.22	0.39
Gasoline	251.43	1.73	225.38	1.73	199.33	1.73	173.27	1.73	171.60	1.73
Oil	15.40	0.11	15.40	0.12	15.40	0.13	15.40	0.15	16.10	0.16
Total	1311.57	9.05	908.81	6.99	862.33	7.49	759.90	7.60	655.46	6.62

	Sixth Year 9,900 miles		Seventh Year 9,500 miles		Eighth Year 8,500 miles		Ninth Year 7,500 miles		Tenth Year 5,700 miles	
	Total Cost $	Cost c/mile	Total Cost $	Cost c/mile	Total Cost $	Cost c/mile	Total Cost $	Cost c/mile	Total Cost $	Cost c/mile
Depreciation	191.00	1.93	155.00	1.63	123.00	1.45	79.00	1.05	50.00	0.88
Repairs/Maintenance	159.56	2.62	322.66	3.40	130.30	1.53	88.69	1.18	30.38	0.53
Replacement Tires	43.31	0.44	41.56	0.44	69.32	0.82	61.15	0.82	46.49	0.82
Gasoline	171.60	1.73	164.67	1.73	147.22	1.73	130.02	1.73	98.71	1.73
Oil	18.20	0.18	18.20	0.19	15.40	0.18	15.40	0.21	12.60	0.22
Total	683.67	6.90	702.09	7.39	485.24	5.71	374.26	4.99	238.18	4.18

* this estimate covers the total costs, excluding tax, of a medium priced 4-door sedan purchased for $3,185, operated 100,000 miles over a 10-year period, then scrapped.

2.2.2 Business Assessments

Business and commercial companies are often interested in running or road user cost data concerning such activities as car rental, goods movement, special delivery and so on. The companies can use such information to estimate annual expenditures from which the rate of charge for services provided (based on some knowledge of their desired business returns) can be established. This information should express variations in running costs with the relevant independent variable. On one hand, they can be variables over which the firms have control such as vehicle type, weight, engine size and so on. On the other hand, they can be those variables whose magnitudes can only be assessed by the company, such as average operating speed of their fleet based on knowledge of operating speeds of the roads under consideration.

Shippy (28) investigated the interest of trucking firms in running cost data during the early 1970's. In his report, Shippy expresses the concern of trucking firms of the effects on their equipment and running and insurance costs due to observed increases in operating speed (authorized by Departments of Highways) from 96.6 to 112.7 km/h (60 to 70 mph). Accordingly, his recommendations included the need to express the magnitude of the total (fuel, oil, tires, maintenance and depreciation cost combined) and single running cost variables for different vehicle types, vehicle weights and operating speeds, in order to assist those firms in their annual cost estimates and subsequently in their decisions regarding type and weight of their fleet. Table 2.3 (28, p.4) is an example of the type of data given in his report.

Another example of information on running and operating cost data that can be utilized by commercial firms to determine fleet size and type is given in the Australian Road Research Board's (ARRB) report #9 (3, p.34). Table 2.4 displays some of this information. The total vehicle operating costs represent not only the five running cost variables but also road tax and tolls, interest on capital, registration, third party and comprehensive insurance, driver wages and expenses, and a 12.5% overhead cost (3, p.6). (This definition of total vehicle operating

Table 2.3 Fuel Cost in Dollars per Vehicle-Mile

Speed mph	65c/Gallon			60c/Gallon	
	Small Car	Large Car	Truck (small)	Truck (3.5 ton)	Truck (15 ton)
30	0.0155	0.0310	0.0302	0.0559	0.1004
35	0.0157	0.0314	0.0310	0.0562	0.0947
40	0.0164	0.0328	0.0327	0.0593	0.0937
45	0.0172	0.0344	0.0354	0.0593	0.0971
50	0.0185	0.0370	0.0392	0.0624	0.1057
55	0.0199	0.0398	0.0445	0.0669	0.1220
60	0.0220	0.0440	0.0523	0.0731	0.1485
65	0.0252	0.0504	0.0637	0.0815	-
70	0.0296	0.0592	0.0786	-	-

Table 2.4 Commercial Vehicles - Typical Gross Operating Cost Data, 1971
Tipper Trucks, 45,000 mpa.

Number of Axles (R = Rigid, A = Articulated, TS = Twinsteer, Tr = Trailer)	Tare Weight (Tons)	Max. Pay Load (Tons)	Gross Veh. Wt. (Tons	Total Veh. Oper. costs (c/mile)
3R	6.5	13.3	19.8	39.2
4R/TS	7.8	16.6	24.4	45.9
4A	9.3	17.7	27.0	45.1
5A	10.4	20.8	31.2	49.9
3R & one 2-axle Tr.	11.9	20.5	32.4	53.5
6A	11.6	24.7	36.3	56.1
5R.Ts & one 2-axle Tr.	10.5	26.2	36.7	77.4

costs is the ARRB's definition and does not necessarily agree with other reports on running costs.) This data can be used quite easily to compute the total cost of operation which, when added to purchase cost, determines the most economical type of trucks or a combination of types of trucks. Example 2.1 is given to illustrate this procedure.

Example 2.1:

Assume a load of 200,000 metric tons (196,000 tons) of quarry products per year (no return load) for a project life of one year. The haul distance is 50 km (31 miles), the average operating speed is 48 km (30 mph) and the number of daily trips per truck is three. Assume that such variables as the size of load in relation to volume discharge hoppers and vehicle length controlling manoeuverability, do not affect the choice of vehicle type. Assuming there is 240 working days a year we get: Total annual travel distance = 240 x 50 x 6 = 72,000 km (44,640 miles, say 45,000 miles). (There are tables for other values of annual kilometerage (mileage) as well.)

Using the information in Table 2.4, an estimate of the total operating cost of the different truck types can be made as shown in Table 2.5. The results of this simplified example show that the 5-axle articulated truck is the most economical choice for this project. (The higher capital cost does not have to be further taken into account as the annual operating costs already include depreciation and interest on capital). Yet it remains to be emphasized that the level of detail of running cost data determines the feasibility of an economic analysis of this type. For instance, the running cost data given in Table 2.3 is not comprehensive enough (does not give running cost information on a wide variety of trucks) to allow cost comparison analysis of this example. Care must therefore be exercised in choosing the variables to be represented in running cost estimation for purposes of business assessments. If the type of use and application of such data is specified before the process of variable selection takes place, more useful running cost information can be obtained.

Table 2.5 Estimate of Total Project Cost Using Different Types of Trucks

Items	Number of Axles R = Rigid, A = Articulated		
	3R	4A	5A
Maximum Pay Load (Metric Tonnes)	13.5	18.0	21.1
Load Carted per Day per Truck (Tonnes)	40.5	54.0	63.3
Load Carted Per Year Per Truck (Tonnes)	9,720	12,960	15,192
Number of Trucks Required	20.5	15.9	13.2
Say	21	16	14
Purchase Price*	13,100	18,900	26,200
Total Veh. Oper. Cost (¢/km) for 72,000 kmpa (45,000 mpa)	24.4	28.0	31.0
Operating cost Per Year Per Truck ($)	17,568	20,160	22,320
Total Fleet Operating Cost ($)	368,928	322,560	312,480

* Figures on purchase prices are taken from ARRB, report #9 (3,p.52)

2.2.3 Modal Costs

Travel cost comparisons by different modes is of interest to many sectors in society. The average person would be interested in comparing the cost of driving his private automobile with that of using public transit. Ideally, all costs involved in using any of the available modes should be included in travel cost estimates. In other words, in the case of an automobile, there is, in addition to running costs, the cost of travel time, comfort and convenience. It can be argued that fixed costs such as insurance, registration and interest on capital contribute to the total cost of using the automobile for travel. But a counter argument can be raised with respect to public transit and the fixed costs involved in running it which is paid by the user in the form of taxes. Nevertheless, for the purpose of modal cost comparisons for individuals, travel cost including the preceding variables, but excluding fixed costs, appears to be sufficient. Travel cost can be approximately aggregated with respect to the independent variables. That is to say, that cost of fuel, oil, tires, maintenance and depreciation be given per unit distance of travel for the average traffic, roadway, vehicle and weather conditions.

Transportation planners form another group that can benefit from travel cost data by using it in forecasting trip distribution, modal split, travel demands, and in the process of transportation systems evaluation. Conventional planning models do not use running cost, as described in this report, in any of the planning phases it applies to; namely trip distribution and modal split. The cost of travel used in most planning models today is, at best, that of travel time, out-of-pocket cost, waiting time, walking time, transfer time, comfort and convenience. Many of the running cost variables such as depreciation, tires and, at least partially, maintenance are ignored. Travel cost used in planning models is usually considered to be the "perceived cost" and not the actual cost. This is based on the fact that what travellers perceive to be the cost of travel by one mode or another determines choice of travel mode, and consequently should be the value used in planning models. Thus, whether all running cost variables should be included in cost estimates used by planners in modal cost comparison remains a controversial question. It is even more so if one compares travel cost estimates used by planners from the traveller's point of view with that from the public investment point of view. Keeler et al (16) evaluated the cost of different transportation modes from the point of view of public investment. Travel costs of the automobile included running cost, interest on capital, parking and accident costs. Data used to obtain figures on running costs were based on values given in FHWA reports. This is different from the travel (perceived) cost used in planning models.

Nash (22) discusses the implications of using each of the perceived and actual or resource cost. He indicates that the distinction between perceived and resource cost (the former used for forecasting and the latter for evaluation) leads to situations such as that depicted in Figure 2.1. Suppose that perceived costs before and after the scheme are given by P_1 and P_2. If people are correct in their assumption that capital costs do not enter into incremental cost, then (ignoring taxation and other possible differences between perceived and resource costs, such as incremental maintenance cost, wear and tear on tires and so on) resource costs will also equal P_1 and P_2, and the benefits to generated traffic will be given by the triangle AHG. If, however, resource costs do exceed perceived costs, so that they are, for instance, C_1 and C_2 before and after the scheme respectively, then the benefits to generated traffic are much reduced, being composed of the triangle ABE less the triangle EFG.

To conclude, for the purpose of modal cost comparisons an estimate of running cost is required, and preferebly disaggregated by the different items to satisfy the needs of varying interest groups. If it is used by the average person or for economic evaluation of road schemes, the total value will most likely be used. On the other hand, if it is to be used by planners, then some of the running cost variables such as depreciation will be ignored.

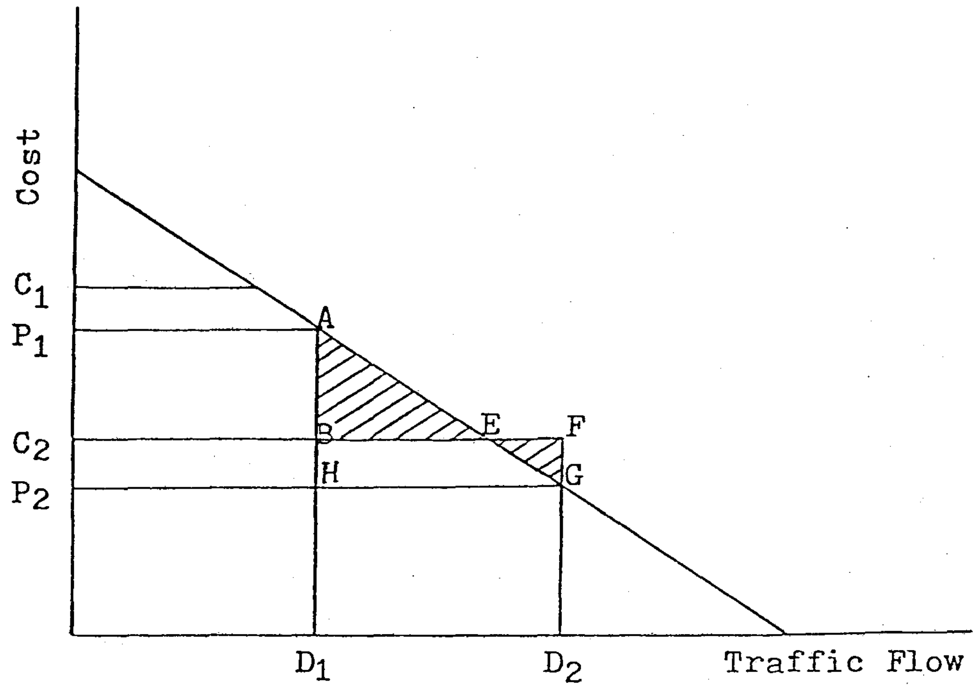

Figure 2.1 Benefits to Generated Traffic Where Resource Costs Exceed Perceived Costs (Ref. 22,p.228)

2.2.4 Road Planning and Design

During the preliminary phases of route location, planning, and design, an economic analysis is often required. Such economic analysis should deal with both the costs and benefits of each alternative to determine economic impact or feasibility. Common analysis methods include annual cost, benefit-cost ratio, rate-of-return and present worth. (A brief outline of these four methods is given in Appendix "A".) It is interesting to note that each method includes road user cost (operating cost) as one of the three road cost components; the other two being the construction cost and maintenance cost. To illustrate how road user cost enters economic analysis in choosing among alternatives, the following example is given (8, p.8-11).

Example 2.2:

Suppose that three alternatives for a certain road are under consideration. Alternative A involves improvements of an existing facility, while alternatives B and C represent relocations which would reduce total route length. The initial costs for each alternative are given in Table 2.6 (8, p.10). If an interest rate of 4% is used, the annual cost would be as shown in Table 2.7 (8, p.10). Using the benefit-cost ratio to determine the best alternative, and the annual costs from Table 2.7 we have:

Benefit-cost ratio of alternative B to alternative A is:

$$R_{BA} = \frac{E_A - E_B}{(D_B+M_B)-(D_A+M_A)} = \frac{286,000 - 239,000}{(34,300+8,400)-(7,900+10,000)} = 1.9$$

Similarly,

$$R_{CA} = \frac{286,000 - 223,900}{(53,100+7,900)-(7,900+10,000)} = 1.5$$

and

$$R_{CB} = \frac{239,000 - 223,900}{(53,100+7,900)-(34,300+8,400)} = 0.9$$

Using this simple procedure, alternative B is deemed the best. Both

Table 2.6 Initial Cost for Each Alternative

Initial Cost ($)	Life (years)	Alternatives		
		A	B	C
Right of way	60	0	12,000	11,000
Grading	40	48,000	227,000	390,000
Structures	40	30,000	235,000	468,000
Pavement	20	55,000	142,000	127,000
Total cost		133,000	616,000	996,000

Table 2.7 Annual cost for Each Alternative

Annual Cost ($)	Capital Recovery Factor (CRF)	Alternatives		
		A	B	C
Right of way	0.040	0	500	500
Grading	0.051	2,400	11,500	19,700
Structures	0.051	1,500	11,900	23,600
Pavement	0.074	4,000	10,400	9,300
Total		7,900	34,300	53,100
Length (miles)		10.05	8.40	7.85
Maintenance cost at $100,000/mile		10,000	8,400	7,900
Road user cost at $28,520/mile		286,000	239,000	223,900

alternatives B and C are better than alternative A (R_{BA} and R_{CA} are both greater than one). But alternative B is better than C because the benefit cost ratio of B over A is greater than that of C over A, which is shown again by the value of R_{CB} being less than one. It is interesting to note that road user cost is, by far, the largest among all three road costs. Consequently, a reliable estimate of road user cost is required to achieve sound economic evaluation both at the planning and design stages. For the sake of simplicity, road user cost per mile was considered identical for all three alternatives, while in reality this is likely to be different depending on the variation in the independent variables involved in each alternative of road characteristics and expected traffic conditions.

The use of running cost data in choosing among alternatives at the planning and design stages is better illustrated in Curry and Anderson's National Cooperative Highway Research Report #133 (NCHRP) (11). They developed a methodology, and include some illustrative examples, to be used in running cost estimates for various road characteristics under different levels of service and other traffic conditions for the purpose of economic evaluation. Also included in the report are work sheets that can make such economic evaluation procedure standardized and easy to follow.

In summary, an economic evaluation of road projects is not an easy task to perform. A considerable amount of work is involved in preparing the road and traffic characteristics data (for the projects under consideration) required for any reasonable economic evaluation scheme. All this effort would be of little value if reliable running cost estimates were not available to complement it and result in acceptable economic evaluation. Additionally, running cost data must be dissaggregted with respect to the road and traffic characteristics data and not necessarily with respect to the dependent variables (fuel, oil, tires, maintenance and depreciation). In short, the effect of any of the road and traffic characteristics on the total running cost value is the basic requirement.

2.2.5 Road Improvement Programs

Road improvements incorporate a wide range of projects such as reduction in grades, straightening or elimination of curves, lane widening, resurfacing, construction of new roads to supplement or replace existing roads, among others. Running cost is encountered in the phase of economic evaluation of road improvement programs. Examples of the use of running cost are available in many reports (3,5,11). Example 2.3 that follows on the next several pages, demonstrates the use of running cost data in estimating running cost before and after road improvement. Information on running cost values have been taken from Claffey's NCHRP report #111 (5), and references with specific page or table numbers are cited throughout.

Example 2.3:

Consider a 3.22-km (2 mile) section of a rural road with a good concrete surface built on a succession of 4^{o} curves and 4% grades. One-half of the 3.22-km (2-mile) section is on a positive 4% grade and the other half is on a negative 4% grade. The improved road is 0.8 km (1/2 mile) shorter with a good asphalt surface and all gradients and curvatures eliminated. Before the improvement all vehicles suffered an average of three, 16 km/hr (10 mph) slowdown speed cycle per 1.6 km (mile) due to slight distance limitations and one, 30 sec. stop at a troublesome stream ford or 0.3 stop per km (half stop per mile). The slowdowns and stops were eliminated by the improvement. Running speeds were 48 km/hr (30 mph) and 80 km/hr (50 mph) before and after the improvements respectively. For simplicity, running costs were estimated, before and after improvements, for passenger vehicles only with a daily traffic of 5,000 vehicles. Gasoline costs of twenty cents per litre (76 cents per gallon) and oil costs of 95 cents per litre (one dollar per quart) were assumed. The running cost before and after the improvement is given in Table 2.8. Note that depreciation cost is not included because Claffey (5) does not consider that it varies with these factors of highway design. In other words, depreciation is assumed to be the same before and after improvement.

Table 2.8 Calculating Running Cost of Road Improvement

GAS CONSUMPTION AND COST

Running Cost Before Improvement 48 km/hr (30 mph)

Positive Grade Section:

Consumption rate for +4% grade (Table 1.5)
= 0.18 litre/km (0.078 GPM)
x factor for 4^{o} curve (Table 1.6)
= 0.18 x 1.022 = 0.184 litre/km
+ gasoline for half, 30-sec. stop (Table 1.7)
= 1/2 x 0.102 = 0.012 litre/km (0.005/GPM)
+ gasoline for three, 16 km/hr (10 mph)
slowdowns per 1.6 km (mile) (Table 1.8)
= 3 x 0.0035 = 0.025 litre/km (0.0150 GPM)
Total = 0.184 + 0.012 + 0.025 = 0.221 litre/km
Cost = 0.221 x 20 = 4.42 c/km

Negative Grade Section

Consumption rate for -4% grade (Table 1.5)
+ 0.033 litre/km (0.014 GPM)
x factor for 4^{o} curve (Table 1.6)
= 0.033 x 1.022 = 0.034 litre/km
+ gasoline for half, 30-sec. stop (Table 1.7)
= 1/2 x 0.0102 = 0.012 litre/km (0.0051 GPM)
+ gasoline for three, 16 km/hr (10 mph)
slowdowns per 1.6 km (mile) (Table 1.8)
= 3 x 0.035 = 0.025 litre/km (0.0105 GPM)
Total = 0.034 + 0.012 + 0.025 = 0.0071 litre/km
Cost = 0.071 x 20 = 1.42 c/km
Total Cost = 4.42 x 1.6 + 1.42 x 1.6 = 9.34c

Running Cost After Improvement 80 km/hr (50 mph)

Total Length

Consumption rate for 0.0% grade,
no curvature, stops or slowdowns,
Table (1.5) = 0.122 litre/km (0.052 GPM)
Cost = 0.222 x 20 = 2.44 c/km
Total cost = 2.44 x 3.25 = 7.81c

OIL COMSUMPTION AND COST

Running Cost Before Improvement 48 km/hr (30 mph)

Total Length

Oil consumption remains the same regardless of grades and curvatures
Consumption due to contamination (p.37)
= 0.00046 litre/km (0.0007 qt./mile)
+ Consumption due to leakage (Table 2.7)
= 0.00016 litre/km (0.00027 qt./mile)
+ Consumption due to half, stop-go cycle (Table 2.7)
= 0.000027 litre/km (0.000045 qt./mile)
Total = 0.00046 + 0.00016 + 0.000027 = 0.000647 litre/km
Cost = 0.000647 x 95 = 0.0615 c/km
Total Cost = 0.0615 x 3.2 = 0.197c

Running Cost After Improvement 80 km/hr (50 mph)

Total Length

Consumption due to contamination (p.37)
= 0.0046 litre/km (0.0007 qt./mile)
+ Consumption due to leakage (Table 2.7)
= 0.00044 litre/km (0.00075 qt./mile)

No slowdowns or stop-go cycles

Total = 0.00046 + 0.00044 = 0.0009 litre/km

Cost = 0.009 x 95 = 0.0855 c/km

Total Cost = 0.0855 x 3.2 = 0.27c

TIRE COST

Running cost Before Improvement 48 km/hr (30 mph)

Total Length

Tire Cost remains the same regardless of grades

Cost for concrete surface (p.31)

= 0.12 c/km (0.19 c/mile)

x curvature factor (p.31)

= 0.12 x 2 = 0.24 c/km (0.38 c/mile)

+ cost due to half, stop-go cycle (p.31)

= 0.09 c/km (0.15 c/mile)

+ cost due to three, 16 km/hr (10 mph)

slowdown cycles (p.31) = 0.15 c/km (0.24 c/mile)

Total cost = (0.24 + 0.09 + 0.15) 3.2 = 1.54c

Running cost After Improvement 80 km/hr (50 mph)

Total Length

Cost for asphalt surface (p.31)

= 0.28 c/km

No curves, stop-go cycles or slowdowns

Total cost = 0.28 x 3.2 = 0.896c

MAINTENANCE COST

Running Cost Before Improvement, 48 km/hr (30 mph)

Total Length

Maintenance remains the same regardless of grades

Cost (Table 2.4)

= 0.72 c/km (1.15 c/mile)

+ Cost due to half, stop-go cycle (Table 2.6)

= 0.037 c/km (0.06 c/mile)

Total Cost = (0.72 + 0.037) 3.2 = 2.42c

Running Cost After Improvement 80 km/hr (50 mph)

Total Length

Cost (Table 2.4) = 0.72 c/km (1.15 c/mile)

No stop-go cycle

Total Costs = 0.72 x 3.25 = 2.3c

TOTAL RUNNING COST

Running Cost Before Improvement, 48 km/hr (30 mph)

Cost/vehicle

= 9.34 + 0.197 + 1.54 + 2.42 = 13.497c

Daily Cost

= 13.497 x 5000 = $674.85

<u>Running cost After Improvement, 80 km/hr (50 mph)</u>

Cost/vehicle

= 7.81 + 0.27 + 0.9 + 2.3 = 11.28c per vehicle

Daily Costs

= 11.28 x 5000 = $564.00 per day

The preceeding example shows the potential for savings in running cost as a result of specified improvements in road geometric characteristics. For such minor changes as reduction of 4% grades and a 4^{o}-curve on a 3.22-km (2-mile) section of a rural road, the daily savings in running costs for an assumed traffic volume of 5,000 passenger vehicles amounts to $110.85. This illustrates the impact that road improvement programs have on savings in running costs and the importance of availability of reliable information on running costs in the economic assessment and ultimate implementation of such programs.

This example indicates the type of running cost data required for the assessment of road improvements. Apart from running cost, construction, maintenance, and accident cost are among the costs involved in economic evaluation of road improvement programs.

Sawhill (27) conducted a study to evaluate the impact that urban freeways have on vehicle fuel consumption and travel time, in the Seattle area. One of the differences between this approach and that used in example 2.3 is that evaluation of running cost is conducted before and after implementation of the project rather than at the design stage. The study purpose was to investigate the effects that construction of a freeway, parallel to four of the existing arterials, would have on travel time and speed on all five routes. The "before" portion was conducted in 1962 on the four arterials before freeway construction was completed and the facility opened for the public. The "after" portion was conducted in 1968 on the freeway and the same arterials used in the "before" portion. Seven test route sections were selected with lengths that varied from 3.2 km (2 miles) to 27.2 km (17 miles). A group of five test vehicles was selected to represent vehicles using the facilities under consideration. Accurate and frequently calibrated test equipment was used to measure fuel consumption, travel time, distance and traffic volumes. Traffic volume counts were recorded at one or more location(s) on each test run route while test vehicles were conducting their runs. Screenline volumes for all five routes for each year of the period starting 1958 and ending 1968 were collected to study the effect of the freeway on traffic volumes which indicated a 30% increase over the projected volume had the freeway not been built. In estimating fuel consumption, savings that resulted from vehicle or arterial route improvements were discounted from the total savings.

This approach for estimating running costs before and after a road improvement program (building an additional facility) is quite accurate, yet the extent of effort involved and the period of time required to complete the analysis cannot be ignored. In addition, if the economic evaluation of road improvement is required to determine whether the improvement is to be implemented, then readily available running cost data is necessary for the evaluation process. So, depending on the purpose of the economic evaluation and the resources at hand, the choice of one or the other of the above approaches to estimating running costs can be determined.

2.2.6 Traffic Control Systems

The basic terms traffic control systems is meant to include consideration of traffic signals, intersection channelization, road widening and many others. Such projects apply principally to urban travel, and consequently running cost data should be expressed as it is affected by urban traffic conditions. Marcellis (18) conducted a study to evaluate economic utility (cost) of resources consumed by the highway transportation industry for various speeds of travel in rural and urban areas. The costs considered relevant to this type of evaluation were running cost, time, accident, comfort and convenience cost. An estimate of running costs for passenger vehicles in rural areas was obtained through studying the pertinent literature. To estimate running costs for urban conditions, a simplified approach was adopted. It was assumed that running cost for restrictive-flow operation (urban conditions) is equal to that of free-flow operation plus the additional cost of slowdowns, stops, turns and so on. Furthermore, all slowdowns come to a stop as a result of the presence of a traffic control device. Running cost for a normal stop was taken as the extra cost of a typical driver decelerating from a given speed to a stop, then immediately accelerating to the same speed. The results of this report include many graphs relating vehicle speed to cost of traffic movement. Figure 2.2 is among these graphs and represents cost of traffic movement for passenger vehicles during the daytime at various speeds. Cost of traffic movement is taken as the sum of running time and accident cost. For each value of the number of stops per km (mile) there is an optimal speed which corresponds to a minimum cost of traffic movement. For passenger vehicles operating on urban roads during daytime, optimal total cost of traffic movement ranged from 4.4 cents per kilometer (seven cents per mile) at a speed of 68 km/hr (42 mph) for zero stops, to 11.4 cents per

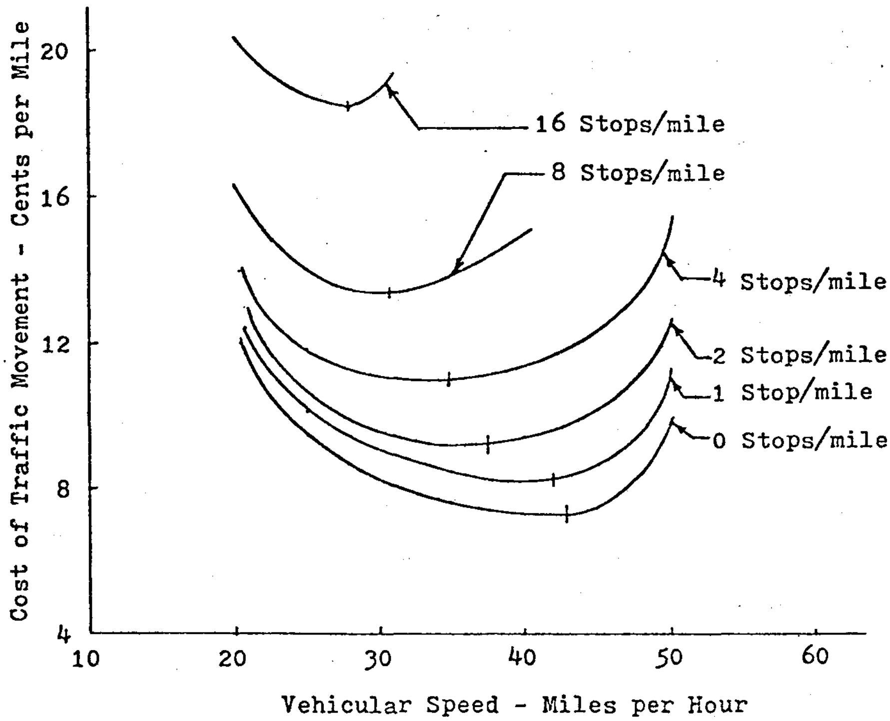

Figure 2.2 Cost of Traffic Movement versus Vehicular Speed, Daytime, Passenger Cars on Urban Streets. (Ref. 18,p.35)

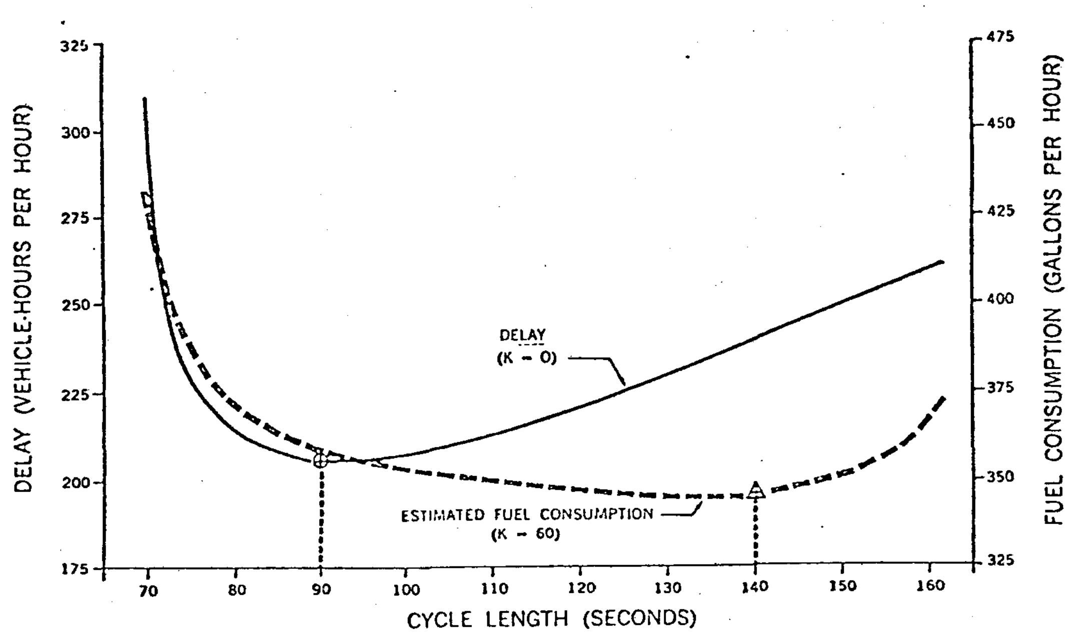

Figure 2.3 Fuel Consumption and Delay versus Cycle Length for Gainsville's Central Business District's Signal System (Ref.10,p.25)

kilometer (18.4 cents per mile) at a speed of 43.5 km/hr (27 mph) for ten stops per kilometer (sixteen stops per mile), as shown in Figure 2.2.

Despite the fact that the study purpose was related to economic evaluation of highway transportation, the recommended direct application of the results was their use towards establishment of statewide or areawide maximum or minimum speed limits. In this manner, the number of stops per km (mile) for the desired speed can be determined and traffic engineers can plan the traffic control systems based on this information.

Courage and Parapar (10) investigated the problem of delay and fuel consumption at traffic signals. Although signal timing is usually designed with primary emphasis on minimizing delay, current national interest in energy conservation is dictating a broader approach. In particular, fuel consumption is affected almost by all the independent variables of road characteristics, traffic conditions, vehicle design and driver characteristics. Signal timing will influence none of these factors except for the traffic conditions of speed, stops, delays and speed changes. To simplify the analysis tasks, the authors ignored the effects of signal timing on mid-block speed and speed changes were ignored. As a result, only two variables (total stopped delay and number of vehicles required to stop) were considered for the analysis of change in fuel consumption due to signal timing. The basic concept is to utilize the portion of the green signal after queues have been serviced (no vehicles are going through portion of the green traffic light). This can be achieved by increasing the red signal duration until the queue is increased to the point where all green signal duration is used for discharging vehicles. The simulation technique implemented in the computer program TRANSYT was used to handle the complex relationship. The results obtained in this report are shown in Figure 2.3 for the central business district (CBD) signal system of Gainesville, Florida. It was estimated that fuel savings in the order of 3.785 litres per hour (one gallon per hour) at each signalized intersection can be accomplished without resorting to cycle lengths which many traffic engineers today would consider unreasonable (greater than 120 seconds). This may not appear very impressive, but in such delay-energy trade-offs, the fact that total benefit is the sum of a large sum of very small quantities needs to be emphasized.

To conclude, the traffic engineer can apply running cost data in planning or improving traffic control systems on new or existing facilities. The two studies mentioned in this section illustrate how running cost data can be used to determine optimum operating speeds or traffic signal timing on urban facilities. Undoubtedly there exists many more applications of running cost estimates in the field of traffic control systems. The level of detail of such data depends on the nature of the project at hand, but generally it is of the disaggregated type similar to that used in economic evaluation of road improvement programs, with the exception that is normally applied only to urban conditions.

2.2.7 Special Road Services

There are many services supplied by provincial transportation departments, which should receive economic evaluation using running costs, one of which is snow removal. Claffey (6) states that state and local highway departments responsible for maintaining road service must determine how frequently roads are to be ploughed during and after snowstorms, the tolerable depth of snow on road surfaces for various traffic volumes, and when to use salt rather than sand to remove ice to give traction on ice surfaces. Since decisions relate to the operating costs of highway users as well as to levels of maintenance expenditure involved in snow clearing, adequate data on the effect ice and snow have on vehicle operating costs (especially fuel consumption) are required. To make it possible to compare fuel consumption under snow conditions with those under dry ones, test run sections, a test vehicle and fuel meter used in an earlier study (5) for measuring fuel consumption under dry conditions were adopted. A temperature correction factor was applied to adjust dry-condition fuel consumption data for the lower temperature at which fuel measurements during snow conditions were recorded. A summary of the results of this study is shown in Table 2.9. The proposed applications of these results in economic analysis are:

1. Evaluation of extra cost to road users of operating on ice or snow in order to justify the cost of accelerated ice and snow removal,
2. Comparison of total passenger vehicle fuel consumption costs over alternate routes where one is subjected to substantial ice and snow cover and the other is free of snow problems;
3. Determination of spacing of gasoline service stations along limited-access roads subject to ice and snow;
4. Selection of geometric design details for roads in snow areas to compensate road users for the extra operating costs incurred as a result of snow conditions; and
5. Prediction of fleet fuel consumption costs when operations are in regions where roads are snow covered for a significant portion of the year.

Table 2.9 Correction Factors to Adjust Passenger Vehicle Fuel Consumption for Ice and Snow Conditions (6, p.35)

Speed (mph)	Dry Pavement	Very Slippery Hard-Packed Snow	Hard-Packed Snow on Ice with Bumpy Surface	New Snow on Hard Packed Snow (in.)				
				1/2	3/4	1	1 1/2	2
20	1.00	1.23	1.30	1.36	1.43	1.47	1.51	1.60
30	1.00	1.16	1.20	1.28	1.32	1.35	1.45	1.54
40	1.00	1.11	1.14	1.20	1.23	1.28	1.40	1.48
50	1.00	1.06	1.10	1.12	1.18	1.24	1.34	1.45
60	1.00	1.04	1.08	1.10	-	-	-	-

This work by Claffey (6) investigated only one of the five running cost variables as affected by snow and ice conditions, that is fuel consumption. Measurement of the effects of snow and ice on depreciation and maintenance might not be feasible, but such effects on tire wear and oil consumption may prove worthy of investigation. Such information on running cost as directly affected by a specific independent factor (snow and ice) which requires a special road service (snow removal operations) can make the decision-making process easier to manipulate and more conceptually sound because it is based on facts.

2.3 SUMMARY

The seven purposes discussed in this chapter by no means represent either all possible uses or all possible interests of researchers working in the field of running cost estimates. These purposes were presented to illustrate use and application of running cost estimates by various sectors of society and at different levels of the decision-making process ranging from individuals to highway departments. It is evident that the type of running cost data used (in terms of data source, disaggregation and accuracy) is somewhat dictated by the purpose at hand. The more disaggregated estimates have a greater number of applications, and consequently cover a greater number of purposes than the disaggregated ones.

Despite the fact that researchers from around the world have produced estimates on running costs, lack of coordination of these efforts imposes some limitations. First, an obvious variation in definition of some of the variables used by different authors in different reports is evident. For instance, some studies refer to running costs in the same context as this report, and in others, accident cost due to running is included. So, if users of running cost estimates are not extremely careful, incorrect application of data can quickly result. Second, research efforts on some running cost variables, such as gasoline consumption, are much more comprehensive and numerous than those carried with respect to depreciation or maintenance. It is apparent that serious efforts towards coordinating research work must be effected if the research work on running cost variables is to be more homogeneously distributed. In conclusion, emphasis on explicit definiton of variables used in any study plus coordination of efforts to help produce more homogeneous coverage of research efforts on running cost variables is strongly recommended.

3. RUNNING COST ESTIMATION

One of the important aspects of this study involves a detailed review of pertinent literature in the field. In addition to identifying the most important contributions over the past several years, at least thirty documents were scrutinized to ascertain the different research approaches adopted, and inherent advantages and disadvantages were noted. These studies either agree or disagree with each other in some or all portions of their reported research work. Thus, discussion of each report separately can result in repetition of discussion on those parts common to more than one study. For instance, use of literature as the data source for running cost estimates is adopted in many studies and they would be repeated with the discussion of each of these studies. Thus it was not considered reasonable to discuss each report or approach separately. Instead, all reports were discussed with respect to certain criteria. Accordingly, a set of criteria was selected and all reports were investigated with respect to each criterion.

The first two criteria involve the variables used in the different studies, namely the dependent and independent variables respectively. A brief discussion of each variable involves a description of what each represents, in what form it appears in the different reports, and how it is used in relation to estimates of running costs of motor vehicles. The third criterion used is that of the data sources incorporated in the analysis, along with the advantages and disadvantages of each. The fourth criterion considered is the level of aggregation of both the dependent and independent variables as they are represented by different researchers in the reports. The impact of time-dependence criterion follows and deals with updating running cost information, the time, manpower and cost requirements for such a process. The sixth criterion deals with the methods and analytic techniques used by different researchers, depending on their approach, to arrive at the results. Finally, the results, their form, comprehensiveness, ease or difficulty of use, and storage requirements are summarized for the different research approaches in the seventh criterion.

3.1 INDEPENDENT VARIABLES

The independent variables are those factors that affect values of the dependent or running cost variables (fuel, oil, tires, maintenance and depreciation). As defined in the introduction, independent vaiables can be classified into five major categories, namely; road characteristics, vehicle characteristics, traffic conditions, environmental factors and operator or driver characteristics. In the next few pages each of these variables will be discussed in terms of the effects on the dependent variables, how such effects can be measured and how different researchers approached, considered or ignored it. In all available reports, depreciation has not been related to most of the independent variables excepting age and mileage of vehicle. It will therefore not be discussed in relation to many of the independent variables.

3.1.1 Road Characteristics

Road characteristics include grade, curvature, surface type and condition, at-grade-intersections on free flow roads, entry-exit points, lane and shoulder width, and length. Each of these characteristics has an influence on each of the five running cost variables, and are discussed briefly below:

i) Grade

Grade is the change in vertical elevation of the roadway. Grades probably affect all running cost variables, but are particularly important in estimating fuel consumption and tire wear. The greater the positive grade (upgrade), the more energy and traction needed to overcome it, and vice versa. Oil consumption and maintenance increase due to the extra load imposed on the engine as a result of operation on positive grades (5). The value of grades is usually expressed in either rise or fall in m/km (ft./mile) or positive and negative slopes as a percentage.

ii) Curvature

Curvature is the change in horizontal alignment of the roadway. Tire wear due to curvature is evident for tires on all vehicle wheels but more pronounced for steering-wheel tires. These latter tires suffer extra wear on curves because of the pavement friction resistance induced by turning and directing wheels against the direction of vehicle motion to develop necessary turning forces (5, p.4). Extra fuel consumed on curves provides the additional energy required to propel the vehicle against this pavement friction. Curvature is usually expressed in degrees per kilometer (mile) in alignment change (accumulated degrees for all curves divided by total section length), degree of curvature of single curves or radius of curvature of single curves. It has not been mentioned in any of the studies how curvature affects oil, maintenance or depreciation cost, if at all.

iii) Road Surface

Road surface as discussed in this report deals with the type of pavement and its condition. Road surface type can be concrete, asphalt, gravel stone, or earth. Road surface condition varies from excellent for new roads, to very poor for old, broken and poorly maintained roads. Road Comfort Rating (RCR) is one of the measures used to express the pavement condition (also PCR as used by the Ministry). It is based on the severity of such factors as cracking, alligatoring and dishing. RCR value varies from 0-20 for very poor pavement condition to 90-100 for excellent pavement condition.

Fuel consumption is increased on gravel or stone over paved roads due to the extra energy required to either force wheels over the gravel or to push gravel or stones aside. On earth roads or under snowy conditions extra fuel is required to force wheels out of depressions or to push soil or snow aside. Tires are subject to extra wear on loose stone or icy roads due to the deteriorating effects of heavy buffeting (5). On the other hand, slip-resistant surfaces or abrasive pavements result in excessive wear due to friction. Oil consumption is affected by the dust-producing characteristics of road surfaces. Driving on dusty roads such as gravel or earth roads results in more frequent oil changes than driving on paved roads. Maintenance is mainly influenced through the effects rough roads have on the suspension system, and dusty roads have on the wear of cylinder walls, piston rings and bearing surfaces. Depreciation, plus parts cost increase as the road surface type changes from paved to gravel to earth (7,8).

iv) At-Grade-Intersections

At-grade-intersections is an element of road design. Such intersections are responsible for vehicle slowdowns and stops. Increase in fuel consumption is due to the necessity to supply the energy required to accelerate a vehicle to its original running speed after it has been slowed or stopped. Extra tire wear occurs when vehicles stop and start due to frictional wear while braking and due to traction slip while accelerating. Speed changes involved in the stopping process increase oil contamination rate and consequently oil consumption. Maintenance is increased due to brake wear during deceleration and transmission wear during acceleration. This variable is usually expressed as the number of speed-change cycles and the speed limits associated with it per unit distance.

v) Entry-exit Points

Entry-exit points are locations, on free-flow roads, where vehicles are often required to slowdown, because of entering and/or leaving traffic. The effects of slowdowns on fuel, oil, tire and maintenance are the same as those included under the previous variable of at-grade-intersections. This variable is usually expressed in terms of the number and speed changes of slowdowns per unit distance.

vi) Road Lane-Width

Road lane-width together with the number of lanes affect vehicle running speed and road capacity. For a given traffic flow rate, an insufficient number of travel lanes may cause interference among vehicles, resulting in frequent vehicle speed-change cycles. These speed changes induce extra fuel, oil, tire and maintenance cost. But since running speed and road capacity are factors of traffic conditions they will be discussed under Section 3.1.2. Road-lane width is usually expressed in meters (feet).

The inclusion or exclusion of any of these six road characteristics in the researched reports depends on the level of aggregation of running cost data which, in turn, depends on the purpose for which this data was accumulated. Only estimates of running costs meant for use in economic evaluation of road projects would give the effect that some or all of these six characteristics have on running costs.

3.1.2 Traffic Conditions

Traffic conditions on both urban and rural roads affect vehicle running costs only where traffic volumes or traffic control systems interfere with the uniformity of speeds of individual vehicles. The influence of traffic on motor vehicle running costs is a combined effect of road design factors which determine capacity (grade, curvature, road width, intersection at grade and entry-exit points) and traffic volumes. Where traffic volumes are low relative to road capacity, vehicles may move at uniform speeds and traffic conditions would have little effect on running cost. Where traffic volumes are high or approaching capacity vehicles may be slowed to a stop, or even a series of stops of uncertain duration, with a corresponding increase in the running cost associated with slowdowns and stops. At such high volumes, running costs depend on many factors which are difficult to predict and which include traffic composition, frequency of congestion stops, duration of such stops, driver's response to congestion situations, racing of engines to promote engine cooling, and the duration of congestion periods. The only condition remaining is medium-to-heavy traffic flow where traffic conditions (such as slow-downs on highways) are severe enough to produce a measureable effect on running cost variables.

There are two approaches to assess the effects of traffic conditions on running cost. The first approach is to express the change in magnitude of running costs for different traffic volumes and at different operating speeds. In addition, the effects of such traffic conditions as stops and slowdowns on each of the running cost variables are to be measured and recorded. Tables 3.1 and 3.2 are examples of data produced using this approach (5). Table 3.1 gives factors by which gasoline consumption increases due to increases in traffic volume for free-flowing operation. Table 3.2 shows the excess gasoline consumed due to different durations of stop-go-speed-change cycles.

The second approach is to choose different traffic conditions with different combinations of traffic factors and measure running cost variables. Through many measurements, it is possible to derive relationships between running cost variables and the independent factors of traffic conditions. Pelensky (24) applied this approach and Table 3.3 (24, p.57) represents a portion of the results he obtained on gasoline consumption. Equations 3.1 and 3.2 (24, p.70) are some of the relationships he obtained through regression analysis on data obtained from Table 3.3.

Table 3.1 Correction Factors to Adjust the Gasoline Consumption for Traffic Volume, Six-Lane Expressway*(5)

One-Way Traffic Volume (VPH)	Correction Factors by Attempted Speed of Vehicle (mph)			
	45	50	55	60
0 - 2400	(level of service A = Free-flowing Traffic)			
2400 - 2800	1.000	1.000	1.010	1.020
2800 - 3200	1.000	1.005	1.015	1.025
3200 - 3600	1.000	1.010	1.020	1.030
3600 - 4000	1.000	1.015	1.030	1.045
4000 - 4400	1.001	0.020	1.040	1.060
4400 - 4800	1.002	1.030	1.050	1.070

* Correction factors determined for standard-size U.S. cars represented by Cheverolet sedan at 4,400 lb. G.V.W.

Table 3.2 Excess (Gallons) of Gasoline Consumed per Stop-Go Speed Change Cycle for Passenger Vehicles (5)

Speed (mph)	Excess Gasoline Consumed (Gallon) By Duration of Stopped Delay (sec.)			
	0	30	60	90
10	0.0016	0.0021	0.0026	0.0031
20	0.0066	0.0071	0.0076	0.0081
30	0.0097	0.0102	0.0107	0.0112
40	0.0128	0.0133	0.0138	0.0143

TABLE 3.3 Gasoline Consumption For Different Traffic Conditions

Variable	Quantities Per Mile of Travel					
Gasoline Consump. (GPM) P,p	0.209	0.124	0.106	0.123	0.092	0.091
No. of Gear Changes A,a	11.72	7.26	2.37	4.79	2.94	4.51
No. of Brake Appl. B,b	9.62	3.87	1.75	2.84	2.90	2.82
No. of Stops H,h	6.20	1.99	0.79	1.45	0.88	1.27
No. of Left Turns C,c	0.86	0.76	0.0	0.0	0.0	0.0
No. of Right Turns E,e	0.86	0.76	0.0	0.0	0.0	0.0
Total Travel Time (sec.) T,t	322.4	133.8	103.7	120.7	116.3	115.7
Cumulated Stopped Time (sec.) S,s	147.0	23.6	20.7	25.4	24.4	20.9
Difference (T-S), (t-s)(sec.) R,r	175.4	110.2	83.0	95.3	91.8	94.8
Rate of Rise and Fall% Z,z	0.41	0.22	0.60	0.66	0.60	0.66
Average Grade % I,i	0.00	0.00	+0.97	+1.81	-0.97	-1.81

$$P_k = 23.0 + \underset{(0.005)}{0.120\ t} + \underset{(0.60)}{3.0\ C} + \underset{(0.14)}{3.9\ i} \tag{3.1}$$

$R^2 = 0.96$, SE = 2.0 gal/1000 miles

$$P_k = 26.3 + \underset{(0.01)}{0.070\ t} + \underset{(0.5)}{2.1\ C} + \underset{(0.5)}{3.3\ e} + \underset{(0.2)}{0.53\ Z} + \underset{(0.1)}{3.9\ i} \tag{3.2}$$

$R^2 = 0.98$, SE = 1.7 gal/1000 miles

P_k = Gasoline consumption per 1000 miles

(the figures in brackets are the standard errors of regression)

It is obvious that the approach to be chosen at any time depends on the traffic conditions under consideration. If urban traffic is the case when the second approach would be more suitable in terms of variables measured. But if rural travel prevails, the first approach would be more appropriate in assessing running costs. The number of traffic conditions considered varied from one report to another, and in some reports it was expressed in the aggregated form of rural or urban conditions.

3.1.3 Vehicle Characteristics

Vehicle characteristics that can affect running cost dependent variables are many, yet only a few have a measurable effect on the dependent variables. Among vehicle characteristics that have measurable effects on the dependent variables and that have been investigated by researchers are vehicle type, weight, engine power, transmission type, price, age and tire pressure. The findings of such research efforts are reported in the next few pages.

i) Type

The type of vehicle, in a general context, refers to vehicle class, whether it is a passenger vehicle, commercial vehicle, pick-up truck, transport truck and so on. In a more specific context, vehicle type refers to its dimensions and dynamic characteristics. For the purpose of running cost estimates several approaches are possible for representing vehicle type. One approach is to give running costs for each vehicle type as defined by the major classes (passenger, commercial, pick-up truck, transport truck and so on). Another alternative is to determine traffic composition for the road under consideration (percentage of each vehicle class) and estimate running costs for the vehicle that represents such traffic composition. Yet a more disaggregated approach is to subdivide each vehicle class according to one or more of its dynamic characteristics such as weight or engine size, in estimating running costs. Running costs depend greatly on vehicle type and thus estimates should be given by type.

ii) Vehicle Weight

The weight of the vehicle, expressed in tons (lbs), is either the curb weight or the loaded vehicle weight. Gasoline consumption and tire wear generally increase with vehicle weight (25, p. 468 and 31, p. 349). On level roads, weight has its greatest impact on fuel consumption at low speeds. On grades, fuel consumption at higher speeds varies directly with weight (5, p. 62). The effect of weight on oil, maintenance and depreciation, if any, is very small (25). For running cost estimates, either several vehicles with different weights are used or a vehicle with the weight that represents the average traffic composition is used. For example, Claffey (5) used a 2.0 ton (4,400 lbs) standard size vehicle to represent the composite passenger vehicles of 20% large vehicles, 65% standard vehicles, 10% compact vehicles and 5% small vehicles. Running cost data disaggregated by vehicle weight would have a wider application since traffic composition may vary with time and facility type.

iii) Engine Power

Engine power is usually represented by displacement in cc. (cu.in.) or by gross horsepower and engine revolutions per minute (rpm). Claffey (5, p. 63) gives some graphs that show how engine size (piston displacement) affects vehicle fuel consumption for vehicles that have similar design and weight characteristics. The larger engines consume more fuel than the smaller engines at all speeds and at all loads up to a 6% grade. At 96.6 km/h (60 mph), for example, the vehicle with a 7210 cc (440 cu. in.) engine consumes approximately 17% more fuel than does the vehicle with a 4916 cc. (300 cu. in.) engine. There is no mention in any of the studies reviewed about the effect of engine size on other running cost variables.

iv) Transmission Type

Transmission type refers to manual and automatic transmissions. Automatic transmissions weigh and cost more than manual ones. The increase in cost is reflected in an increase in depreciation rate. The increase in weight along with decrease in engine efficiency increases both maintenance and gasoline consumption. Pelensky (24) reports data obtained from test runs on measured gasoline consumption for both standard and automatic transmissions. The results indicate that the increase in gasoline consumption can be as much as 0.59 litre/km (0.25 gal/mile) for an automatic transmission over standard transmission at a speed of 80.4 km/h (50 mph), for identical vehicles and driving conditions.

v) Price and Age

Price and age of vehicle affect depreciation directly; any increase in price or age can cause an increase in depreciation rate. Maintenance cost increases with the vehicles age and mileage (19, p.4). Fuel consumption increases slightly with age (about 5 or 6% after four years of service and 60,000 miles of travel) (5, p.62). For running cost estimates, only the effect of mileage on any of the running cost variables is to be considered.

vi) Tire Pressure

Tire pressure affects both tire wear and fuel consumption (24). At a speed of 40.2 km/h (25 mph), the fuel consumption increases with a decrease in tire pressure (24, p. 24). No other effects of tire pressure, on running cost variables, have been reported.

Different reports used different combinations of vehicle characteristics to represent vehicles for which running costs are given. The most aggregated approach is that of refering to vehicle type as "typical" or "average" vehicle as given in Table 2.1. A very disaggregated approach is that of representing the vehicle by its class, weight, engine power, transmission type, price and age.

3.1.4 Environmental Factors

Environmental factors which can affect the magnitude of running cost dependent variables include topography, altitude, temperature, wind and precipitation. Research work conducted in this regard is rather limited when compared with research work on such independent variables as road characteristics and traffic conditions. Many researchers expected that the effects environmental factors would have on the dependent variables would be rather small and accordingly chose not to investigate them. The following discussion on each factor indicates the rather limited number of researchers who reported work conducted in this regard.

i) Topography

Topography refers to the general geometric features of the terrain, whether it is mountainous, rolling or flat. Almost all researchers considered grades and curvature representative of topography and that different topographies would not have a great influence on running cost variables. None of the researchers, however, investigated the effect on running costs for two roadway sections that exhibit different topographies but have the same length and other road characteristics including average grade. Claffey (5, p.40) indicates that fuel consumption is greater for level roads than for successive equal length grades that are alternatively plus and minus. After many test runs he concluded that the sum of the fuel consumed operating a given distance up and down a 3.5% grade was invariably a little less than that for operating twice the distance on a level road. This was for passenger vehicles at medium speeds and degree of curvature up to 3°.

ii) Altitude

Altitude refers to elevation above sea level. Winfery (31, p. 350) explains the effects of higher altitudes on fuel consumption as follows; at higher altitudes air weighs less which decreases the power output of the engine because this power is proportional to the weight of air intake into the cylinder, which consequently causes an increase in fuel consumption. Claffey (5, p.62) reports that variations in altitude have no measureable effect on passenger-vehicles fuel consumption for elevations up to 609 m (2000 ft) above sea level. Above 609 m (2000 ft) however, there is a small increase in fuel consumption for altitudes up to 914 m (3000 ft). A sharp rise in fuel consumption from 0.36 litre/km (0.155 gallon/mile) to 0.44 litre/km (0.185 gallon/mile) at 50 km/h (30 mph) occurs between altitudes of 914 m (3000 ft) and 1219 m (4000 ft). The effect of altitude on the other running cost variables is not indicated in any of the reports examined. In general, altitude is ignored in running cost studies.

iii) Temperature

The temperature under consideration here is the air temperature. Air temperature affects engine performance; the power output being approximately inversely proportional to the square root of absolute temperature (31, p.351). Temperature affects the specific gravity of fuel, and engine thermal efficiency is approximately inversely proportional to fuel density (24, 31). In addition, fuel consumption is appreciably higher at lower temperatures with nearly the same increase in fuel consumption per unit of temperature drop at all speeds (5, p.62). Claffey (5, 62) indicated that at 96.6 km/h (60 mph), fuel consumption rate increases by 2% for 15.5^{o}C (60^{o}F) over that for 26.7^{o}C (80^{o}F) and by 8% for a temperature of -6.7^{o}C (20^{o}F) over that of 26.7^{o}C (80^{o}F). Fuel consumption is the only running cost variable reported in previous studies with respect to temperature effects.

iv) Wind

Wind has some measureable effects on the fuel consumption variable; the other running cost variables have not been investigated. When the wind is blowing in any direction but that of the vehicle's travel, fuel consumption increases due to the higher resistant force required to overcome it. It was reported that winds of 12.9 - 16.1 km/h (8-10 mph) may, at speeds typical for urban travel, change fuel consumption rate by $\pm 6\%$ depending on wind direction (24, p.22). Inspite of this measureable effect, very few details are available regarding effects of wind on fuel consumption or other running cost variables.

v) Precipitation

Precipitation (rain or snow) increases running cost through the extra power required to overcome conditions created by precipitation. As discussed in Section 2.2.7, snow and ice influence fuel consumption. Generally, fuel consumption under icy or snowy conditions increases over that under dry conditions for the same characteristics of the highway and at comparable temperatures. Oil is contaminated from snow, sand and salt used on roads at a higher rate than that under dry conditions. Maintenance increases due to accelerated rusting caused by wet and slushy conditions as well as a more rapid brake wear. Tire wear increases due to buffeting on non-slip-resistant surfaces created by rain and on packed snow due to excessive friction. When running cost data is recorded, the influence of environmental conditions is often ignored. Running cost values are often recorded for summer temperatures 30-35^{o}C (80-90^{o}F) with no wind or precipitation and no mention of altitude or topography. The effects of temperature, precipitation, altitude and wind are given separately.

3.1.5 The Operator

The final independent variables affecting running cost is the operator (driver). The operator can affect running costs in the way he applies brakes, speeds up, and cares for his vehicle. In this regard research done by Pelensky (24) is inconclusive. Other researchers did not investigate this variable.

However, inclusion of any of the independent variables depends on the comprehensiveness of running cost data produced. More comprehensive studies, such as Claffey (5), Pelensky (24) and Winfrey (31), include most of the independent variables discussed in this section. Other less comprehensive reports, such as those conducted for purposes of public information (9, 19, 20, 21) do not include any independent variables except for two or three vehicle characteristics.

3.2 DEPENDENT VARIABLES (RUNNING COST VARIABLES)

The dependent variables are fuel consumption, oil consumption, tire wear and the portion of maintenance and depreciation related to vehicle use. Obviously, from the discussion concerning independent variables presented in the previous section, each of the values of the dependent variables is affected by some or all of the independent variables. This does not indicate that all studies and reports on running costs investigated all these effects and recorded them. On the contrary, researchers followed various approaches in estimating running costs. Accordingly, the form of analysis results varied depending on the scope and comprehensiveness of the study. In the following section, the various approaches used to express relationships between dependent and independent variables are described.

3.2.1 Fuel Consumption

Fuel consumption is the mostly investigated item among running cost variables. The cost of gasoline which varies with the change in gasoline price represented about 25% of the total running cost for an average passenger vehicle in 1970 (9). The principal reasons for extensively investigating the fuel consumption variable are:

a) It is a day-to-day out-of-pocket cost that is easily noticed by the owner,

b) concerns about the energy shortage experienced during the past few years have resulted in an increase in interest regarding gasoline consumption and the possible factors that can affect its value, and

c) the fuel measurement devices are much more advanced in technology and accuracy compared to devices required to measure other dependent variables.

Fuel consumption is either expressed in quantitative units, litre/km (gallon/mile), or in monetary cost, cents/km (cents/mile). Several approaches are used to express the effect of independent variables on fuel consumption. The simple and most aggregated approach is that discussed previously in Section 2.2.1. In this approach, all independent variables are aggregated by using a typical private motor vehicle without explicitly defining what they represent. A more disaggregated approach is that of classifying each of the independent variables into classes. For example, road characteristics can be classified into freeway, rural and urban conditions and vehicle characteristics expressed in small, large, truck and so on. An example of classifying vehicle characteristics as they affect fuel consumption at different speeds was previously given in Table 2.3. A third, and yet a more disaggregated approach would be that used by Claffey (5) and Pelensky (24) in expressing change in fuel consumption due to changes in the independent variables. In this method, a particular set of independent variables is chosen as the datum for fuel consumption measurements as shown in Table 3.4 (5, p. 17). The effect on fuel consumption of changing the value of the independent variables from that of the datum is measured and recorded separately. The effect of traffic volumes and stop-go cycles on fuel consumption were previously reported in Tables 3.1 and 3.2, respectively.

Table 3.4 Automobile fuel Consumption As Affected by Speed and Gradient - Straight High-type Pavement and Free-Flowing Traffic*

Speed	Gasoline Consumption (GPM) on Grades of:										
(mph)	Level	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
	(a) Plus Grades										
10	0.072	0.080	0.087	0.096	0.103	0.112	0.121	0.132	0.143	0.160	0.179
20	0.050	0.058	0.070	0.076	0.086	0.094	0.104	0.116	0.128	0.144	0.160
30	0.044	0.051	0.060	0.068	0.078	0.087	0.096	0.110	0.124	0.138	0.154
40	0.046	0.054	0.062	0.070	0.078	0.087	0.096	0.111	0.124	0.138	0.156
50	0.052	0.059	0.070	0.076	0.083	0.093	0.104	0.118	0.130	0.145	0.160
60	0.058	0.067	0.076	0.083	0.093	0.102	0.112	0.126	0.138	0.152	0.170
70	0.067	0.075	0.084	0.093	0.102	0.111	0.122	0.135	0.148	0.162	0.180
	(b) Minus Grades										
10	0.072	0.060	0.045	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
20	0.050	0.040	0.027	0.022	0.021	0.021	0.021	0.021	0.021	0.021	0.021
30	0.044	0.033	0.022	0.016	0.014	0.013	0.013	0.013	0.013	0.013	0.013
40	0.045	0.035	0.025	0.018	0.014	0.012	0.012	0.012	0.012	0.012	0.012
50	0.052	0.041	0.030	0.025	0.021	0.018	0.014	0.013	0.010	0.010	0.008
60	0.058	0.038	0.036	0.037	0.030	0.027	0.022	0.018	0.014	0.011	0.008
70	0.067	0.058	0.048	0.043	0.039	0.036	0.031	0.027	0.022	0.016	0.013

* The composite passenger vehicle represented here reflects the following vehicle distribution: large cars, 20%; standard cars, 65%; compact cars, 10%; small cars, 5%.

3.2.2 Oil Consumption

Engine oil is consumed as a result of dissipation by combustion and evaporation contamination by impurities, and leakage. Winfery (30) indicates that oil consumption varies with manifold pressure, throttle opening, horsepower output, gear ratio, engine revolutions per minute (rpm) and engine temperature. Oil dissipation through combustion, evaporation and leakage is accelerated by travel at high speeds. Oil consumption through contamination is promoted by driving under urban traffic conditions and with dust particles from dusty roads. Even though oil consumption due to contamination is not very large in quantity oil should be replaced according to manufacturers' recommendation to protect the engine. Accordingly, oil consumption due to contamination can be estimated by review of manufacturers' guides. Oil consumption due to dissipation and leakage is to be measured from operation at various speeds, traffic conditions, road characteristics and weather factors.

Very few researchers investigated the effects of the different independent variables on oil consumption. Only variables such as road surface type, stop-go cycles, traffic flow (urban, freeway) and speed (5,7,8,15,29,31) were considered. However, due to the fact that the cost of oil is very small when compared to other running cost variables (less than 5% for passenger vehicles up to 1973 (9,28)) and that it does not appreciably change with the independent variables, many studies applied one average value for oil consumption, which was assumed to be constant throughout the life of the vehicle(1,3,14,19,23,25). Oil consumed while removing contamination is much greater than that lost by combustion and leakage combined; 1.65 litre/1000 km (0.7 qts/1000 miles) versus 0.64 litre/1000 km (0.27 qts/1000 miles) for passenger vehicles on dust-free roads and free-flowing traffic conditions (5, p.37).

3.2.3 Tire Wear

Tire wear can be measured either by loss of tire weight or tread wear per unit distance. Tire cost can be assessed by calculating the cost of tires used during the life of the vehicle, and dividing it by total mileage to obtain cost per unit distance. The choice between tire wear and tire cost methods depends on the purpose or use of the data. Assessment of road projects requires information on tire wear as affected by the independent variables, while tire information used for educating the public can be expressed in terms of tire cost per unit distance. In the first method, the loss of tire weight is measured under varying conditions of road characteristics, speed, and other independent variables. The loss in tire weight due to variations in each of speed, curvature, surface type, and speed change cycles was reported by Claffey (5). No measurements of tire wear for any other indepedent variables were recorded. Apparently the reason for this is the excessive number of runs or mileage required to produce a measureable loss in tire weight. Other researchers (2,7,26) reported tire wear for variations in grades and level of service.

The other method, of expressing tire wear, in cost per unit distance is easy to comprehend and use, particularly by private individuals. Yet, among its drawbacks is complete dependabilty on the cost of tires which may vary substantially with location and passage of time. For instance, tire cost for the average vehicle in the United States in 1970 was 0.242c/km (0.39c/mile) (9) while in New Zealand (1972) the tire cost was 0.291 c/km (0.468c/mile) (19) for a small vehicle with engine size of 1350-2000 cc (82.4-122 cu.in).

3.2.4 Maintenance and Repairs

Maintenance and repairs considered for running cost estimates are those incurred as a result of normal wear and tear and not due to accidents. Maintenance cost can be divided into three categories (4). The first includes regular maintenance of filter replacements, motor tune-ups, lubrications, electric system repairs, and inspections. The second includes muffler repairs, brake lining and batteries which are relatively infrequent but constantly replaced throughout the life of the vehicle. The third category involves heavy maintenance such as valve repair.

Maintenance cost varies greatly because it is influenced by many of the independent variables such as driver skill, weather conditions, road surface type and roughness, traffic congestion, average speeds and the type of vehicle use. The effects of many of these variables on maintenance cost is very difficult to measure. For this reason, many researchers (14,15,23,26,28) used available information on maintenance cost for different vehicle types. This information is often available from one or more sources such as motor vehicle industries, commercial companies, local highway departments, and other available literature. In turn, such data bases gives aggregated maintenance cost per unit distance. Dawson (12,13) deviates from this method slightly and considered two-thirds of the maintenance cost per unit distance to be constant while the remainder is assumed to vary with speed in the same manner gasoline consumption does.

Other researchers (2,4,7,9) measured and reported maintenance cost as it varies with one or more of the independent variables. Abaynayaka (2) gives maintenance cost as it varies with road roughness and vehicle type. Claffey (5) measured the effects of stop-go cycles on the brake system (brake shoe, brake fluid and brake lining) as well as giving average maintenance cost per travel distance in the same manner explained in the previous paragraph. Clark and Soberman (7,8,29) presented how the change in type of road surface and speed affects maintenance cost by vehicle type. Botzow (4) expressed maintenance cost on a yearly bases as it varies with vehicle age. He reports the increase in average yearly maintenance cost with the decrease in vehicle age in years. For instance, a vehicle retired at the age of four years would have a maintenance cost of $200 per year while a vehicle retired at the age of nine years would have an average maintenance cost of $133 per year.

3.2.5 Depreciation

Depreciation cost refers to the part of capital value of a vehicle which is consumed in the course of operating kilometerage (mileage) or which is used up by obsolescence (age). For the purpose of estimating running costs only the portion of depreciation cost that results from vehicle operation should be considered. According to Cope and Gauthier (9) depreciation was the greatest single cost of owning a vehicle or about 46% of running cost in 1970, even though depreciation cost is exclusive of tire cost.

It is not surprising that suitable approaches have not yet been devised to properly evaluate the effects of the independent factors on depreciation due to kilometerage (mileage). Despite this, several writers (5,9,22, 30 and 31) made the following observations:

(a) Users travel faster and farther per year when possible speeds are increased through highway improvement, which results in lower average depreciation per unit distance because total depreciation is distributed over a greater kilometerage (mileage) (5,p.39)
(b) Increase in annual kilometrage (mileage) has little effect on depreciation due to age during the early years of a vehicle's service life.
(c) Depreciation rates under urban driving conditions are higher than those incurred in rural areas.

Many writers (3,9,12,13,14,16,25,31) agree that 50% of total depreciation should be allocated to kilometerage (mileage). A few (19,20,21), however, believe that depreciation of passenger vehicles is solely influenced by kilometerage (mileage). Others (7,8,29) related depreciation to road surface type and speed.

The simplest approach for estimating total depreciation per unit distance is to divide the vehicle capital cost (difference between its price when new and its salvage value) by the kilometerage (mileage) run. Abaynayaka et al (2) uses the same method to estimate total depreciation, with a small added variation. He assigns values for a depreciation factor which decreases with increases in vehicle age, on yearly bases. For example, depreciation factors for the first and fourth year are 220 and 80 respectively. This factor when multiplied by the price of the new vehicle and divided by the average annual kilometerage of that vehicle gives a depreciation cost per 1000 km. This means that the depreciation rate decreases as vehicle age increases, which agrees with the depreciation cost procedure given in another report (9).

Pelensky (24) used a different approach to estimate depreciation. He selected a sample of 114 vehicles of the same make but different ages and kilometerage (mileage). From the statistical analysis conducted on the data from these vehicles, a regression equation that gives depreciation percentage "D" in terms of age in years "Y" and mileage "M" (total mileage divided by 1000) was obtained as follows:

$$D\% = 4.0 + \underset{(1.67)}{11.0Y} - \underset{(0.43)}{1.75Y^2} + \underset{(0.035)}{0.123Y^3} + \underset{(0.066)}{0.78M} - \underset{(0.0009)}{0.0048M^2}$$

Figures in brackets are standard errors of the regression coefficients, which are all highly significant. The coefficient of multiple determination is $R^2 = 0.98$ and the standard error of estimate SE = 1.9%. Pelensky set "Y" equal to zero to obtain depreciation due to mileage only, and deleted the less significant terms of the regression equation (the terms with low values of regression coefficients) to obtain the following relationship for depreciation due to mileage alone:

$$D\% = 18 + \underset{(0.032)}{0.85M} \quad , \quad R^2 = 0.86 \quad SE = 5.4\%$$

In all of the above approaches, depreciation cost is estimated with respect to changes in age and kilometerage, regardless of any of the other independent variables such as road characteristics, speeds, and so on. Shippy (28) expressed depreciation per vehicle mile as it varies with changes in operating speeds for the different vehicle types. He concluded that the increase in average operating speeds reduces the useful life of vehicles. Accordingly, total depreciation costs given in the report by vehicle type and per mile bases increase with the increase in vehicle operating speed. For example, at operating speeds of 48.2 km/h (30 mph) and 96.5 km/h (60 mph) depreciation costs for passenger vehicles are 0.75 c/km (1.2c/mile) and 0.99 c/km (1.6 c/mile) repsectively. Winfery (31,p.306) gives some running cost data, on yearly bases which generally indicate that total depreciation cost per mile decreases as the annual mileage increases. It is interesting that this finding as well as the one presented in section 3.2.5 a) contradict the values given by Shippy (28).

As displayed, approaches to estimating depreciation cost vary a great deal, yet none of them relate it to more than three or four of the independent variables (vehicle age and type, speed and road surface). Some of the researchers not only disagree on the percentage of depreciation to be allocated for mileage, but also contradict each other, especially with respect to the passenger vehicle. A lot of these contradictions are mostly due to the lack of complete information on the conditions and variables for which figures on depreciation are given.

From the discussion of dependent variables presented in Section 3.2 it is obvious that fuel consumption is the most comprehensively investigated among all five dependent variables. Fuel consumption has been investigated with respect to all of the independent variables, despite the fact that investigations of some variables such as the operator were inconclusive. The other four variables have been investigated with respect to one or more of the independent variables. Among the reasons for such discrepency in research efforts are the following:

(a) Difficulty in obtaining measurements of change in dependent variables due to change in the independent variables is often blamed on the absence of suitable measuring devices and techniques. Maintenance and depreciation are the two variables included under this category.

(b) The extensive work required to reach a measurable value of the effects of independent variables on the dependent variables. In the approach of actual field measurement, the kilometerage (mileage) required to produce a measureable effect of, for example, road surface condition on shock absorbers and consequently on maintenance cost would be considerable.

(c) The negligible effects produced by change in the independent variables on the dependent variables, particularly if the dependent variable represents a small percentage of total running cost as exemplified by the consumption variable oil.

3.3 DATA SOURCES

Four approaches are often used to collect and generate running cost estimates including direct field measurement, computer simulation, questionnaires, and available literature. To choose among these data sources, the purpose of conducting the research must be clearly defined. In this regard, the scope of the work and resources required to conduct the research must be determined. Available data sources place many limitations on the outcome of any research effort. It determines, to an extent, the form of expressing the results, be it tables, graphs, equations or a combination of two or more of these. In addition, data sources dictate the level of aggregation of running cost estimates. For instance, the level of aggregation of running cost estimates produced by using literature as the data source can not be more disaggregated than that of the original source of data. The different data sources which are often used are discussed in the following sections.

3.3.1 Direct Field Measurements

The most accurate method of collecting information on running cost is that of taking direct measurements through test runs, provided the measuring techniques and equipment are reliable. This method has been used by some researchers (3,5,24,25,27,31) to obtain information on one or more of the running cost variables as affected by one or more independent variables. Usually the effect of each independent variable on any of the dependent variables is measured separately.

Although this method may be very accurate it has several disadvantages. First, it requires a great deal of time and money to measure all possible effects that the change in independent variables may have on each runnng cost variable. Second, the equipment used for measurement must be accurate, which makes it correspondingly expensive, and should be frequently calibrated. Although accuracy is the main advantage of this method, it is occasionally compromised in view of other restrictions. Abaynayaka (1) emphasizes the fact that measurement techniques should be simplified in light of the technologic resources, manpower and facilities available in the area where the research is conducted. Third, the measurement becomes obsolete as soon as test vehicles used for the measuring technique become obsolete. Fourth, the effect of many independent variables on some of the dependent variables is difficult or impossible to measure through test runs, as exemplified by the effect of weather on depreciation.

3.3.2 Computer Simulation

In view of the high cost of test runs to measure the effects of independent variables on running cost variables, many researchers resorted to simulation. In computer simulation techniques, the computer is provided with information on the independent variables and unit costs of the dependent variables. In addition, the mathematical models that relate each of the running cost items to the independent variables are fed into the computer. The mathematical models predict vehicle motion from the basic laws of physics. For example, fuel consumption is predicted on the basis of power from the engine. However, a problem with computer simulation is that it can not handle too many variables simultaneously. Another problem is the difficulty of simulating the effect of such variables as traffic interference on vehicle performance and thus on running costs (17,p.31). A third problem is the lack of mathematical relationships that would relate all of the running cost variables to the independent variables. Clark (7,p.10) indicates that earlier simulation models expressed some of the running cost variables, such as tire wear and maintenance in terms of distance travelled only, ignoring the effects of the remainder of independent variables. In other words, the reliability of running cost estimates obtained from computer simulation is only as acceptable as the mathematical formulae used. Despite these shortcomings of simulation programs, the advantage is that their data can be easily updated at reasonable cost and may therefore offset inherent shortcomings.

3.3.3 Questionnaires and Statistics

This method of data collection is adopted when both the previous two methods are not feasible either due to their disadvantages, or because relevant techniques using these methods have not yet been developed. In such cases, this method would be the only source to use in running cost estimation. It may also be used as complementary information to data obtained using any of the other sources. This type of data is often collected from agencies with large vehicle fleets, managers and dealers of the automotive industry, government statistics and records, local authorities of highway departments and many others. Among the advantages of this data source is the continuously available, up-to-date information on running cost dependent variables for currently used vehicles running on routes under normal traffic conditions (not simulated).

Running cost estimates obtained using records encounter some problems. Aggregation of independent variables is an example. Usually, the effects on running cost items of only a few independent variables such as vehicle age in kilometers (miles) and years and vehicle type can be obtained. An example of running cost estimates using this data source was shown previously in Table 2.2. In addition, the accuracy of results obtained is usually low and results would be outdated within a short period of time unless updated as current records are produced.

Questionnaires and statistics are usually not an adequate source of data if running cost estimates are required for economic evaluation of road programs or services. On the other hand, it can be suitable and adequate for use by the public and possibly for model cost comparisons. In such cases, many researchers found it a suitable method for their purposes and used it to conduct their research and publish reports (3,9,19,20,21,23,30,31), while others used it to compliment other work (5,24,25) since it is a relatively easy method to employ.

3.3.4 Literature

Many of the currently available reports on running cost estimation of motor vehicles are completely or partially a collection of previously researched and reported data, with or without rearrangement (3,5,14,15,16,18,24,25,31). Clark (7) used data available in the literature to produce tables relating running cost variables to many of the independent variables used in economic studies for highway planning and design projects. His work included use of a simple computer program to generate running cost tables per unit distance, to reduce the required time of hand calculations. Dawson (12,13) used available information in literature to produce vehicle operating cost formulae in the laboratory. The reports include formulae given for the operating cost per kilometer for traffic characterizing an average composition of different classes of vehicles with and without fuel taxes (12,p.1).

Data obtained by this method is as accurate and up-to-date as the sources it is compiled from. The number of variables represented can be as many as the reporter wishes, which in return depends, to a certain extent, on the number of sources used. In addition, this data source suffers from the problem of discrepancy or variation among variable definitions used by authors of the studied literature. For example, not all authors adopted the same definition of running or operating cost; some use running cost as defined in this report, others add accident cost to it (road user cost). Depreciation due to running is often considered 50% of the total depreciation, yet some authors (19,20,22) consider passenger vehicle depreciation as 100% of total depreciation. Thus care must be excercised when compiling information on running cost from literature.

To summarize, care must be excercised in selecting the data collection source. The objective or purpose for conducting the study must be first identified, then the appropriate source(s) of data can be selected. In addition, the required resources (technology, personnel, finance and so on) for conducting the research work should be compared with the available ones to determine if the selected method of data collection is feasible. If not, the next best source or a combination of any number of the other sources considered suitable, can be selected. Records available from different government departments and private agencies could prove to be a good source of information for purposes of obtaining running cost estimates. The fact that they are up-to-date records on currently used vehicles can assist in producing up-to-date estimates of running costs.

3.4 LEVEL OF DATA AGGREGATION

As previously described, there are five dependent running cost variables and a large number of independent variables under five different categories, namely; roadway characteristics, traffic conditions, vehicle characteristics, enviornmental factors and the operator. The ideal method of disaggregating the data to make it fit each purpose is to give the relationship, where applicable, between each dependent variable and each of the independent variables. Figure 3.1 shows how this disaggregation can be applied to the fuel consumption variable. Obviously, this would require an inordinate amount of research effort, regardless of the method of data collection. Consequently, none of the available reports includes all the possible relationships that exist among dependent and independent variables in the manner mentioned above, nor can one expect them to. Among the most comprehensive reports available today are those by Claffey (5), Pelensky (24) and Winfery (31) for developed countries, and Abaynayaka et al (2) for developing countries.

One method used to reduce the disaggregtion problem is to show the effect of each independent variable on the total running cost value. In Figure 3.1 this would mean replacing fuel consumption by total running cost. Another method is to eliminate some of the independent variables. Applying this procedure to the road characteristic variable in Figure 3.1 would, for example, mean equating some of the independent variables to zero (grade, curvature) and assuming the absence of some (entry-exit points, intersection at grade) and incorporating only two variables, road surface and lane number and width. Consequently, road

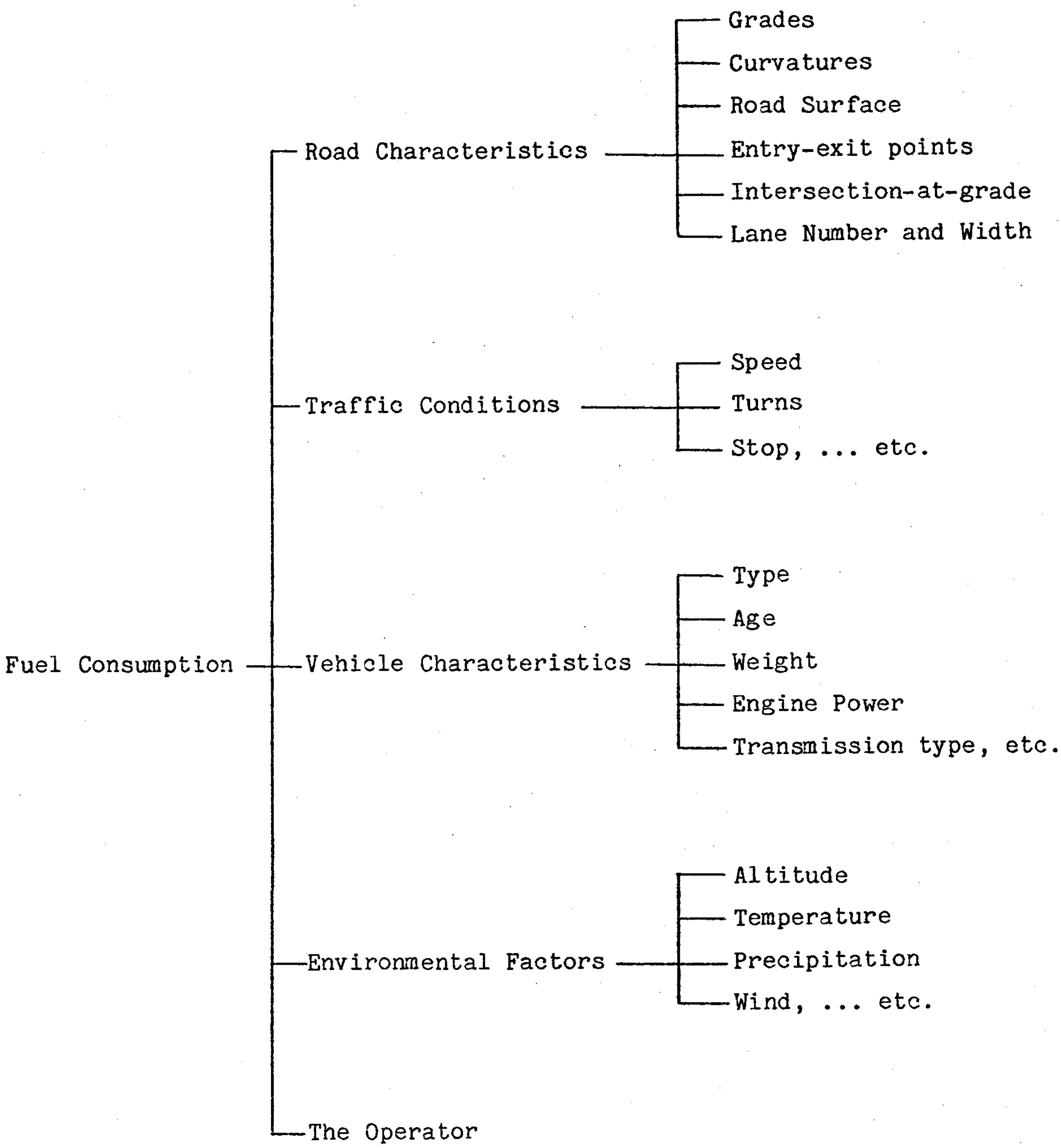

Figure 3.1 The Diagramatic Relation between the Dependent Variable of Fuel Consumption and the Independent Variables, Most Disaggregated Approach.

characteristics would be expressed as flat, straight, x-lane concrete road. The same system would be applied to other independent variables. For environmental factors, running cost is usually given for summer temperature around 30°C (86°F) with calm wind conditions and no precipitation; all the other variables would be eliminated. A third method is to ignore some of the variables that have been found to have insignificant effect on running cost estimates such as altitude, or variables whose effect is difficult to measure such as the operator. A fourth approach used by researchers is that of using the average condition for the independent variables. In the case of vehicle characteristics, instead of using different vehicle types with several engine powers and different ages and weights, one vehicle with a weight, age, size and engine power representative of the average of all vehicles running on the road under consideration would be chosen. Figure 3.2 shows an example of this approach where average representative values are used for the independent variables in each category. This could be referred to as the least disaggregated approach.

To summarize, the importance of disaggregation depends on the purpose of the study. If the purpose is to assess highway improvements, disaggregated data with respect to roadway and traffic characteristics would be essential. If the data is to be used in estimating the limit of expenditure on snow removal service, then the effects of precipitation on running cost must be given in a very disaggregated form. On the other hand, if the purpose is using the data in planning models or for cost comparisons among modes, then data can be less disaggregated, in which case the fourth approach should be sufficient.

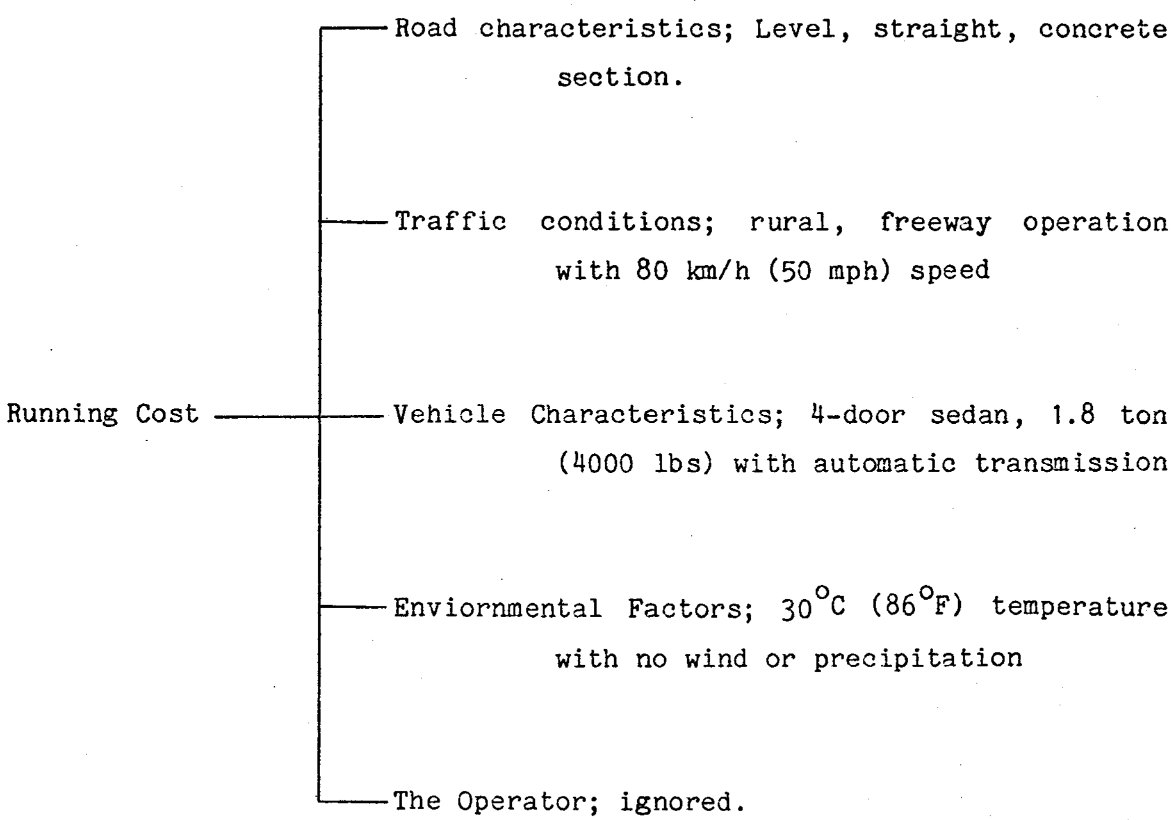

Figure 3.2 The Diagramatic Relation between Running Cost and the Independent Variables, Least Disaggregated Approach.

3.5 IMPACT OF TIME-DEPENDENCE

One of the major problems encountered in estimating running cost, particularly for economic evaluation of road projects, is to find data relevant to the time period under consideration. Running cost estimates are often outdated either because of the unit prices on which running cost estimates are based, or vehicle characteristics for which data was obtained, have significantly changed. In addition, there is no method by which running cost estimates can be automatically updated and there will always be some work involved in the updating process.

If running costs are given in monetary values without detailed information on unit prices which would allow adjusting them to represent price changes, then all results would have to be reproduced periodically or whenever changes in costs seem to warrant. On the other hand, if running costs are given in quantitative terms, the change of prices would not affect the running cost estimates. However, for either monetary or quantitative estimates, a change in vehicle characteristics from those used for the original estimates would also require an updating procedure.

As to the ease or difficulty of updating this information, the process depends principally on the data source and its comprehensiveness. Running cost estimates obtained from questionnaires, government statistics or literature can only be as current as the original information. Updating it would mean reproducing the report using additional sources. Running cost information obtained from computer simulation can be updated in a relatively simple manner. For example, if unit prices or vehicle characteristics are changed, a simple procedure of replacing the pertinent cards with new ones that include the updated information would be the only task required. If the running cost estimates have been obtained through field measurements using actual test runs, then one of two cases can occur; 1) either the data is so comprehensive that it covers a wide range of vehicle characteristics which allows adjustment of the information to accommodate any change in vehicle characteristics, or 2) it is limited and the work is to be redone in case of change in vehicle characteristics.

An ideal situation would occur if a continuously current and reliable source of information on running cost dependent variables for a specific set of independent variables was available. This can be represented by specific vehicles covering (patrolling) specific routes for the life of the vehicles, an example of which would be vehicles used by some departments of local government ministries. In this case, data on the independent variables remains constant over finite time periods except for road surface condition and vehicle age. The work required to obtain updated information on running cost would involve application of the previously estimated (unchanged) values of independent variables, the newly estimated (changed) independent variable, and the current running cost variables.

3.6 METHODS AND TECHNIQUES

Methods refer to the manner of, or steps involved in, data collection and estimates of running costs. Techniques refer to the mathematical models or formulae, used in obtaining running cost estimates. The application methods varied among reports depending, to some extent, on the source of data selected, and generally, the technique is dependent upon the selected method.

3.6.1 Field Measurements

In terms of accuracy, actual field measurements of the effects on dependent variables produced by changes in the independent variables is the most accurate method. In practice, this can be prohibitively expensive, particularly with respect to such variables as depreciation and maintenance that require extensive testing. The steps involved in this method are:

(a) The test vehicle is selected. It can be a single vehicle that represents the average of all operating vehicles of its class on the road. For example, Claffey (5) used a 2-ton (4,400lb) four-door sedan to represent passenger vehicles in the United States for 1970. On the other hand, several vehicles of the same class but with different characteristics can be chosen for measuring running costs. Whichever vehicle(s) is selected it has to be equipped with the appropriate devices to measure the variables under consideration.

(b) Certain variables such as grades, curvatures and road surface roughness must be obtained either from available documents or by measurement. If measurements are necessary, the measuring devices and accuracy applied must be compatible with the technology and environmental conditions that prevail at the time and place of measurements.

(c) The devices attached to the test vehicle to measure running cost variables are then selected. Devices such as a fuelmeter to measure gasoline consumption, speedometer to record speed and others to measure distances, grades and curvature are among the devices required. These devices should be calibrated frequently to assure their proper functioning.

(d) Selection of test run routes is another task. The lengths, geometric features and road surface type and condition must be specified. Generally, straight flat sections of very good surface type and condition are chosen for measurement of running cost variables and any changes over the base conditions are measured and recorded separately. For example, excess fuel consumption for positive grades over that of a flat road section is given for different grades and so on.

(e) Traffic conditions under which test runs are conducted must also be specified. The same method applied to road characteristics can be utilized, i.e. free-flow conditions with specified speeds are selected and the effect of other traffic conditions such as stops or slowdowns on running costs are recorded separately for representation of urban conditions (5). Another alternative is to drive the test vehicle at specified average speeds and for different combinations of stops, slowdowns and turns, and running cost values recorded for these different combinations of traffic conditions to represent the effect of urban conditions (24).

(f) The last variable included is the environmental impact of temperature, wind, altitude and precipitation. Once more, conditions that affect running costs least are usually chosen to conduct the test runs. Temperatures around 30°C (86°F), little or no wind, with no precipitation and altitudes within 610 meters (2000 ft) above sea level are the commonly selected conditions. The effects of rain, snow, wind or altitude can be shown separately.

Some of the authors that used this method such as Claffey (5) recorded the results in tables or graphs. Others such as Pelensky (24) tried to apply the mathematical technique of regression analysis to relate results obtained from test runs on fuel consumption to different urban driving conditions. Some of the relationships obtained by Pelensky (24,p.70) are given next, as an example of the techniques associated with this method.

$$P_k = 28.5 + \underset{(0.02)}{0.065t} + \underset{(0.8)}{2.85h}, \quad R^2 = 0.96 \quad SE = 2.0$$

$$P_k = 26.3 + \underset{(0.01)}{0.070t} + \underset{(0.5)}{2.1h} + \underset{(0.5)}{3.3c} + \underset{(0.2)}{0.53A} + \underset{(0.1)}{3.9i}, \quad R^2 = 0.98 \quad SE=1.7\text{gal}/1000 \text{ mi.}$$

The figures in brackets are the standard errors of regression coefficients.

P_k = Petrol consumption in gal./1000 miles

t = Total travel time in seconds

h = Number of stops

c = Number of sharp corners, left turns

Z = Rate of rise and fall, in percent

i = Average grade (+ or -), in percent

As more independent variables are used in the second equation, lower values of standard errors of regression coefficents are obtained improving the accuracy of the relationship between fuel consumption and some of the traffic condition and road characteristics variables.

3.6.2 Simulation

The use of computer simulation was selected by some researchers (17,26) as an easily applied technique for determining the effect of relatively minor changes in road characteristics on running costs. The method as summarized in Section 3.3.2 involves simulation of the physical operation of a sample vehicle or vehicles to obtain running costs under varying conditions of the independent variables.

The method is as follows: first, mathematical expressions which describe motor vehicle operation are formulated (this is the task of the engineer). Second, predictive ability of the program is tested by comparing the performance of actual vehicles in the field to computer simulations with identical conditions of alignment, speed and vehicle characteristics. Third, provided the mathematical expressions are satisfactory, information on the independent variables and unit prices are fed into the computer with the mathematical expressions to obtain running costs.

Lang and Robbins (17) developed a simulation program that gives satisfactory results for fuel consumption and travel time. They could not obtain mathematical expressions that predict tire wear, oil consumption, maintenance or depreciation. The information required on the independent variables is easily obtained. For vehicle characteristics, information given in the manufacturer's manual is sufficient. Desired road characteristics and operating speeds must be specified. Examples of the mathematical models used to predict fuel consumption in simulation techniques are as follows (17, p.32-35).

Vehicle speed: $VE = VO + (AO)(DT)$

where: VO = speed at start of cycle

AO = average acceleration used in previous cycle, and

DT = specified time increment

Distance: $SN = SO + (VO)(DT) + 0.5(AO)(DT)^2$

where: SO = station at beginning of cycle, and

SN = station at end of cycle

Grade resistance: GR = (G)(W)

where: G = grade (in feet of rise per horizontal foot),

W = gross vehicle weight, and

GR = approximate grade resistance in pounds of tractive effort

This technique is adequate if all running cost variables can be predicted under different conditions for all independent variables. Since this is not currently possible, considerable research must be conducted to permit better utilization of available computer simulation programs.

3.6.3 Empirical Statistics

The empirical method implies the use of statistical data and personal experience to obtain information on running cost. Mathematical models or techniques can be associated with this method, but in general, data obtained using this method is often presented in the form of tables or graphs. Winfery (31) represents a good example of using this method. He derived reasonably comprehensive results using the empirical method, and presented it in a manner similar to that used by Claffey (5) in Table 3.4. Dawson (12,13) on the other hand, used available sources of information to derive, in the laboratory, equations that give running cost data for four different classes of vehicles. Table 3.5 (13, p.5) shows some of the results he obtained. The operating cost variables included in these estimates are fuel, tires, oil, maintenance, depreciation and vehicle occupant's time.

The accuracy of running cost estimates depends on the method and technique used. Field measurements are the most accurate provided that measurement devices are frequently calibrated. Computer simulation methods can produce results almost as accurate as those produced by field measurements, but not all running cost variables can be predicted, as yet, using this method. Empirical techniques are probably the least accurate, yet the easiest to apply. To conclude, accuracy is not always a prerequisite in running cost estimates. Applying the most accurate research method does not necessarily indicate sound decision making. For example, producing very accurate estimates for the exclusive use of individuals represents over-qualified data for the purpose at hand. Accurate estimates can be used for all purposes, but the reverse is not true; i.e. not all types of estimates are suitable for all purposes. Thus different estimates should by employed towards the appropriate purposes.

Table 3.5 Operating costs per Vehicle Kilometer and Per Vehicle Mile (pence)

Vehicle	Per Vehicle Kilometer	Per Vehicle Mile
Car	$1.13+100/v+0.000043v^2$	$1.83+100/V+0.000181V^2$
Light Van	$2.12+144/v+0.000054v^2$	$3.41+144/V+0.000227V^2$
Other good vehicle	$4.73+158/v+0.000101v^2$	$7.61+158/V+0.000416V^2$
Public Service Vehicle	$6.46+689/v+0.000101v^2$	$10.39+689/V+0.000419V^2$

v = Average vehicle speed in km/h

V = Average vehicle speed in mph

3.7 RESULTS

Results of running cost estimation can be evaluated using several criterion; efficiency of use, comprehensiveness, and storage space requirements. Three common forms of results are often used and include tables and graphs, equations, and computer programs. These forms of results are discussed in this section with respect to each of the three criteria mentioned above.

3.7.1 Tables and Graphs

Tables and graphs are the simplest form of presenting data that relates running cost variables to various vehicle, traffic, environmental, road and driver characteristics. They are easy to visually interpret and apply. Results in graph form are easy to comprehend since the relation between the represented variables can be recognized at a glance. Tables are slightly more difficult to comprehend but the magnitude of all items (cost or quantity) are readily available. Both tables and graphs can be used to obtain running cost estimates with little knowledge and understanding of vehicle operation. One of the basic problems with tables and graphs though, is the space requirement. In addition, since they are limited in dimensions, only two or three variables can be shown while a few others can be specified in any one table or graph. Table 3.4 is an example of tabulated results. It shows the magnitudes of three variables; speed, grade and fuel consumption. The specified variables are those given with the table, namely curves and pavement type (straight high-type), traffic conditions (free-flowing) and vehicle characteristics (composite vehicle represented). Furthermore, hand calculations using tables and graphs for some of the highway projects can become tedious, especially if the operating conditions vary widely.

3.7.2 Equations

Obviously, equations remove the problem of cumbersome storage and presentation. They can either replace tables and graphs to save storage space, or represent the results of a separate analytical technique such as regression analysis. Equations either give the total running cost in terms of some of the independent variables (12,13,14) or the value of each of the running cost variables in terms of some of the independent variables (2,3,19,24,25). On one hand, they are easy to use and require relatively little time to arrive at the results. On the other hand, they sacrifice accuracy in the interest of computational ease. This is a result of the limited number of independent variables that can be accommodated in any one equation with an acceptable level of statistical significance. In addition, calculations are obviously required to achieve results and if many variables are involved, manual calculation can be cumbersome. Thus equations are useful when simple input requirements and approximate running cost values are required as is the case in evaluation of running costs over a network of highways, or for use by individuals.

3.7.3 Computer Programs

Computer programs can be used in two different contexts; to replace hand calculations of running costs using tables and graphs or equations or to produce results on running costs through simulation techniques. In the first context, its usefulness is in simplifying the use of available data. Thus the comprehensiveness of this data type is as acceptable as that of the original data. In the second context, comprehensiveness and accuracy of results are limited by the mathematical relationships derived to relate running costs to the independent variables. The advantages of this form of results are that it does not require excessive space and that it is easily and quickly applied to obtain results.

Whether the results are in the form of tables, graphs, equations or computer programs, the choice should be made depending on the problem at hand. Equations can be used for simple problems while computer programs can be used for more complicated problems. Tables and graphs can be used at any time provided the calculation does not become tedious and time consuming.

3.8 SUMMARY

This chapter presented a detailed description of the various aspects of running cost estimation including variables involved, data sources, techniques and resulting presentations. The objective was to focus on the phases and problems involved in the process of running cost estimates which in turn should aid future researchers in identifying the limitations of approaches available to them.

Selection of the data source should be compatible with the purpose for which running cost estimates are obtained. Use of available sources such as records should be investigated before adopting any of the more lengthy and costly data collection methods such as field measurements. If a reliable data source exists that can provide running cost information on a continuously current basis, the work required in data collection would be greatly reduced.

The second most demanding phase in the process of obtaining running cost estimates is the updating process. Unless the data source contains reliable, compiled and current records of running costs, there will be a relatively large amount of work involved in updating the estimates. This would either be in the form of reproduction of estimates using the latest information, or the dependent or independent variables. The remaining phases of the process, namely; selection of independent variables, methods and techniques of analysis and form of results, are relatively straight forward.

4. INVESTIGATION OF DATA SOURCES

Discussions in the previous chapter indicated that none of the three basic approaches used by researchers in collecting data on running costs have been proven ideal. Each approach suffers from one or more deficiencies and tend to lead to inadequate data for application. For example, obtaining running cost data from direct field measurements places considerable emphasis on resource availability and when the appropriate resources of technology, personnel and finance are not available, full scale field research is not feasible. Furthermore, computer simulation techniques are not yet capable of producing all the information required for establishing comprehensive running cost estimates. This is due to difficulty encountered in developing mathematical expressions that correlate running cost items to some of the independent variables, and consequently, difficulty in predicting the magnitude of such runnning cost items. The third approach of using data available from literature suffers from, among other deficiences, the important problem time-dependence. Running cost information obtained in this manner is by definiton always out-of-date by at least a time-period equal to that of conducting the study. In most cases a much longer time-period is involved depending on the age of the data sources used and time durations for publication.

A fourth approach is possible and relies on use of records and statistics on empirically derived running costs as compiled by many public and private organizations including various government departments and ministries, car-rental agencies, and trucking and transport companies. Running cost estimates obtained using this empirical data vary in level of aggregation and accuracy depending on the level of aggregation of the records used. In general such estimates have exhibited a high degree of aggregation with respect to geographic area covered and variables represented. Some of the running cost estimates, such as those produced by the New Zealand government, represent average vehicles in New Zealand which would cover a wide variation in geographic characteristics. In other cases, the geographic area represented was that of large cities such as Baltimore.

Based on the above evaluation, it was decided to adopt the fourth approach and to investigate a data source consisting of current records on running costs available at the Ontario Ministry of Transportation and Communications (MTC). Three main advantages in using these records to obtain running cost estimates were recognized. First, records on running cost items are given for specific routes travelled by Ministry patrol vehicles. Second, these same routes are regularly maintained and reconstructed by MTC and an estimate of running costs would substantially assist in any economic evaluation of future maintenance, improvement or reconstruction programs regarding these routes. Finally, running cost data is aggregated by district, which is a relatively small geographical area, and would therefore result in a more representative and accurate estimation.

A detailed description of the aspects involved in this investigation is presented in this chapter. A description of how the work was initiated within the Ministry and the objective of this study is given in the first section. In the second section, the type of data available on the dependent and independent variables is discussed along with data limitations. The new data collection method adopted for data analysis is described in the third section. Included in the fourth section is a brief investigation of additional data sources thought useful for future research work. Finally, the results of the analysis are reported and comments and conclusions stemming from the investigation are included.

4.1 SUMMARY OF PILOT STUDY

The Ministry maintains complete records of gasoline consumption (quantity and cost), engine oil consumption (quantity and cost) and maintenance (parts and labour costs) for all its maintenance and operational vehicles. Many of these vehicles patrol specific routes during their service life. These routes are mostly rural roads or secondary highways (one or two lanes in each direction) with traffic volumes usually much below capacity. This fact essentially eliminates the effect of traffic conditions on running cost estimation. The only traffic condition on which there is no specific information available is operating speeds of patrol vehicles. The nature of the service these patrol vehicles provides requires them to stop several times during work hours, which results in a different average speed from the expected posted speeds for such roads. In addition, the effects of weather conditions on running cost variables are held uniform by using only records for the summer period of July through September.

The remaining independent variables to be applied against running cost items are road characteristics and the operator. Road geometric characteristics are obtained from survey plans available at the Ministry. Individual patrol vehicles are identified using a numbering system which allows precise identification of each vehicle. Most information relevant to running cost studies can be obtained from the manufacturer's manual. Regarding the operator, investigations conducted on the effects that various operators have on running cost variables are inconclusive. Thus the possible variable effect of having different drivers for patrol vehicles was assumed insignificant.

In view of the magnitude and detail of available running cost information, the Ministry initiated an investigation of its potential use and a pilot study was organized in 1975 in an effort to establish preliminary relationships between road geometric characteristics and surface roughness, and each of the three running cost items for which data was available.

The pilot study involved selection of a small sample of patrol links (sample size = 24) which Ministry vehicles travelled during their service life in two districts in Ontario; District 1 and District 10. District 1 is Chatham and is located in southwest Ontario and exhibits a relatively flat topograpy. District 10 is Bancroft and is located in central Ontario but exhibits a rather 'mountainous' topography. Data on the geometric characteristics (grades and curvatures) was collected from available survey plans. Grades were expressed in feet per mile of rise plus fall and curvatures were expressed in average degrees per mile. In addition, road surface roughness was measured using the MTC method for condition rating of road surfaces for each of the 24 patrol links under consideration. Road surface roughness was recorded in the form of a dimensionless index called Road Condition Rating (RCR) which varied from zero for very poor condition to 100 for excellent condition of road surface. The weather conditions were not explicity incorporated since running cost data were collected for the summer months. Data on the three dependent variables was also available. Gasoline consumption was available in total quantity (gallons) and cost (dollars) for the three-month period and was expressed in the analysis in miles per gallon (MPG). Oil consumption was available in total quantity (quarts) and cost (dollars) for the same period and was expressed in quarts per thousand miles. Finally, the maintenance data was expressed in labour hours per thousand miles.

Having identified the variables to be included in the analysis, the method of analysis was to be determined. First, a plot of the data points for each of the three running cost variables (gasoline, oil, maintenance labour) versus each of the three road characteristics (grade, curvature, RCR) was established. A regression analysis was then conducted on the data in an attempt to identify and obtain possible relationships between each of the running cost variables and each of the road characteristic variables. Due to the wide scatter of some points, only seventeen out of the twenty-four patrol links were selected for the regression analysis. Even then only seven out of the expected nine relationships were accepted; the other two were rejected on the basis of visual observation. These seven relationships are still somewhat unsatisfactory. Several reasons were responsible for the unsatisfactory results and are thought to be mainly related to the available data on the independent variables. Among these reasons are the possiblity of inaccuracy in road geometric data and the small sample size used in the regression analysis.

4.2 SCOPE AND OBJECTIVE

As mentioned before, results of the pilot study were generally inconclusive. Investigation of the accuracy of road geometric data and reliability of MTC records on running costs was deemed necessary. A second study was recommended and work started during 1977. The objective of this study was to initially continue and extend investigation of the potential of MTC records on running costs and to give recommendations regarding future research efforts. The reasons for conducting this second investigation are:

(a) The possibility of improving the collected data on geometric characteristics of patrol links. The method of calculating grades and curvatures was not clearly identified in the pilot study. For example, curvature was expressed in average degrees per mile and it was not explicitly given whether this value meant the degree of curve (D) or the external deflection angle (Δ). Similarly, grade was expressed in rise and fall in feet per mile, but whether this represented a simple algebraic sum of the rise and fall is not known.

(b) Collecting more information on geometric characteristics that would allow expressing grades and curvatures in different terms could possibly allow a better representation of these characteristics. For instance, if the slope and distance are recorded, the grade can be calculated in slope (percent), slope (ft/mile), total rise (ft/mile) with respect to the total length of the road section and so on. Similarly, if D or Δ and length of curves are recorded, several methods can be used to express curvature such as deg./mile using D or using and curvature in $deg.^2/mile$ using D^2 or using Δ^2 (a sample of the type of data collected is given in Table B.2.). Plotting the various forms representing geometric characteristic versus running cost variables might result in more meaningful relationships than those obtained using only the one particular form of grades and curvatures used in the pilot study.

(c) Possible disaggregation of running cost data by the highway rather than by the patrol link as used in the pilot study and shown on the computer printouts, which would increase the sample size by three or four fold (the average number of highways in each patrol link). This increase in sample size would undoubtedly improve the accuracy of estimation results.

4.3 DATA AVAILABILITY AND LIMITATIONS

The data available for this study can be divided into two groups. The first group represents records on the running cost variables which are maintained on computer printouts at MTC. The second group represents the data describing the independent variables which include road geometric characteristics, road surface condition and operating speed.

Data describing the dependent variables are accumulated on a quarterly basis and complete records of cumulative magnitudes during the fiscal year are availabe at the Ministry. An example of such records is given in Table B.1 which shows gasoline consumption, oil consumption, and maintenance for patrol vehicles under consideration in Districts 1 and 10. It should be noted that only some of the data recorded in the tables is used in this investigation. As shown, gasoline consumption data given in columns 5 and 6 is recorded in quantity (gallons) and cost (dollars). Engine (motor) oil consumption given in columns 9 and 10 is recorded in quantity (quarts) and cost (dollars). Maintenance given in columns 14 and 15 is recorded in cost (dollars) of parts and labour. In addition, accumulated mileage (miles) for these consumptions is recorded in column 13 for the time period indicated at the top of the table. It is interesting to note that, even though data was collected on a quarterly basis, records are maintained only in a cumulative manner. In other words, data for the second, third and fourth quarters of the year are added to the previous quarter(s) data and recorded in the manner shown for the first quarter of the year, (April through June). For instance, if the time period is shown as "2nd quarter - September 1975", it would mean that magnitudes given are for the first two quarters combined (April through September). In addition, all magnitudes are given for patrol vehicles, which means that running cost variables are aggregated by patrol links.

As mentioned previously, the independent variables considered relevant to this study were road characteristics, vehicle characteristics, traffic conditions and weather conditions and data describing these variables are given below.

i) Road Characteristics

The road characteristics included were the grade, curvature and surface roughness. To obtain information on grades and curvature, survey plans for the patrol links under consideration were identified. The information collected on grades and curvatures was sufficient to permit expressing the values in any form desired at the analysis stage. For instance, grade can be expressed in average slope (ft/mile), average slope (percent), average rise (ft/mile) and so on. The problems involved in data collection of geometric characteristics were those of missing or out-of-date plans for portions of the patrol links under consideration. This resulted in incomplete or nonrepresentative road geometric information on those patrol links, and, in turn, produced inaccurate values. This deficiency in road geometric information is a limitation of this method of trying to relate available data on running cost to road characteristics data that is yet to be collected.

Road surface roughness is expressed in RCR values, as mentioned earlier in this chapter. For the purpose of this study no further work was conducted regarding this variable over that completed for the pilot study.

ii) Vehicle Characteristics

Patrol vehicles were identified, on the computer printouts, by year of make, vehicle identification number, serial number, and mileage (columns 1 to 3 and column 13 respectively in Table B.1). More information on vehicle characteristics can be obtained, if so desired, from the manufacturer's manual since they can be identified from information given on the computer printouts. All the patrol vehicles were either a 1/2-ton or 3/4-ton pick-up truck. Consequently, the effect of variation in vehicle characteristics on running cost estimates was assumed insignificant and in turn omitted from the analysis. In addition, the effect of potential variability in vehicle age in years and mileage and in engine size among patrol vehicles was not taken into consideration. Including all vehicle characteristics in the analysis would mean too many variables to evaluate and would result in a further reduction of the sample size.

iii) Traffic Conditions

Traffic conditions were treated in a similar manner to that of vehicle characteristcs. The patrol links under consideration represent mostly rural driving conditions in terms of facility type, typical operating speeds and traffic volumes. In other words, facility type includes two-lane and multi-lane highways with operating speed of 80 km/h (50 mph) and low to medium traffic volumes. Clearly, minor variations in these variables would have little effect on running cost estimation. In addition, it is significant to know that patrol vehicles make many stops during their trips which involves not only slowdowns and stops but also idling of the engine. Unfortunately, there is no available information on the frequency, number or duration of these stops. This limitation could likely have a measurable effect on running cost variables.

iv) Weather Conditions

The final independent variable in this study was weather conditions. As indicated before, running cost data for only the summer period was selected to eliminate the impact of weather variations on vehicle running cost estimation. The only variations in the independent variables of summer weather conditions are possible changes in temperature within the range of minimum to maximum daytime temperatures and presence or absence of precipitation and wind. The effects of these variations on running costs should be very small especially recognizing that some of these effects such as wind would negate each other. This is true since the effect on running cost of the wind when blowing in one direction is equal and opposite to that when the wind is blowing in the opposite direction at the same speed and time period. So it was therefore assumed that it is unlikely that weather conditions would have an appreciable effect on the accuracy of running cost estimation.

4.4 NEW DATA COLLECTION

As mentioned previously, several factors may have contributed to the unsatisfactory results of running cost estimates using the data of running cost and independent variables analyzed in the pilot study. The principal reason could be the inadequacy of running cost data, independent variables data, or both. To determine which of the variable(s) is responsible for this two new data sets were collected. The first represented geometric characteristic data on an approximately 50% sample of the 24 patrol links used in the pilot study, that is thirteen patrol links. The limited number of patrol links used was due to the time and financial limitations imposed on this research project. A plan showing the thirteen patrol links is given in Figures B.1 and B.2. The selection of the patrol links was based on three objectives. First, that they form a representative sample of the original 24 patrol links used in the pilot study. This meant choice of some of the patrol links included as well as those excluded from regression analysis. This selection method would allow comparison of the results on running cost variables versus road characteristics between the pilot study and this study. This in turn will help determine the cause of the inconclusive results obtained in the first report. Second, to identify and select the patrol links for which plans were expected to be available based on the information given on Ministry strip plans for those patrol links. While the first objective was fulfilled, efforts to satisfy the second objective have somewhat failed. This was the case for many of the road portions reconstructed during the past two or three years and accordingly up-to-date plans were available but only in the draft forms. The third was to find out if care in collecting geometric characteristics would produce more accurate or significantly different geometric characteristics data.

The second represented seven test run sections, to measure gasoline consumption on different patrol links among thirteen selected patrol links. The selected test run sections incorporated the following features and characteristics:

i) Test run sections were selected as representation of the thirteen patrol links involved in this study. First, geometric characteristic data for these sections would be collected as part of the work done on the selected thirteen patrol links. Second, the same geometric characteristic data was used for both the test run sections and selected patrol link analysis. Thus any discrepancy in the results of selected patrol links and test runs would not be due to inaccuracy in geometric characteristics, but rather to inaccuracy in running cost variables.

ii) It was agreed that speed at which test runs were to be conducted should be that of the operating (posted) speed of the road which presumably was also the speed at which the patrol vehicles were driven. The speed was kept constant during fuel measurements unless the geometric characteristics and/or surface condition of the road were restrictive. This procedure would eliminate the effect of speed variations on fuel consumption. Any inconsistency in the results obtained using the selected patrol link data or the test run sections data would unlikely be due to difference in operating speeds but rather due to stops and slowdowns occuring during patrol vehicle coverage of the routes.

iii) Test vehicles were similar to patrol vehicles in weight and engine size which eliminated any discrepancy in results due to vehicle type.

iv) The test runs were conducted during the summer months to be consistent with fuel consumption data used in this study on patrol links and to eliminate variability in weather effects on fuel consumption magnitudes.

v) Seven test run sections were selected and varied in length from 3.2-8 km (2 - 5 miles). Those sections have different average grade value (ft/mile) and direction. The geometric characteristics of the seven test run sections are given in Table B.3. The number of runs conducted for each test run section varied from two to six, depending on the number of runs required before gasoline consumption measurements stabilized.

Fuel consumption readings were recorded every 150 meters (500 ft.) and at the 1.6 km mark (mile) throughout each test run section. In addition, fuel measurements were to be recorded in both directions to double the sample size from seven to fourteen points and cover a wider range of grade values (zero to 30 m/km (100ft/mile) for each of the positive and negative grades). Table B.4 shows a sample of gasoline consumption data collected in this study.

The previously mentioned features insure that the same independent variables apply to fuel consumption of both test runs and new patrol links. However, several important points should be remembered. The number and length of slowdowns and stops involved in driving patrol vehicles were not known and therefore not included in the analysis. Another factor is whether the patrol vehicles cover patrol links in a homogeneous manner (cover all portions of patrol links equally). In addition, a third factor is whether the inadequate geometric information on a few patrol links due to missing or out-of-date plans would have an appreciable effect on the average geometric characteristic data used in the analysis.

In general, the previously established features and procedure regarding gasoline consumption test run were adopted. However, several factors were entered in the analysis and included the following:

i) All test runs were carried out at the posted speed of 80 km/h (50 mph) except for test run number 4 where speed was 50 km/h (30 mph) for a considerable part of the test run section. This variation in speed introduced an additional variable that affects gasoline consumption for this particular section.

ii) Gasoline consumption measurements were to be conducted during the summer to minimize the weather effects. Due to lack of man power, test runs were conducted in late October which resulted in a variation in temperature between the test sections data and patrol link data for the summer quarter. For example, one test run (number 7) was carried out at a temperature of $21^{o}C$ ($70^{o}F$). The remainder of the test runs were carried out at a range of temperatures from $6^{o}C$ ($43^{o}F$) to $19^{o}C$ ($67^{o}F$).

iii) Test run section number 3 was not the one originally selected. This deviation resulted in an average grade value very close to that of test run section number 1, and consequently a cluster of data points near the centre of the plotted graphs resulted.

It is possible that these three variations could result in less accurate gasoline consumption - grade relationships for the test run data.

4.5 INVESTIGATION OF OTHER DATA SOURCES

Upon this comprehensive review of what is involved in this data type, a search for other available data sources similar to this one but more reliable was recommended. Suggested sources were automobile industry, gasoline and tire companies that are likely to conduct some research on running cost items for their own purposes and are willing to give it out. The procedure followed in searching for these sources included an initial phone call to some of the candidate sources, namely Shell Canada Limited, Gulf Oil of Canada, Ford Company and General Motor Company to investigate the availability of the required data. As a result of this initial step Gulf Oil of Canada and Ford Motor Company were eliminated because they did not have any relevant data available. Shell Canada Limited gave a favourable answer and thus was contacted by a letter, but later a negative reply was received with a recommendation to contact the Federal Energy Administration for information on fuel consumption. This recommendation was carried through but no information was received. Authorities at General Motors indicated that they have a lot of information on running cost but that much of it is for the company's own use and not to be given out to other researchers. A promise of sending allowable material was given, none of which has been received to date, inspite of a phone call, to the person in charge, during the month of December, inquiring about the delay.

4.6 ANALYSIS

Three sets of data were available for analysis and comparison. The first set was data on the (old) 24 patrol links used in the pilot study. Geometric characteristics information on these 24 patrol links was of a limited nature (both grades and curvaures were expressed in one form only) as will be discussed in Section 4.7. The gasoline consumption information for these 24 patrol links was obtained from MTC's records on running costs. The second set was data on the (new) selected thirteen patrol links. New geometric characteristics data collected for these thirteen patrol links permits expressing grades and curvatures in many forms. Gasoline consumption information was obtained from the same source as that of the (old) 24 patrol links; that is MTC's records. The third set was that of the seven test run sections. Geometric characteristics information was collected as part of the information collected on selected thirteen partol links. The gasoline consumption was measured using several test runs.

With respect to test run sections, fuel consumption measurements were compiled using a computer program developed specifically for this project and written by Mr. E. Schroeder. The values obtained from the computer program were for the gasoline consumption per 150 m (500 ft.), per 1.6 km (mile) and per test run section, in each direction separately then the average for both directions. In addition, a plot of road profile and gasoline consumption in each direction for 150 m. (500 ft.) distances was produced on the same plot so that the reader can observe the change in gasoline consumption as grade changes. Computer printouts for the seven test run sections are given in Figures B.3 through B.9. In these figures, the central plot of points (+ sign) represents the profile of the test run section while the upper and lower plots (- and * signs) represent the accumulated gasoline consumption, each in one direction of the test run sections. The lower plot of gasoline consumption should be read from left to right while the upper plot should be read from right to left. The horizontal axis (x-axis) represents the distance from the beginning of the test run section (ft). The vertical axis (y-axis) represents two magnitudes; the first is the evevation (ft), the second is the gasoline consumption (ml). To have all profiles and gasoline consumption magnitudes fit within one plot some mathematical manipulations were necessary. Magnitudes used in the lower plot of gasoline consumption was divided by ten. Magnitudes used in the upper plot of gasoline consumption were divided by ten then a constant of 30 was added to them. Elevation magnitudes were reduced by either 900 (test run section 1, 2, 3, 4, and 7) or by 1200 (test runs 5 and 6) depending on their elevation.

The geometric characteristics of the test run sections (grade and curvature) were also compiled using a computer program (E. Schroeder prepared the basic program). Thirteen magnitudes on grades and four on curvatures were calculated and printed out for each test run section. A summary of these magnitudes on grades and curvatures are given in Tables 4.1 and 4.2, respectively.

With respect to the thirteen patrol links, new data on grades and curvatures was collected and compiled using the same computer program used for the test run data. A summary of grade and curvature data for the thirteen patrol links is given in Tables 4.3 and 4.4 respectively in

TABLE 4.1 DATA OBTAINED FROM COMPUTER PROGRAM ON GRADES FOR TEST RUN SECTIONS

Geometric Characteristic	Test Run Number						
	1	2	3	4	5	6	7
1. Total Fall (ft.)	-300.9	-116.9	-172.7	-351.1	-253.2	-175.1	-348.8
2. Fall Length (ft.)	11615.0	5600.0	7160.0	11330.0	8100.0	4860.0	13950.
3. Total Rise (ft.)	315.5	270.3	185.5	251.9	48.3	8100.0	13950.
4. Rise Length (ft.)	12085.0	10340.	6600.0	9540.0	2160.0	6300.0	2450.0
5. Flat Length (ft.)	2700.0	400.0	800.0	1250.0	300.0	400.0	1440.0
6. Total Length (ft.)	26400.0	16340.	14560.	22120.	10560.	11560.	17840.
7. Fall Rate (Fall/Fall Length) (ft./mile)	-136.8	-110.2	-127.4	-163.6	-165.1	-190.2	-132.0
8. Fall Rate (%)	-2.59	-2.09	-2.41	-3.1	-3.13	-3.60	-2.50
9. Rise Rate (Rise/Rise Length) (ft./mile)	137.8	138.0	148.4	139.4	118.1	127.6	138.14
10. Rise Rate (%)	2.61	2.61	2.81	2.64	2.24	2.42	2.62
11. (|Fall|+|Rise|)/T. Length (ft./mile)	123.29	125.1	129.9	143.9	150.7	149.5	122.19
12. (|Fall|+|Rise|)/T. Length (%)	2.34	2.37	2.56	2.73	2.86	2.83	2.31
13. (Fall2+Rise2)/T. Length (ft^2/mile)	5.34	4.63	4.94	9.38	5.58	9.16	6.18

TABLE 4.2 DATA OBTAINED FROM COMPUTER PROGRAM ON CURVATURES FOR TEST RUN SECTIONS

Curvature Variable	Test Run Number						
	1	2	3	4	5	6	7
1. ΣD/T. Length	16.1	7.75	2.54	21.01	1.567	11.88	1.924
2. ΣΔ/T. Lengthh (0/mile)	76.13	46.98	22.25	101.38	15.22	114.52	20.16
3. $\Sigma(D^2 x L_c)$/T. Length (Deg.^{2}ft/mile)	66603	18859	7812.7	57999	2721.6	61203.0	3758.0
4. $\Sigma(L_c^2 x D)$/T. Length (Deg.ft^2/mile)	4953800	4038400	1979500	10023000	1587000	12784000	2497200

TABLE 4.3 DATA OBTAINED FROM COMPUTER ON GRADES FOR PATROL LINKS

Geometric Characteristic	Patrol Link Number												
	2	5	8	11	17	102	103	104	110	112	114	115	116
1. Total Fall (ft)	-1373.6	-2396.8	-1884.2	-2215.2	-1754.9	-154.3	-217.4	-511.4	-240.1	-304.1	-627.3	-611.1	-323.5
2. Fall Length (ft)	51450.0	94187.8	56140.0	91521.2	105001	45860.7	44785.3	92708.3	68229.7	66507.9	95306.6	97768.3	74000
3. Total Rise (ft)	895.9	2565.0	2316.5	2105.7	3123.4	180.6	216.9	608.4	216.86	288.7	545.12	564.2	269.1
4. Rise Length (ft)	46930.5	112036.7	62100.5	96659.9	119616.6	42134.2	31580.0	82179.6	56203.5	64678.3	81888.5	66968.2	57810.2
5. Flat Length (ft)	9437.2	34370.9	9086.4	21140.0	15984.3	128578.7	68080.6	54700	136709.7	77917.2	36319.4	39763.6	48718.6
6. Total Length (ft)	107817.8	240595.4	127326.9	209321	240602	216573.6	144446	229587.8	261142.9	209103.4	212887.4	204500.0	180259.9
7. Fall Rate (Fall/Fall Length (ft/mile)	-323.9	-48.7	-346.7	-263.3	-551.5	-52.3	-104.6	-94.36	-55.5	-72.5	-185.7	-118.3	-122.7
8. Fall Rate %	-6.14	-7.93	-6.57	-4.99	-10.45	-0.99	-1.98	-1.79	-1.05	-1.37	-3.52	-2.24	-2.324
9. Rise Rate (Rise/Rise Length (ft/mile)	181.1	388.3	373.1	220.76	555.9	72.4	131.0	116.16	63.45	77.9	174.7	123.76	92.7
10. Rise Rate %	3.43	7.36	7.06	4.18	10.53	1.37	2.48	2.2	1.20	1.48	3.31	2.35	1.712
11. (|Fall|+|Rise|)/ T. Length (ft/mile)	249.3	372.76	3.35.2	218.2	522.7	23.7	73.4	83.28	28.04	47.86	158.4	103.3	72.24
12. (|Fall|+|Rise|)/ T. Length %	4.72	7.06	6.35	4.13	9.91	0.45	1.34	1.54	0.53	0.88	3.0	1.96	1.368
13. (Fall2+Rise2)*/T. Length (ft/mile)	9.99	18.85	18.79	9.15	25.11	0.34	1.09	1.00	0.273	0.45	2.02	1.69	0.972

* Fall2 = $(\text{Slope})^2$ x horizontal distance

TABLE 4.4 DATA OBTAINED FROM COMPUTER PROGRAM ON CURVATURES FOR SELECTED PATROL LINKS

Patrol Link	Highway	ΣD/T. Length (Deg./mile)	$\Sigma \Delta$/T. Length (Deg./mile)	$\Sigma(L_c x D^2)$/T. Length (ft. Deg.^{2}/mile)	$\Sigma(L_c^2 x D)$/T. Length (ft^2 Deg./mile)
2	41	5.58	61.89	23,958	8,226,100
	500	1.23	12.24	2,435	1,250,700
5	62	26.22	78.44	74,239	3,759,600
	512	122.82	284.95	432,110	5,038,300
8	60	4.14	25.39	8,544	2,107,500
	523	64.83	146.44	298,470	4,632,000
11	62	4.64	33.53	12,062	3,637,300
	127	10.59	76.31	33,302	43,394
17	507	21.01	101.38	57,999	10,023,000
	503	7.39	55.89	22,471	6,549,700
	121	31.32	51.32	108,890	46,666,000
	519	27.04	88.67	91,691	4,272,600
102	2	3.85	11.64	13,917	3,109,750
	77	2.14	8.32	8,667	567,000
103	18	15.35	67.97	29,788	6,628,900
	3	1.95	3.39	2,695	64,031
	401	0.99	22.01	3,853	5,085,900
104	18	66.99	85.14	466,570	1,715,070
	18A	2.66	26.69	7,589	74,247,000
110	78	5.28	16.89	8,119	1,421,500
	21	3.61	20.05	14,419	1,228,500
	40	6.26	35.52	14,822	2,866,400
112	21	1.77	17.37	10,447	1,987,000
	40	6.71	37.51	11,062	2,914,800
	80	1.35	10.43	5,351	994,240
114	22	0.0	0.0	0	0
	7	3.93	21.09	9,802	1,468,100
	21&7	0	0	0	0
	21	0	0	0	0
	79	0.98	10.31	3,033	1,223,700
115	82	9.87	61.16	62,187	6,650,300
	7	0.49	2.00	906	82,242
	21	3.48	17.68	9,081	1,806,800
116	40	1.64	13.52	6,998	1,147,600
	21	1.85	8.11	2,99	411,080
	7	0.0	0.0	0	0
	402	1.05	17.31	3,701	3,306,500

the same order they appear at in the printouts. In addition, the profile of all highways was plotted for possible uses that may arise at the analysis stage. A sample of computer printouts on geometric characteristics as well as on profile plots for patrol links is given in Figure B.10. The horizontal axis represents horizontal distance on highway and numbers shown are those taken from survey plans. The vertical axis represent the altitude of highway as indicated on survey plans (elevation above sea level). The first four pages in Figure B.10 represent highway number 60 in patrol link number 8 and District 10 (as indicated on top of first page of printouts). The following four pages are for highway number 523 in patrol link number 8 and District 10. The scale for both axes is shown on top of each page of printouts. The information on grades and curvatures are given on the last page of each highway's printouts.

Gasoline consumption, oil consumption and maintenance data for the thirteen patrol links under consideration was obtained from MTC records. Data for 1975 used in conducting the first report, was also used to permit comparison of results obtained in both studies. While checking the data on running costs it was found that values of running costs used in the pilot study were those of the six-month period of April through September and not the three-month summer period of June through September. This imposes an additional limitation on the accuracy of the results, namely the variation of weather condition over a six instead of a three month period. However, it was decided to use the same data set on running cost for this study for purposes of comparison. Gasoline consumption for all patrol links used in the pilot study and in this study are given in Table 4.5 for April-September during 1975.

Having completed the data collection for test runs and patrol links on the dependent (gasoline consumption) and independent (grades and curvatures) variables, the next step was data analysis. The analysis consisted of plotting running cost variables (which was limited to gasoline consumption) versus grades and curvatures for all three data sets under consideration (new selected thirteen patrol links, seven test run section and old 24 patrol links). Regression analysis was performed

TABLE 4.5 GASOLINE COMSUMPTION (MPG) FOR PATROL LINKS,
M.T.C. RECORDS OF APRIL-SEPTEMBER 1975

Patrol Link	1	2*	3	5*	7	8*	11*	17*	18	102*	103*	104*
Gasoline Consump. MPG	14.9	14.5	15.7	15.4	16.7	16.2	15.6	18.0	15.7	16.8	12.7	18.6
Patrol Link	105	106	107	109	110*	111	112*	114*	115*	116*	118	119
Gasoline Consump. MPG	18.1	13.7	16.6	15.9	18.0	17.5	20.9	16.3	17.5	14.1	14.8	13.3

* Patrol links selected for this study.

and regression equations were obtained. For purposes of comparisons, regression lines of gasoline consumption versus grade for all three data sets were plotted on one graph. However, not all attempted plots and relationships are given in this report. Some of the plots that were absolutely rejected because of the wide scatter of the points are not shown here. The results of the regression analysis are given in detail in the following section.

4.7 RESULTS

The results are presented in the form of a discussion of each plotted relationship. These relationships are as follows:

(a) As mentioned before, gasoline consumption measurements were recorded in both directions of each of the seven test run sections. Table 4.6A shows the grades and gasoline consumption data for each of the test run sections. These data are plotted in Figure 4.1 along with the resulting regression line. Each test run section is identified on the graph by its number and the geographical direction in which measurements were taken (for example 2N indicates section number 2, the northbound direction). One can see from the graph or the resulting correlation coefficient that there is good correlation between grade (in percent) and gasoline consumption. The correlation coefficient (R) is 0.92.

(b) Figure 4.2 is a plot of gasoline consumption in MPG versus grade in ft/mile (rise was taken as positive and fall as negative) sections for both the test run and the new selected patrol link data. The relationship obtained for the test run data was relatively more acceptable than that for the new patrol link data when judged by the R value. The new patrol link points are clustered near the centre of the graph with an R value of 0.34, which was low. The test run points were much closer to the regression line and have an R value of 0.58 which is still low. Data used in plotting this graph is given in Tables 4.6A and 4.6B.

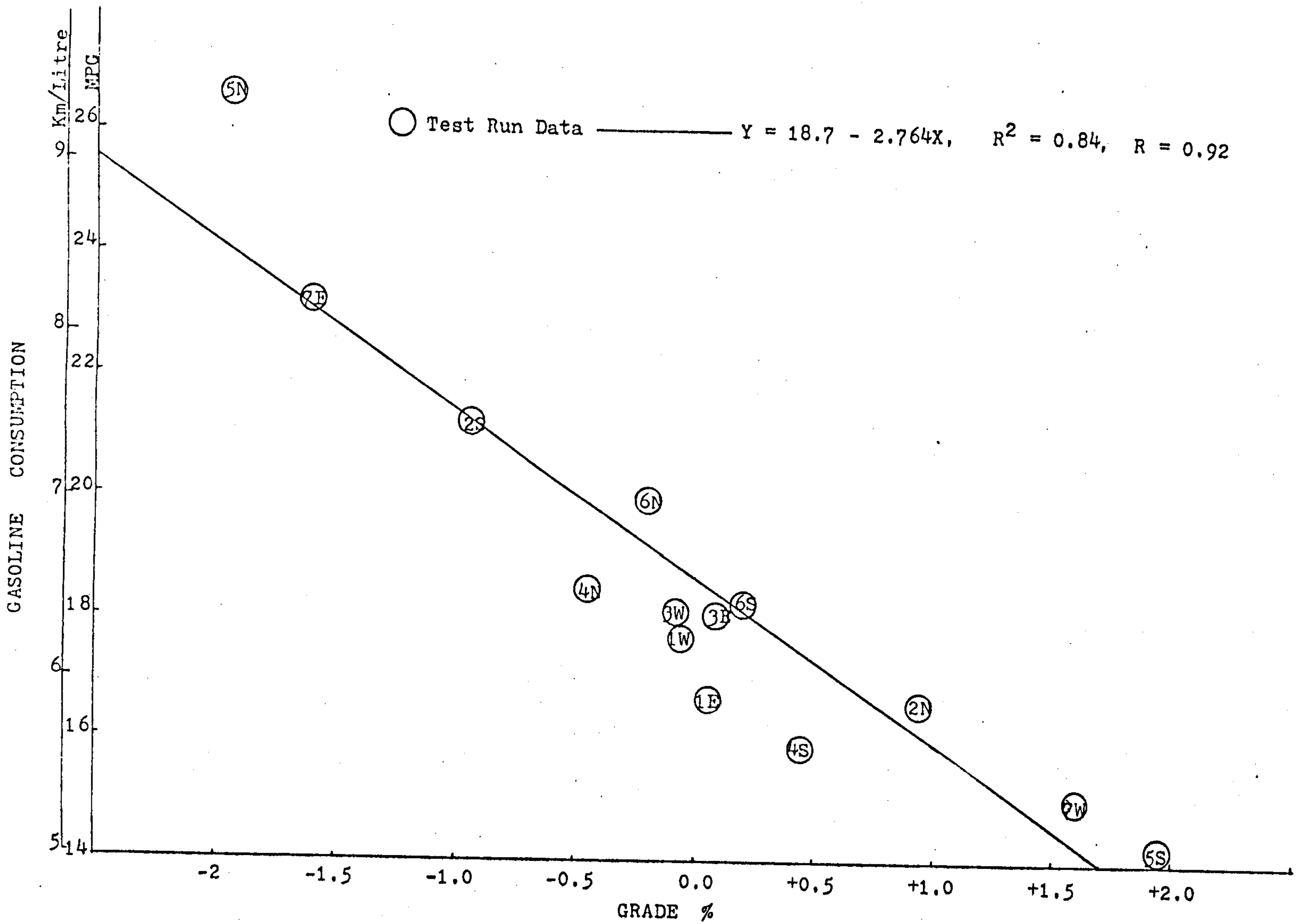

Figure 4.1 Gasoline Consumption versus Grade (Test Run Sections Data)

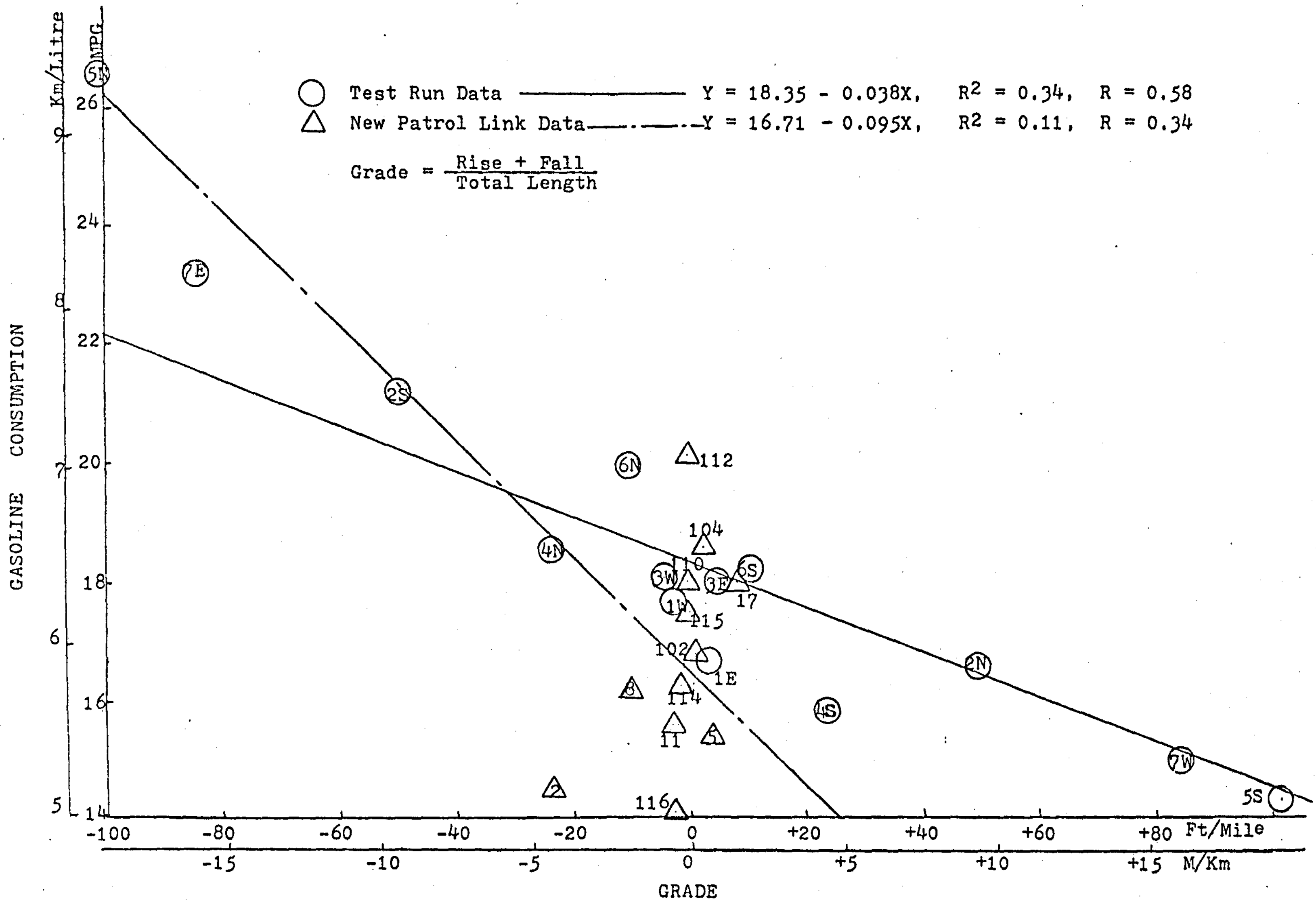

Figure 4.2 Gasoline Consumption versus Grade (Test Run Sections and New Patrol Links Data)

TABLE 4.6A GASOLINE CONSUMPTION AND GRADE DATA FOR TEST RUN SECTIONS

Hwy #	Test Run #	Total Length (ft.)	Total Length (miles)	Total Fall (ft.)	Total Rise (ft.)	Grade (Ft./mi) Fall+Rise / T. Length	Grade % ft./mi. / 52.8	Total Gasoline Consump. (ml.)	Total Gasoline Consump. (Gallons)	Gasoline Consump. (MPG)
519	1E	26400.	5.00	-300.95	+315.52	+ 2.914	+0.055	1366.00	0.300	16.667
	1W	26400.	5.00	-315.52	+300.95	- 2.914	-0.055	1285.30	0.283	17.67
121	2S	16340.	3.095	-270.26	+116.90	- 49.55	-0.94	662.50	0.146	21.199
	2N	16340.	3.095	-116.90	+270.26	+ 49.55	+0.94	848.66	0.1867	16.58
503	3W	14560.	2.758	-185.50	+172.70	- 4.64	-0.088	693.00	0.152	18.097
	3E	14560.	2.758	-172.70	+185.50	+ 4.64	+0.09	695.50	0.153	18.03
507	4S	22120.	4.189	-251.85	+351.09	+ 23.69	+0.45	1201.00	0.264	15.867
	4N	22120.	4.189	-351.09	+251.85	- 23.69	-0.45	1028.66	0.226	18.54
62	5N	10560	2.00	-253.20	+ 48.30	-102.45	-1.94	340.83	0.075	26.60
	5S	10560	2.00	- 48.30	+253.20	+102.45	+1.94	636.50	0.140	14.29
127	6N	11560.	2.189	-175.10	+152.20	- 10.46	-0.198	498.75	0.1097	19.95
	6S	11560.	2.189	-152.20	+175.10	+ 10.46	+0.198	546.50	0.120	18.24
62	7E	17840.	3.379	-348.75	+ 64.10	- 84.24	-1.60	661.50	0.146	23.22
	7W	17840.	3.379	- 64.10	+348.75	+ 84.24	+1.60	1020.25	0.224	15.06

TABLE 4.6B GASOLINE CONSUMPTION AND GRADE DATA
FOR NEW SELECTED PATROL LINKS

Patrol Link	Total Fall(ft)	Total Rise(ft)	Total Length(mi)	Grade (ft/mi)	Gasoline Consumption MPG
2	1373.6	895.9	20.4	- 23.4	14.5
5	2396.8	2565.0	45.6	+ 3.7	15.4
8	1884.2	2136.5	24.1	- 10.5	16.2
11	2215.2	2105.7	39.6	- 2.8	15.6
17	2754.9	3123.4	45.6	+ 8.1	18.0
102	154.3	180.6	41.0	+ 0.6	16.8
103	217.4	216.9	27.4	+ 0.02	12.7
104	511.4	608.4	43.5	+ 2.2	18.6
110	240.1	216.86	49.5	- 0.5	18.0
112	304.1	288.7	39.6	- 0.4	20.9
114	627.3	545.1	40.3	- 2.0	16.3
115	611.1	564.2	38.7	- 1.2	17.5
116	323.5	269.1	34.1	- 1.6	14.1

(c) Figure 4.3 represents a comparison of test run data and Claffey's data (5) of gasoline consumption in gallons per mile (GPM) versus grade in percent. From the regression analysis and the plot of the points it is obvious that the obtained relationships are quite similar. First, the slopes of the curves are almost identical (0.0078 versus 0.0074 in regression equations). Second, the R values for test run sections and Claffey's data were 0.96 and 0.99, respectively. The higher value of the constant in the regression equation for test run sections over that of Claffey's (0.055 versus 0.042) is due to several factors. First, the presence of curves in the test run sections and their absence in Claffey's test run sections. Second, colder temperatures, 4°C (39°F) to 21°C (70°F), at which the test runs were conducted compared to the 30°C (86°F), temperature at which Claffey's gasoline consumption measurements were taken result in higher gasoline comsumption. Third, possible variations in vehicle characteristics that were used as test vehicles, for pavement condition and drivers characteristics. The acceptable grades versus gasoline consumption relationship obtained on the test run data is an indication that collected data on geometric characteristics for this study (selected thirteen patrol links) is reasonably accurate and that expressing grade in percent and gasoline consumption in GPM is appropriate. Data used to plot Figure 4.3 is given in Table 4.7.

(d) Figure 4.4 is meant to be a comparison among the three data sets of test runs, new patrol links and old patrol links. Since the grade data available on the old patrol links is only that of grade in ft/mile where grade is expressed as (|Rise| + |Fall|)/Total Length of patrol link, the other two data sets of test runs and new patrol links have to be expressed in the same manner. From the plot, it is obvious that none of the three relationships obtained is satisfactory. First, the slope of the line for the test run data is opposite that of the other two for the new and old patrol link data. Second, the R values are 0.32, 0.22 and 0.20 for the test runs, new patrol links and old patrol links, respectively. Third, the scatter of the points for both sets of patrol link data is

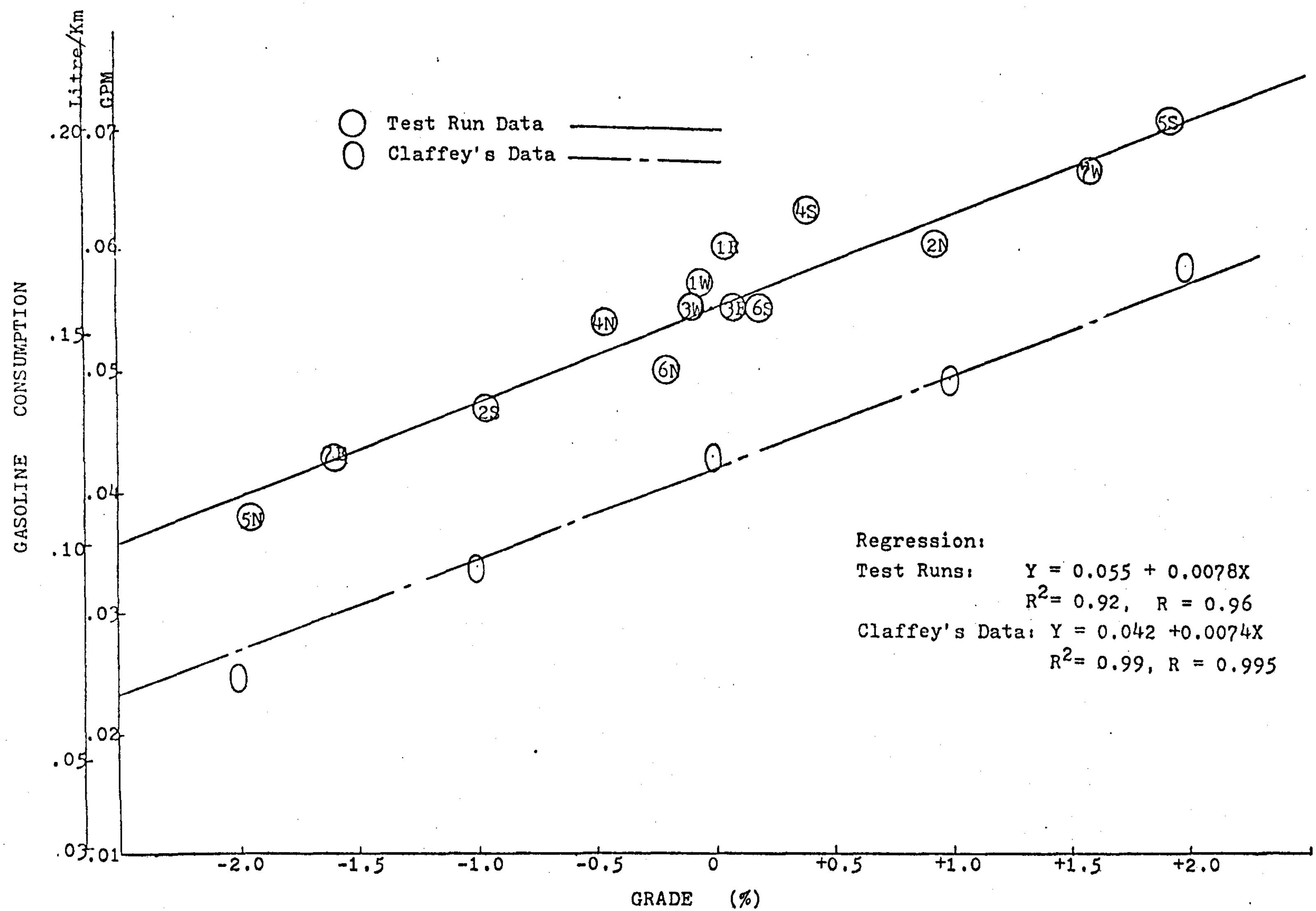

Figure 4.3 Gasoline Consumption versus Grade (Test Run Sections and Claffey's Data)

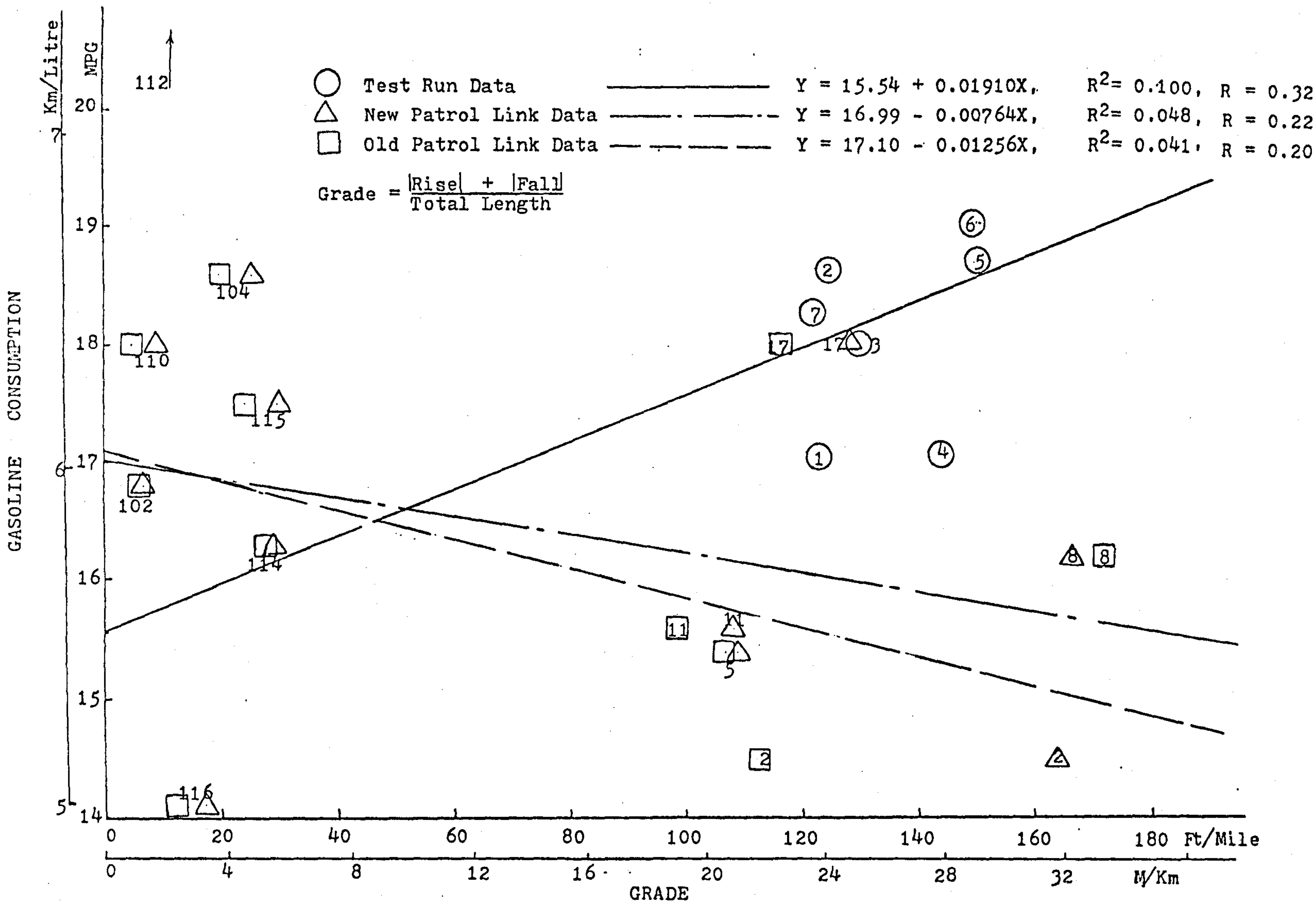

Figure 4.4 Gasoline Consumption versus Grade (Test Run Sections, New Patrol Links and Old Patrol Links Data)

TABLE 4.7 GASOLINE CONSUMPTION (GPM) AND GRADE (%)

FOR TEST RUN SECTIONS AND CLAFFEY'S DATA

Hwy #	Test Run # and direction	Test Run Data		Claffey's Data	
		Grade %	Gasoline Consumption (GPM-Can.)	Grade %	Gasoline Consumption (GPM-Can.)
519	1E	+0.055	0.060		
	1W	-0.055	0.057		
121	2S	-0.940	0.047		
	2N	+0.940	0.060	-3.0	0.021
503	3W	-0.088	0.055	-1.0	0.034
	3E	+0.088	0.055	0.0	0.043
				+1.0	0.049
507	4S	+0.450	0.063	+2.0	0.058
	4N	-0.450	0.054	+3.0	0.063
62	5N	-1.940	0.038		
	5S	+1.940	0.070		
127	6N	-0.198	0.050		
	6S	+0.198	0.005		
62	7E	-1.600	0.043		
	7W	+1.600	0.066		

quite great and for the test run data is quite small (points are clustered in a small area). It is worth noting that the relative position of the points of the new patrol link data, with respect to the axes, remain the same as those of the old patrol link data. This indicates that expressing grade in the form ($|$rise$|$ + $|$fall$|$)/ total length would be among the reasons for obtaining inconclusive results in the pilot study rather than the accuracy of the geometric characteristics data collected. Data used to plot this graph is given in Table 4.8.

(e) Figure 4.5 is a gasoline consumption-grade plot where grade is expressed as rise rate in ft/mile for both test run and new patrol link data. Again, the test run points are much closer to the regression line than are the new patrol link points. This becomes clearer when the R values for the test runs and new patrol links of 0.88 and 0.1, are compared; the first is acceptable while the second is quite low. Data used in plotting Figure 4.5 is given in Table 4.9.

Other gasoline consumption-grade relationships were attempted using test run data and expressing grade in different forms, but were rejected on account of absence of possible correlations. Consequently, attempts at plotting some relationships using the patrol link data were rejected. Among the forms used in expressing grade were (rise x rise length + fall x fall length)/Total length in ft/mile and (rise x rise length/fall x fall length) in dimensionless units. In addition, plots of rise (ft) versus rise length (ft) and rise/rise length versus fall/fall length (ft/mile) were attempted, but no satisfactory results were obtained.

(f) Figures 4.6 through 4.9, inclusive, represent gasoline consumption versus curvature, expressed in four different forms, for test runs. All four plots have the same slope direction and scatter of points around the regression line. In addition the R values are low in all of them (0.014, 0.22, 0.45 and 0.62). One of the reasons that could be cited for obtaining such poor correlations is that the

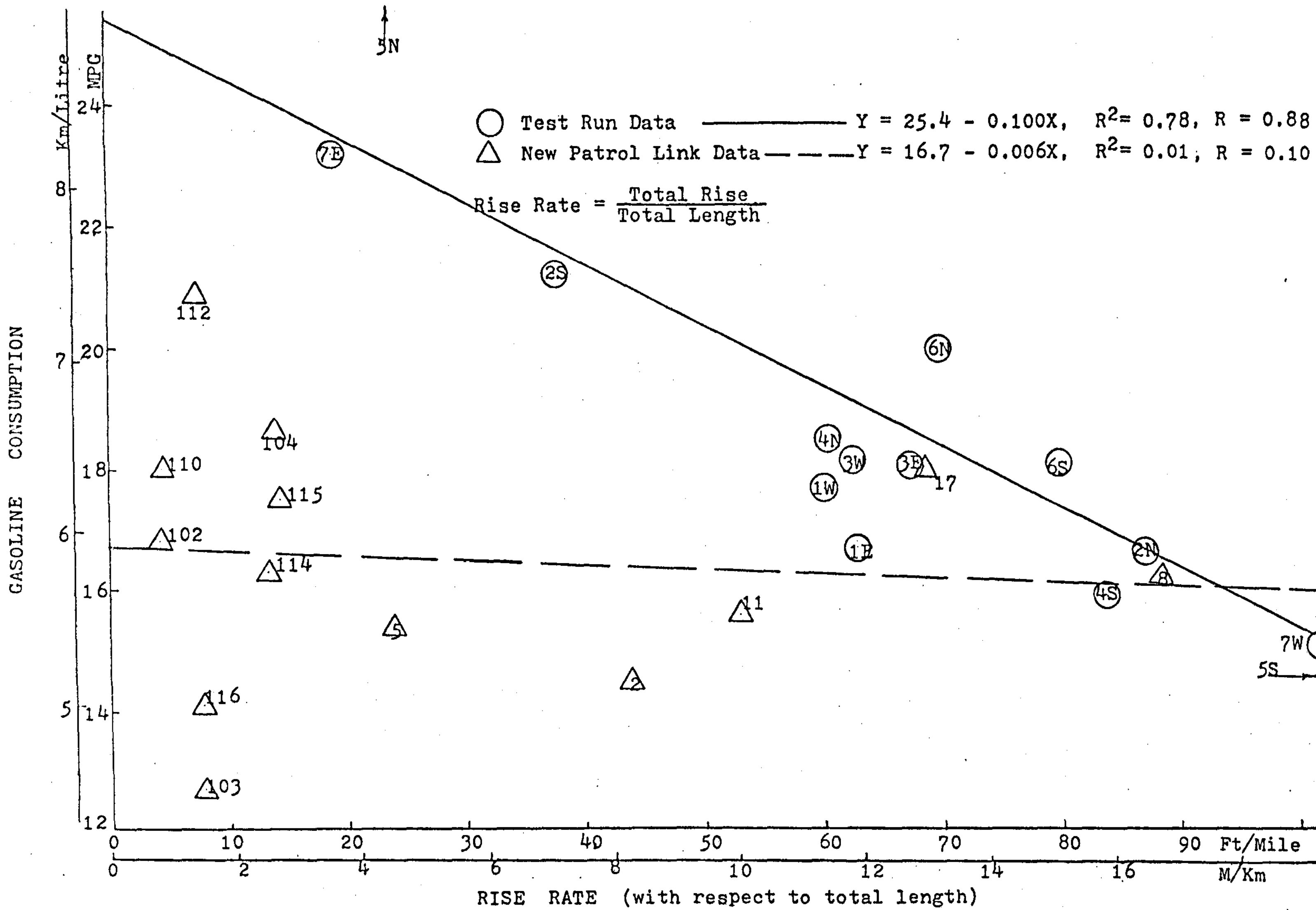

Figure 4.5 Gasoline Consumption versus Rise Rate (Test Run Sectios and New Patrol Links Data)

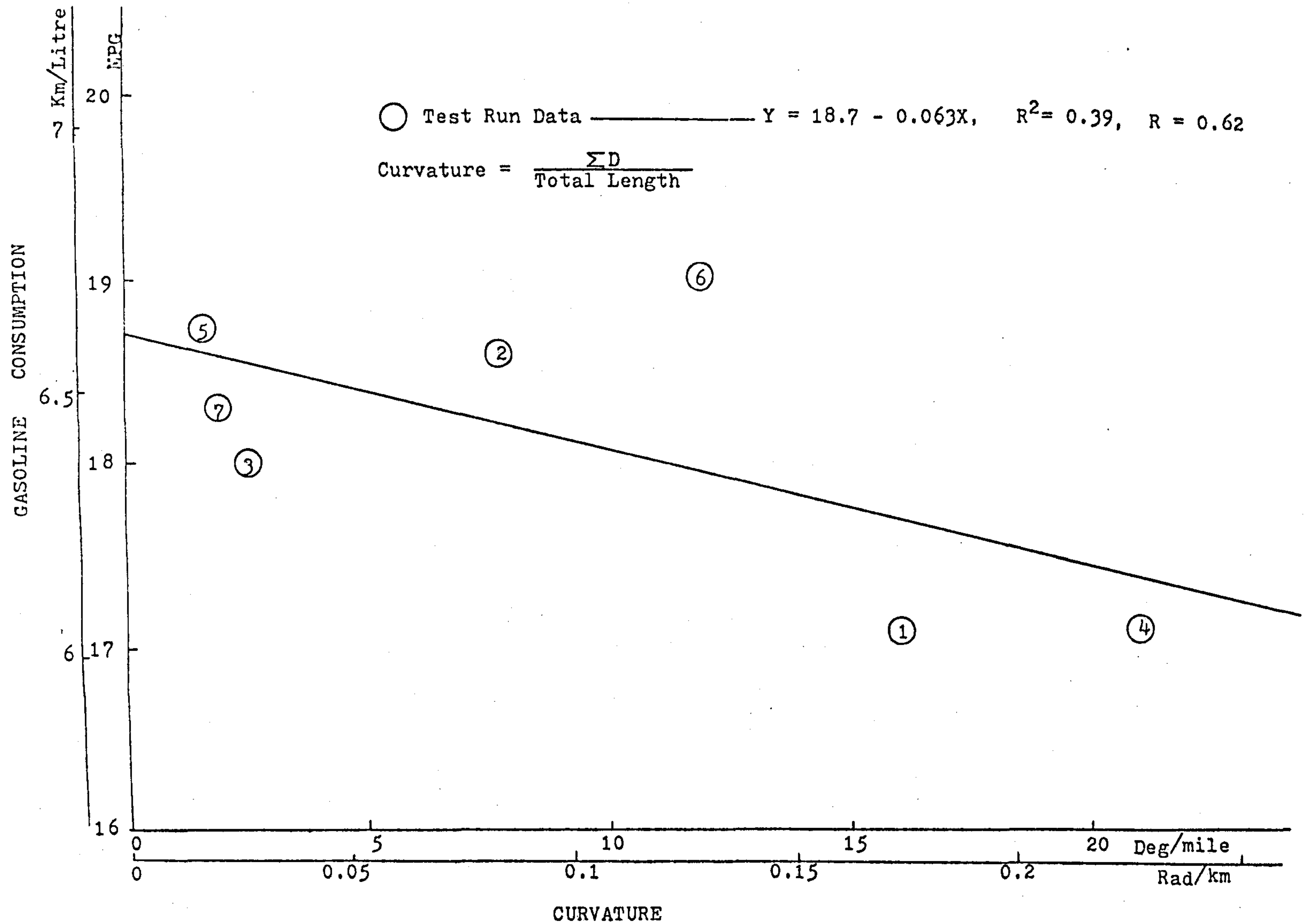

Figure 4.6 Gasoline Consumption versus Curvature (Test Run Data with Curve Degree)

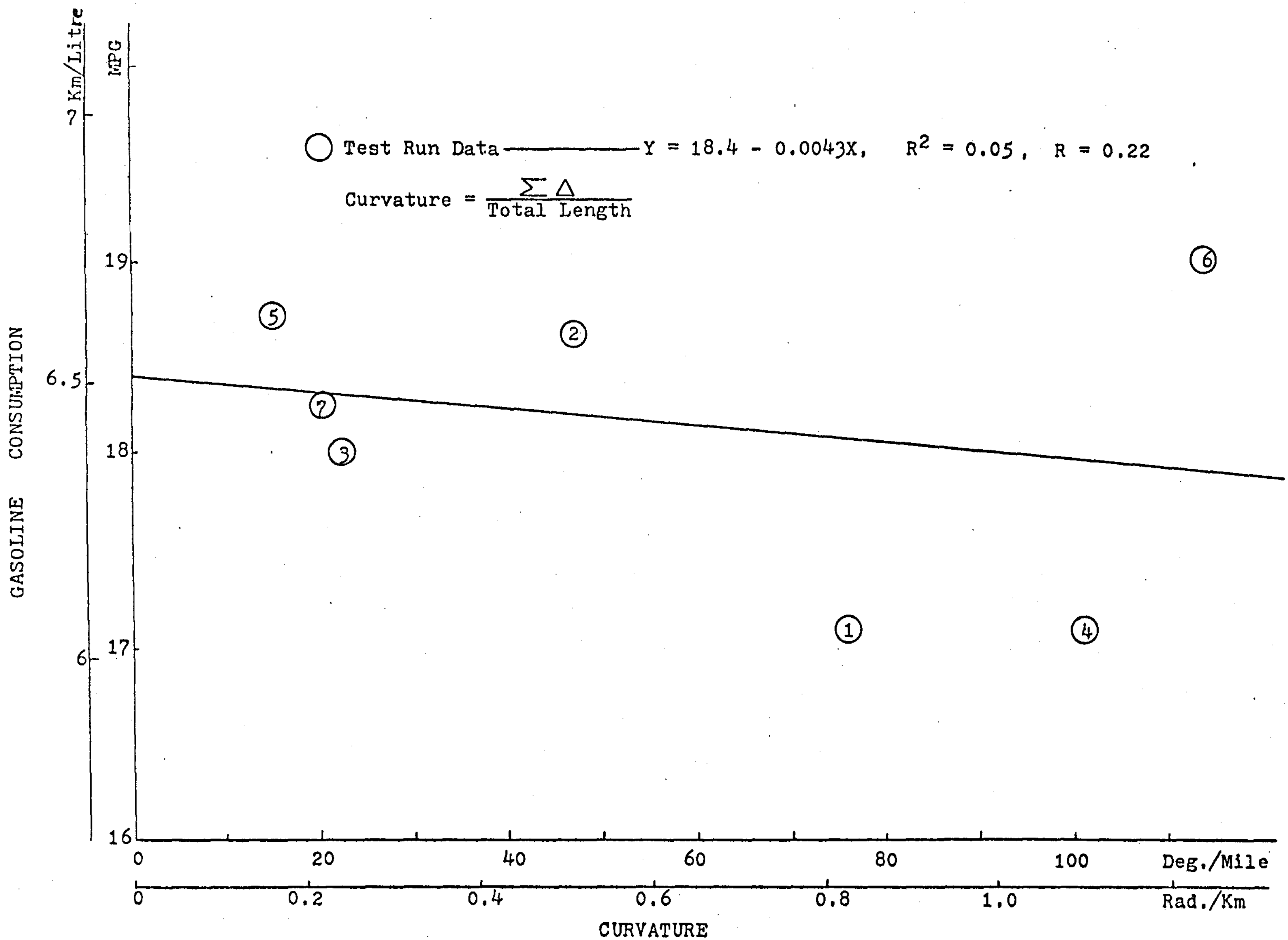

Figure 4.7 Gasoline Consumption versus Curvature (Test Run Data with Angle of Deflection)

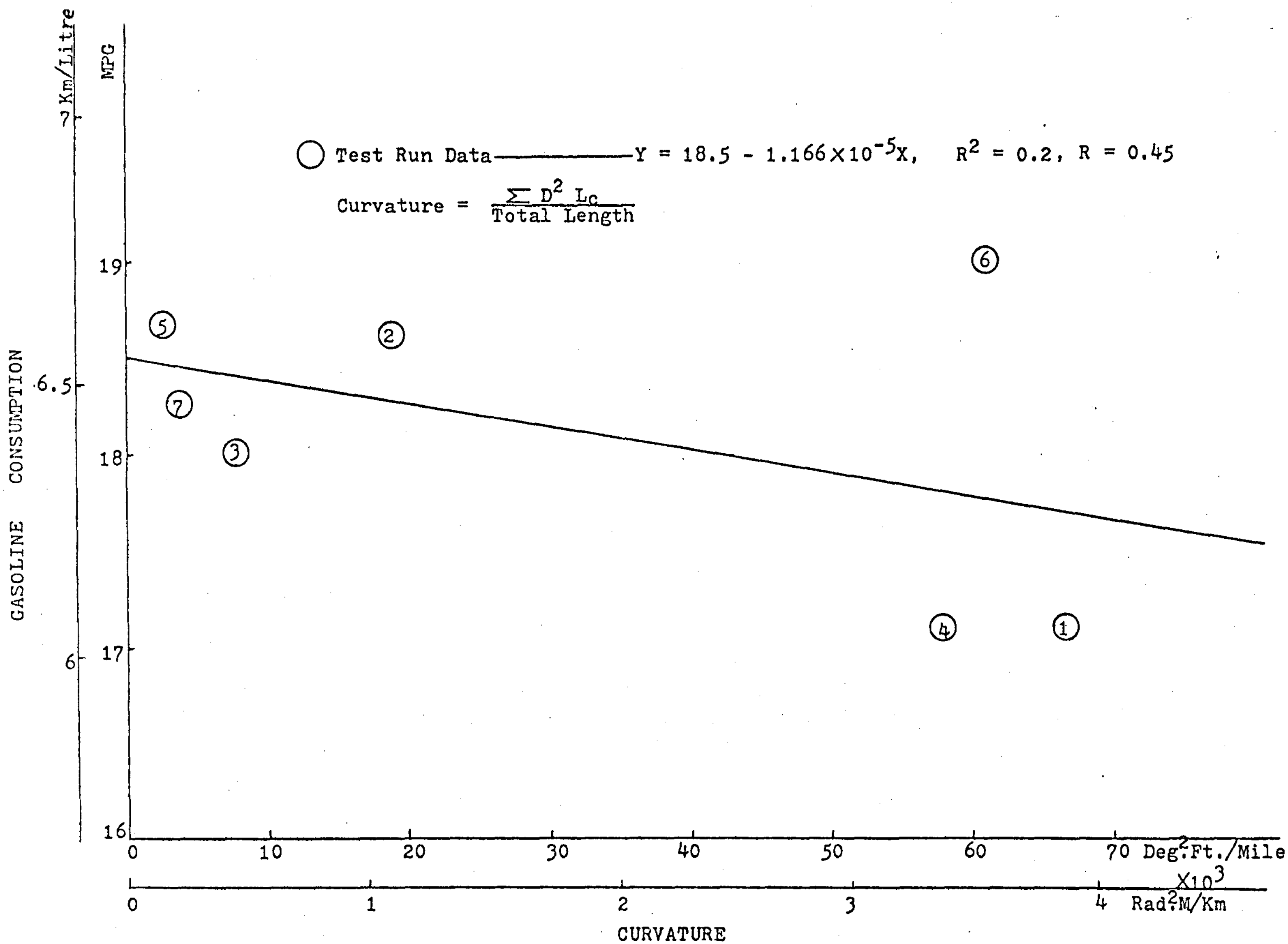

Figure 4.8 Gasoline Consumption versus Curvature (Test Run Data with Square of Gegree of Curve)

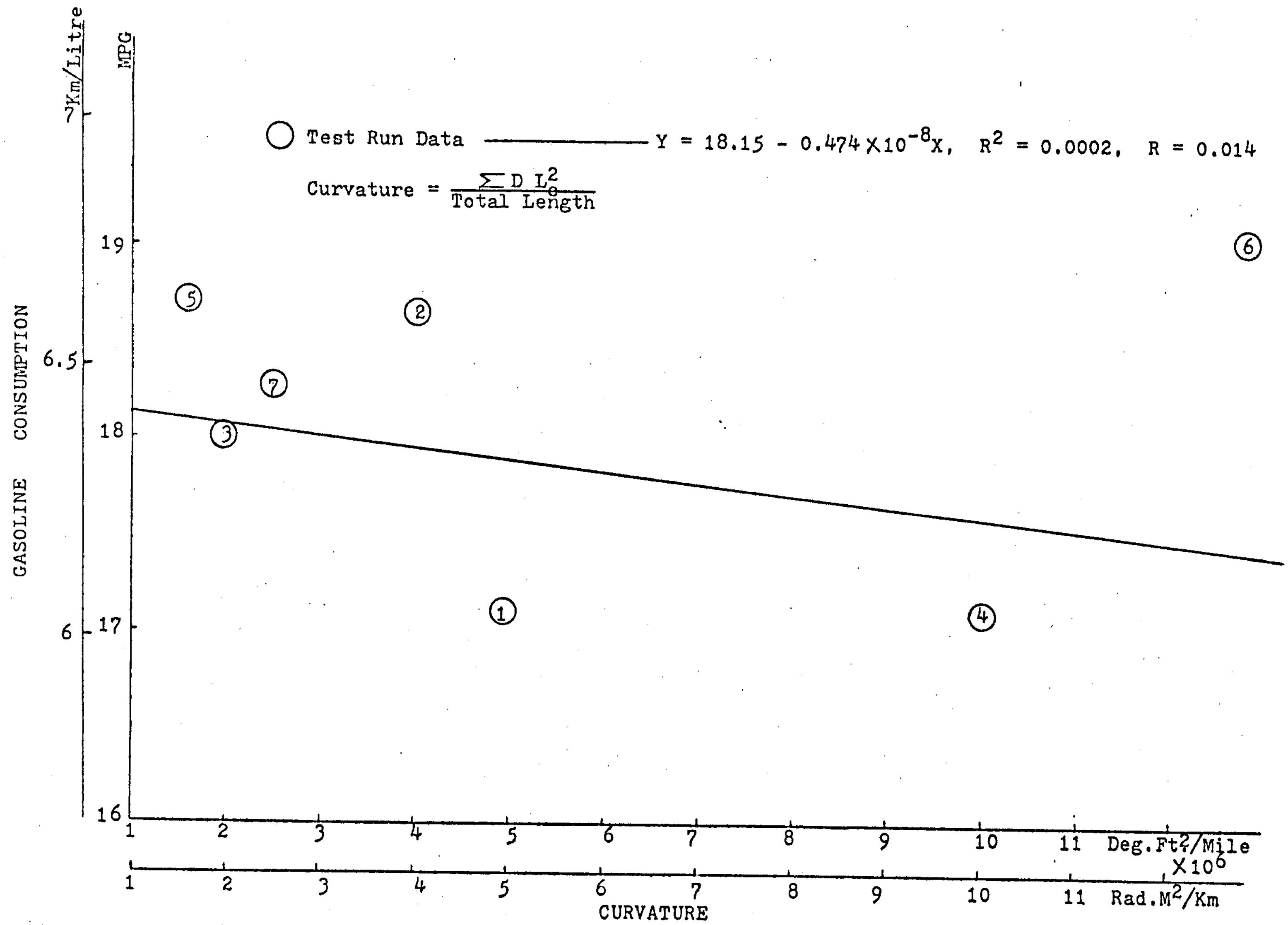

Figure 4.9 Gasoline Consumption versus Curvature (Test Run Data with Square of Length of Curve)

TABLE 4.8 TEST RUN SECTIONS AND PATROL LINKS DATA ON GASOLINE CONSUMPTION AND GRADES

Hwy #	Test Run #	Test Run Data			Patrol Link Data			
		Total Length (miles)	Gasoline Consump. (MPG)	|Rise|+|Fall| / T. Length Grade (ft/mi)	New Data |Rise|+|Fall| / T. Length	Pat. Link #	Fuel Consump. (MPG)	Old Data |Rise|+|Fall| / T. Length
519	1	5.0	17.12	123.30	163.68	2	14.5	112.6
					108.90	5	15.4	106.8
121	2	3.095	18.64	125.10	166.76	8	16.2	172.1
					108.5	11	15.6	98.6
503	3	2.76	18.02	129.40	128.99	17	18.0	117.0
					6.74	102	16.8	6.5
507	4	4.19	17.10	143.92	15.88	103	12.7	7.4
					25.75	104	18.6	19.8
62	5	2.00	18.70	150.75	9.24	110	18.0	5.0
					14.97	112	20.9	8.8
127	6	2.19	19.03	149.44	29.08	114	16.3	27.9
					30.35	115	17.5	24.6
62	7	3.38	18.26	122.19	17.36	116	14.1	11.8

TABLE 4.9 GASOLINE CONSUMPTION (MPG) AND RISE RATE WITH RESPECT TO TOTAL LENGTH (ft/mi.) FOR TEST RUN SECTIONS AND NEW PATROL LINKS DATA

Test Run Data					New Patrol Link Data			
Hwy #	Test Run #	Total Rise(ft)	Rise Rate w.r.t. T.length (ft/mi.)	Gasoline Consump. (MPG)	Patrol Link #	Total Rise(ft)	Rise Rate w.r.t. T.length (ft/mi.)	Gasoline Consump. (MPG)
519	1E	315.52	63.10	16.67	2	895.95	43.87	14.50
	1W	300.95	60.2	17.67	5	2565.0	24.10	15.40
					8	2136.5	88.61	16.20
121	2S	116.90	37.77	21.20	11	2105.6	53.12	15.60
	2N	270.26	87.25	16.58	17	3123.3	68.54	18.00
503	3W	172.70	62.62	18.10	102	180.55	4.40	16.80
	3E	185.50	67.27	18.03	103	216.93	7.93	12.70
					104	608.38	14.00	18.60
507	4S	351.09	83.80	15.87	110	288.65	4.38	18.00
	4N	251.85	60.12	18.54	112	216.86	7.29	20.90
					114	545.11	13.52	16.30
62	5N	48.30	24.15	26.60	115	564.19	14.57	17.50
	5S	253.20	126.6	14.29	116	269.07	7.88	14.10
127	6N	152.20	69.75	19.95				
	6S	175.10	79.98	18.24				
62	7E	64.10	18.97	23.22				
	7W	348.75	103.22	15.06				

grade effect on gasoline consumption is much more dominating than that of curvature. Data used in plotting these four figures is given in Table 4.10.

(g) Figures 4.10 through 4.13, inclusive, represent the same relationships between gasoline consumption and curvature as that in "f" above, but for new patrol link data. These graphs were plotted on the basis that a sample size of thirteen points for the new patrol links might produce better results than that of seven used for the test run data. The first two Figures (4.10 and 4.11) have a negative slope while the other two Figures (4.12 and 4.13) have a positive slope, which is different from results obtained on test runs. In all four figures the R value is low and varies from 0.03 at the lowest, to 0.25 at the highest value. From all eight correlations on gasoline consumption versus curvature, no conclusion can be drawn as to whether any correlation exists. Data used for these plots is given in Table 4.11.

Note that no multiple regressions, using grades and curvatures together versus gasoline consumption, had been attempted here in this study; yet such regressions may produce some acceptable results.

(h) Plots of oil and maintenance versus grade and curvature for the new patrol links were not investigated. This was based on the fact that gasoline consumption versus grades and curvatures for these patrol links did not produce significantly better relationships over those produced in the pilot study, thus it was not expected that oil and maintenance versus new grade and curvature plots would produce acceptable or significantly better results.

It is worth mentioning that for test run data (sample size of fourteen points) the plots that produced best correlations were those of gasoline consumption in GPM versus grade expressed as percent followed by gasoline consumption in MPG versus grade as percent then versus rise rate in ft/mile (R values are 0.96, 0.92

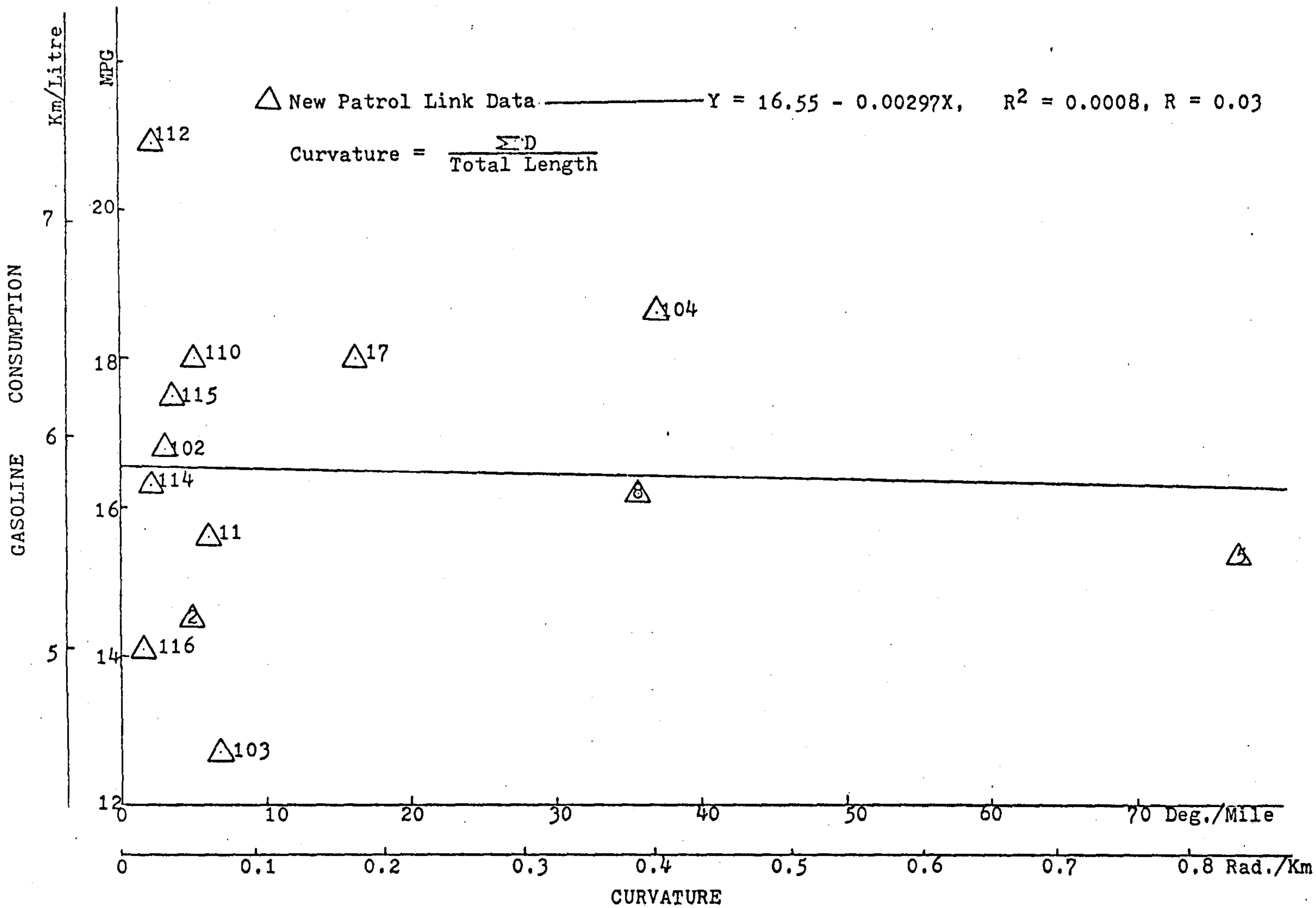

Figure 4.10 Gasoline Consumption versus Curvature (New Patrol Links with Degree of Curve)

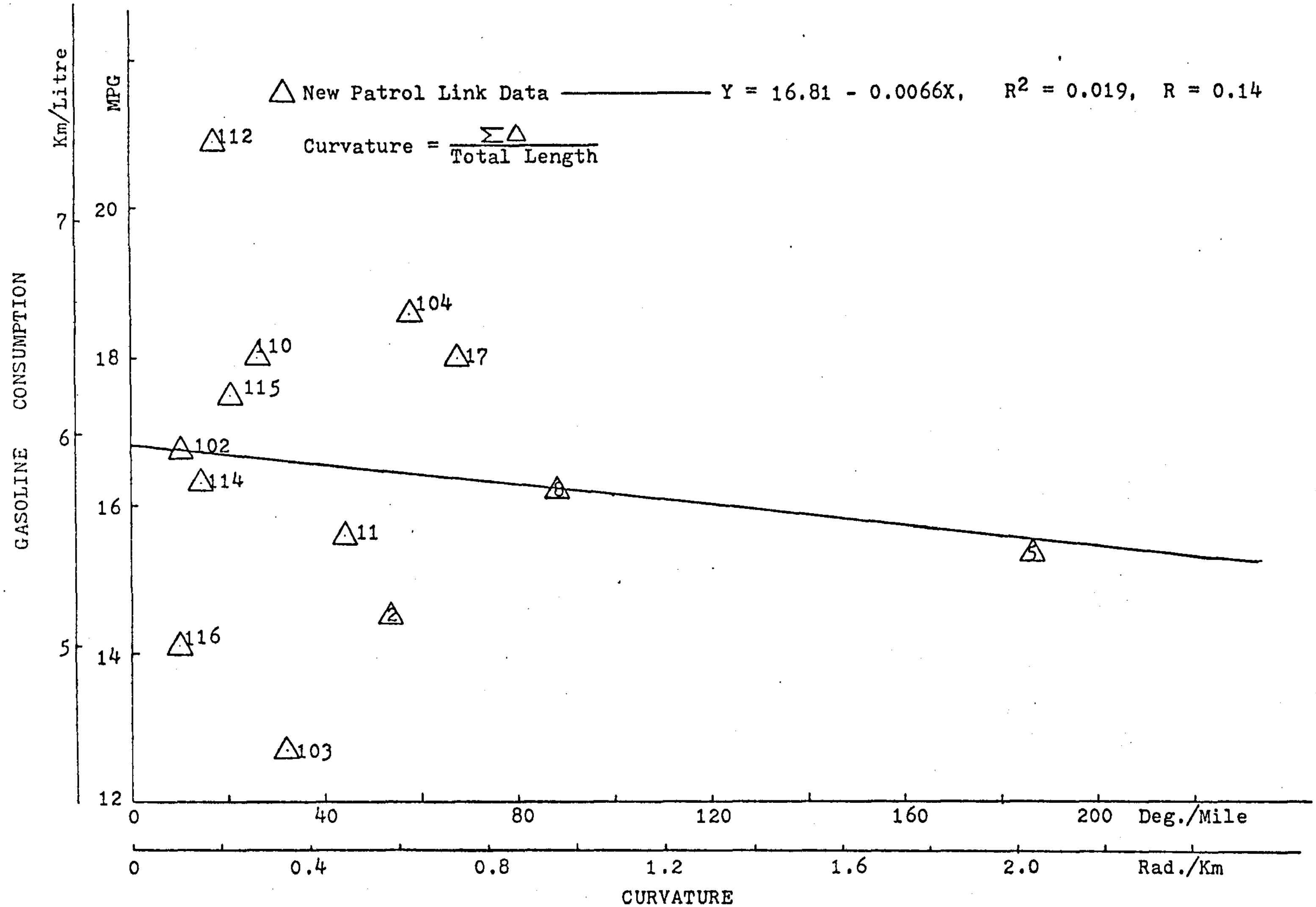

Figure 4.11 Gasoline Consumption versus Curvature (New Patrol Links with Angle of Deflection)

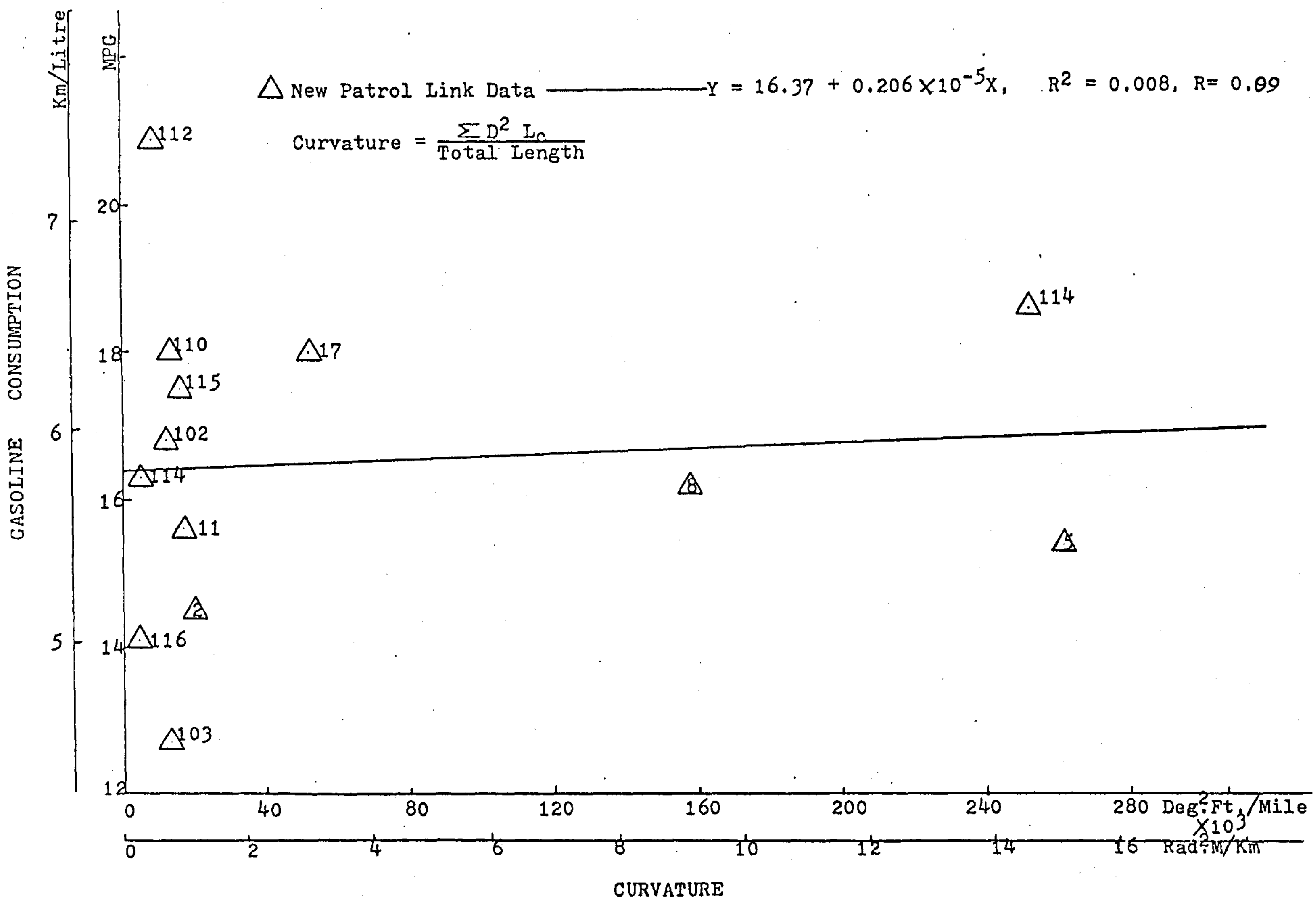

Figure 4.12 Gasoline Consumption versus Curvature (New Patrol Links with Square of Degree of Curve)

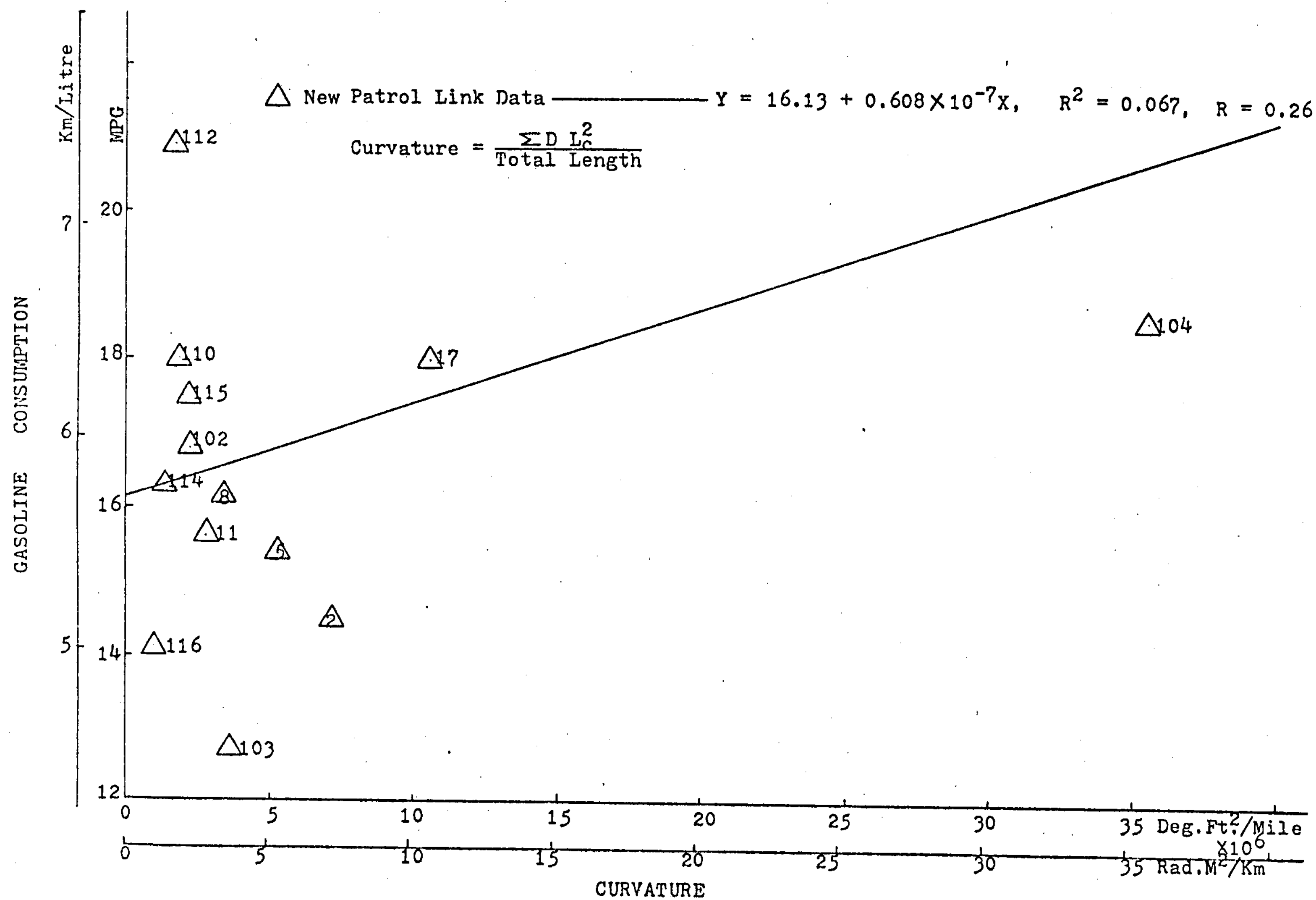

Figure 4.13 Gasoline Consumption versus Curvature (New Patrol Links with Square of Length of Curve)

TABLE 4.10 CURVATURE DATA FOR TEST RUN SECTIONS

Hwy #	Test Run #	Total Length (ft)	Total Length (miles)	Gasoline Consump. (ml)	Total Gasoline Consump. (Gallons) (British)	Gasoline Consump. (Mi/Gal.)	Curvature (Deg./mi) Total D / T.Length	Curvature (Deg./mi) Total Δ / T. Length	Curvature (Deg^2.ft/mi) $\Sigma D^2 x L_c$ / T. Length	Curvature (ft^2.Deg./mi) $\Sigma D x L_c^2$ / T. Length
519	1	26400	5.00	1325.65	0.292	17.12	76.13	16.11	66,603	4,953,800
121	2	16340	3.095	755.58	0.166	18.64	46.977	7.76	18,859	4,038,400
503	3	14560	2.758	694.25	0.153	18.02	22.25	2.539	7,812.7	1,979,500
507	4	22120	4.19	1114.83	0.245	17.10	101.38	21.01	57,999	10,023,000
62	5	10560	2.00	488.67	0.107	18.70	15.217	1.567	2,721.6	1,587,000
127	6	11560	2.19	522.63	0.115	19.03	114.52	11.875	61,203	12,784,000
62	7	17840	3.38	840.88	0.185	18.26	20.155	1.924	3,758	2,497,200

TABLE 4.11 CURVATURE DATA FOR NEW SELECTED PATROL LINKS

Patrol Link	Gasoline Consumption (MPG)	ΣD/T. Length (Deg./mi)	ΣΔ/T. Length (Deg./mi)	$\Sigma(L_c x D^2)$/T. Length (ft.Deg^2/mi)	$\Sigma(L_c^2 x D)$/T. Length (ft^2.Deg./mi)
2	14.5	4.89	54.04	20,557	7,123,863
5	15.4	76.96	186.94	262,259	5,211,149
8	16.2	35.7	88.49	158,943	3,426,755
11	15.6	6.17	44.52	17,519	2,714,193
17	18.0	16.18	67.9	52,368	10,562,233
102	16.8	3.23	10.43	12,008	2,185,398
103	12.7	6.86	32.43	13,338	3,739,264
104	18.6	37.04	57.93	252,901	35,480,827
110	18.0	5.24	26.70	13,223	2,048,753
112	20.9	2.43	17.73	8,263	1,701,162
114	16.3	2.18	14.71	5,503	1,323,508
115	17.5	3.75	20.85	16,103	2,165,252
116	14.1	1.65	11.4	4,371	1,145,183

and 0.88 respectively). Data obtained from regression analysis is summarized in Table 4.12.

The results of this investigation, as presented here, lead to the conclusion that the MTC's records on running costs at this stage can neither be accepted nor rejected as a good data source for running cost estimation. This conclusion is based on the "R" values obtained from regression analysis using data from MTC's records on the new selected (thirteen) patrol links. As it is shown in Table 4.12, values of "R" are 0.335, 0.22 and 0.1 for regression relations of gasoline consumption versus grade (expressed in different forms). Also "R" values are 0.0298, 0.139, 0.091 and 0.26 for gasoline consumption versus curvature (expressed in different forms). For a brief description of "R" and "R^2" see Appendix B, p. 137.

Many reasons could be cited as the possible cause that lead to such results. First, as mentioned before, the running cost data used was for the six-month period from April through September. This six-months period covers a wide range of weather conditions which could have varying effects on gasoline consumption and produce less accurate results. Second, the sample size of thirteen patrol links was not sufficient. A larger sample size could produce better results and is worth investigating. Third, inaccuracy of geometric characteristic data due to absence of survey plans for some patrol links. These three reasons do not include the possible deficiency of running cost data due to previously mentioned reasons, such as frequent patrol vehicle stops and varying road characteristics of roads with each patrol link. These reasons lead to the recommendations given in Section 4.8 regarding future research efforts using MTC's records on running cost data.

4.8 RECOMMENDATIONS

4.8.1 Recommendations for Short Term Research Work

a) Same relationships of geometric characteristics and gasoline consumption produced in this report are to be reproduced using the

TABLE 4.12 SUMMARY OF REGRESSION ANALYSIS OF GASOLINE CONSUMPTION AND GEOMETRIC CHARACTERISTICS

Graph#	Data	Variables Represented	Regression Equation	R^2	R
4.1	Test Runs	Gasoline Consumption (MPG)	$Y = 18.7 - 2.764\ x$	0.84	0.92
		Grade %			
4.2	Test Runs	Gasoline Consumption (MPG)	$Y = 18.35 - 0.38\ x$	0.34	0.58
	New Patrol Links	Grade (ft/mile)	$Y = 16.71 + 0.095\ x$	0.11	0.335
4.3	Test Runs	Gasoline Consumption (MPG)	$Y = 0.055 + 0.0078\ x$	0.92	0.96
	Claffey's	Grade %	$Y = 0.042 + 0.0074\ x$	0.99	0.995
4.4	Test Runs	Gasoline Consumption (MPG)	$Y = 15.54 + 0.0191\ x$	0.10	0.318
	New Patrol Links	Grade (ft/mile)	$Y = 16.99 - 0.00764\ x$	0.048	0.22
	Old Patrol Links	= Rise + Fall/T. Length	$Y = 17.10 - 0.01256\ x$	0.041	0.202
4.5	Test Runs	Gasoline Consumption (MPG)	$Y = 25.4 - 0.100\ x$	0.78	0.88
	New Patrol Links	Rise Rate (ft/mile)	$Y = 16.7 - 0.006\ x$	0.01	0.1
4.6	Test Runs	Gasoline Consumption (MPG)	$Y = 18.7 - 0.063\ x$	0.39	0.62
		Curvature (deg/mile)			
4.7	Test Runs	Gasoline Consumption (MPG)	$Y = 18.4 - 0.0043\ x$	0.05	0.22
		Curvature (deg/mile)			
4.8	Test Runs	Gasoline Consumption (MPG)	$Y = 18.5 - 1.166 \times 10^{-5}\ x$	0.2	0.45
		Curvature (deg^2 ft/mile)			
4.9	Test Runs	Gasoline Consumption (MPG)	$Y = 18.15 - 0.474 \times 10^{-8}\ x$	0.0002	0.014
		Curvature (deg ft^2/mile)			
4.10	New Patrol Links	Gasoline Consumption (MPG)	$Y = 16.55 - 0.00297\ x$	0.0008	0.0298
		Curvature (deg/mile)			
4.11	New Patrol Links	Gasoline Consumption (MPG)	$Y = 16.81 - 0.0066\ x$	0.019	0.139
		Curvature (deg/mile)			
4.12	New Patrol Links	Gasoline Consumption (MPG)	$Y = 16.37 + 0.00000206\ x$	0.008	0.091
		Curvature (deg^2 ft/mile)			
4.13	New Patrol Links	Gasoline Consumption (MPG)	$Y = 16.13 + 0.00000006085\ x$	0.067	0.26
		Curvature (deg ft^2/mile)			

three-month summer data instead of the six month data used in this investigation.

b) Collection of geometric characteristics data on more patrol links, in the same districts of one and ten, and in other districts. The total number of patrol links to be included in any future study should be around thirty, to allow appropriate evaluation of data at hand. Care must be exercised in selecting patrol links to ensure availability of survey plans. This eliminates any doubt in the accuracy of geometric characteristics.

c) Multiple regression analysis should be performed on all possible combinations of grades and curvatures and different forms of expressing them.

If the above three recommendations for short term research work are carried out and running cost estimates obtained are still unsatisfactory, then MTC records on running costs can be concluded as unsatisfactory. This does not eliminate the use of (improved) records as a viable source to be used in obtaining running cost estimates. Some changes in the system of record keeping, whether it be at the MTC or other agencies, can produce a better data source at very little extra effort on behalf of the present data collecting outfits. The following recommendations represent a basic guideline for possible methods of improving the quality of MTC records. Recommendations regarding record-keeping processes in general would require a separate investigation into the present records maintained by the different outfits.

4.8.2 Long Term Recommendations

The factors considered responsible for inaccuracy of MTC's records include the unknown number of stops and slowdowns, wide range of weather conditions within each quarterly period of record accumulation, the accuracy of recorded magnitudes of consumption, and homogeneity with which patrol links are covered. The following recommendations aim at minimizing the effect of such unknown factors.

a) Recording and accumulating running cost data on a monthly basis instead of the present quarterly basis. This change will minimize weather effects on running cost estimates and may allow comparison of costs under different weather conditions.

b) A more accurate and complete record of magnitudes of consumption is required. Quantities used for running only, and not for cleaning or other purposes, should be recorded separately.

c) If possible, the approximate number of stops during each month should be recorded. It is believed that stops have a measureable effect on fuel consumption. Recording, even the approximate, number of stops would help assess their effect on fuel consumption.

If these recommendations are carried out, better running cost estimates can be produced and used for one or more purpose(s). An immediate use could be evaluation of improvement and maintenance programs of the roads for which records are kept and cost estimates obtained.

4.9 SUMMARY

This chapter covered an investigation into the existing records of the MTC on running cost variables. The purpose of the study was to continue the initital investigation of potential use of this data to obtain reliable running cost estimates. Upon examination of the accumulated data from MTC's records, many limitations were realized. Despite these limitations research work was continued in an effort to determine the data potential. An important motive for persuing the work was the viability of up-to-date records on running costs of specific vehicles covering specific routes. In addition to the available records, some gasoline consumption measurements were taken during several test runs, on some of the roads under consideration, to assist in evaluating these records. Data obtained from both test runs and records for patrol links was plotted in an effort to derive relationships between gasoline consumption and each of grade and curvature expressed in different forms. Regression analysis was conducted on all plotted relationships. Results were satisfactory for test run data, but not for patrol link data. Due to limitations on time and scope of this study, the results for patrol links were considered inconclusive. Recommendations for future research efforts were detailed in order that running cost records be investigated in a more complete manner. Other recommendations are concerned with improvement of record keeping methods to provide better data source for running cost analysis.

To conclude, records on running cost variables could become a good source of information if the system of record keeping is improved. MTC's records are particularly good because they maintain information on specific vehicles covering specific routes with specific districts that have the same general topographic characteristics. The availability of similar or better records should be comprehensively investigated. In addition, a system for better record keeping should be developed and standardized as a first step towards a long term solution for the problem of data sources on running costs.

5. COMMENTS, CONCLUSIONS AND RECOMMENDATIONS

From the literature review presented in Chapters 2 and 3 of this paper it is evident that the task of obtaining complete, reliable and up-to-date running cost estimates is a difficult one. This has become more evident during the investigation of the potential of MTC's records on running cost as a data source (in Chapter 4). Research effort in the field of running cost estimates has not been exclusive to any one country or continent, rather it is an experience shared by researchers all over the world. The purpose or objective of research varied from country to country and over the years. The scope of conducted research has, at times, been limited by the available resources at the time of the study.

In this chapter, comments and conclusions on the different stages and decision-making processes involved in any study on running cost estimates are given. In addition, the major problems of the present use, application and conduction of running cost estimates are discussed. In conclusion recommendation for future research efforts regarding the different stages involved in estimation of running costs are summarized.

5.1 COMMENTS AND CONCLUSIONS

The problems encountered with running cost estimation lie principally in two main categories; those problems that are related to the use and application and those involved in the process of that estimation. In the following few pages, discussion and comments highlight the major problems encountered in use as well as the different stages of the process of estimating running costs. This process begins with a definition of the purpose of data collection and ends with the analysis and results of running cost estimates. Conclusions and recommendations for possible ways to avoid or deal with these problems are also included.

5.1.1 Use and Application

Running cost estimates for the developing countries were not available as recently as the early 1960's. In view of the absence of (or difficulty in obtaining) resources such as equipment and financial funds necessary to conduct field measurements from controlled field measurements, researchers resorted to other methods of obtaining running cost estimates. The staff at the National Institute for Road Research, South Africa (NIRR) produced three reports on running cost estimates for the developing countries between 1965 and 1975. The last two reports were just an update of the original report to comply with inflation and the adoption of the International System of Units (S.I. Units). The first report produced in 1965, and consequently the following two reports, were based on Robley Winfery's estimates for American conditions.

During the mid 1960's, when financial funds became available for research on running costs for the developing countries many studies were conducted. One of them was carried out in Kenya and published in 1976 (14). This study was based on information obtained from experimental field measurements and user surveys conducted in Kenya a developing country. In a comparison of running cost estimates obtained in this study and those obtained from the third report by NIRR in 1975 (23) the magnitudes of some of the running cost variables varied significantly. Since the Kenya study (14) was based on developing countries' conditions and on a combination of field measurements and user survey data it is reasonable to assume that it is more reliable than the NIRR data based (mostly) on other than field measurements of American data. This indicates that using an unrepresentative data source can result in inaccurate running cost estimates. Yet, lacking other information, this information can be used because it was intended as an approximate and not a definitive estimate. To conclude, if running cost estimates are only approximate values and are meant for use as a guide users should not, incorrectly take them for definitive documents.

5.1.2 Geographic Representation

The size of the geographical area, which running cost estimates cover, should be the first concern for researchers working in this field. The available reports on running cost data today cover as small an area as one city (9) and as large an area as a country (19,20,21). The choices of geographical area represented depend on the purpose of the study and the level of aggregation of running cost estimates. Estimates obtained for economic evaluation of road programs can be so disaggregated that they cover a wide range of the independent variables such as road characteristics, traffic conditions, environmental factors and vehicle characteristics. In other words, running cost estimates can be obtained for any combination of these four independent variables, which in turn means it can apply to a relatively large geographic area. A close example of this data type is Claffey's work on running costs (5). On the other hand, if the research purpose is public information, then data is usually aggregated with respect to the independent variables. For instance, estimates obtained using records and statistics are usually representative of the average vehicle type used in the area, the weather conditions of the area, average traffic conditions and average road characteristics prevailing at that particular area. Accordingly, such estimates can not be generalized or applied to other or larger-size locations. So, as the scope of the study becomes more comprehensive and the level of disaggregation increases, the geographic area it can apply to increases.

It is recommended that running cost estimates be classified by purpose, so then the size of the geographic area represented will become easy to define. Estimates required for detailed economic analysis require a lot of effort and should be very disaggregated with respect to both dependent and independent variables and, as explained in the previous paragraph, would cover a large geographic area. Estimates required for public information require much less work and do not have to be very accurate or disaggregated. Consequently, estimates obtained using records and statistics would not require too much work but would be limited to representing the location or similar locations (could be classified by city size within each country) for which data was collected.

5.1.3 New Data Sources

None of the data sources represented in chapters three or four represent the ideal source when used separately. A combination of these data sources may be the solution towards achieving an optimum method of data collection, particularly for the more demanding purposes. Controlled field measurements whenever feasible, represent the most accurate method of data collection but they are the most expensive and demanding as well. Computer simulations have succeeded in predicting some of the magnitudes or running cost variables (gasoline and oil consumption), but not all of them. Other data sources such as questionnaires and statistics can also be used in producing estimates for variables (such as depreciation) that can not be produced using computer simulation and are almost prohibitively expensive and demanding to achieve through field measurements. Records are usually an up-to-date source but are often a too aggregated and inaccurate source. It is recommended to investigate the possible simultaneous use of the different data sources to obtain running cost estimates.

Another recommendation regarding data sources is that of investigating the availability of any reliable data that can be used to obtain estimates on running costs. This has been attempted, very briefly and with no success, during the work on the MTC's records.

A third recommendation deals with improvement of record-keeping process applied by MTC and other agencies. Improvement of such a process, even though it is a long range plan, can result in a much better data source than is available today.

5.1.4 Updating Process

The phase of updating running cost estimates is not completely divorced from the phase of data source(s). The updating process depends completely on the type of data used. Consequently, the choice of data source(s) and the updating process should be determined simultaneously. This does not mean that for each data source there is only one method of updating estimates or vice versa. For instance, computer programs can be used to update running cost information obtained from field measurements, records, statistics and literature. A third phase of the process of estimating running costs that requires investigating at the same time as selection of data source(s) and updating process is that of variables. If estimates are to be updated, then running cost variables must be expressed in costs and quantities or else be expressed in quantities with cost per unit given in the same report. To conclude, the three phases of choosing variables, data source(s) and updating process should be conducted simultaneously in order that more useful results be obtained.

5.1.5 Analysis and Results

Information is available, in the literature, on methods of analysis and results. Generally, once the previous phases of data sources, choice of variables, updating process and level of aggregation are determined, the analysis phase and form of results are easily defined. It is the writers opinion that no further recommendations, for the time being, are indicated regarding analysis and results.

5.2 RECOMMENDATIONS

To sum up this chapter, recommendations for future research efforts in the field of running cost estimates are as follows:

i) An explicit description of purpose, variables and data source for any research work dealing with running costs is essential if incorrect application of estimates is to be avoided.

ii) Specification of the geographic area over which running cost estimates, classified by different purposes are considered appropriate.

iii) Investigation of simultaneous use of different data sources to obtain running cost estimates which could possibly reduce the work required for more traditional and comprehensive studies.

iv) Investigation of the potential of new and reliable sources of data that can be used for running cost estimates. Attention is required regarding the level of aggregation of variables available in such data sources prior to adoption.

v) Investigation of improvement of records on running cost variables maintained by many organizations including the Ministry. If records are improved, continuous and current information on running cost would be available at all times and would suggest that estimates could be obtained with much less effort.

vi) The updating process of running cost estimates must be considered at early stages in any research effort. A suggested method for updating information should be included in all reports dealing with running cost estimates.

Although the above recommendations are very general in nature, and the tone of this report has tended to be negative, the authors feel very strongly that continuing efforts should be mounted to more clearly rationalize estimates of running costs. To this end, the Traffic Research Group at McMaster University is currently conducting a follow-up study to more rigorously approach the investigation and specification of possible running cost relationships using available Ministry data.

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APPENDIX "A"

FAMILIAR METHODS OF ECONOMIC ANALYSIS

The following four methods are among the most common methods used for economic analysis of highways today.

1. Annual Cost Method:

In this method the total annual cost of the highway project is determined. The annual cost of construction is that of the initial project cost multiplied by the capital recovery factor. The annual maintenance costs and the annual road user costs are added to it.

$$A = D + M + E$$

where:

A = total annual cost of the highway project

D = annual cost of construction = C x CRF

C = initial cost of construction

CRF = capital recovery factor

M = annual maintenance costs

E = annual road user costs

The highway project having the lowest total annual cost is chosen as the best alternative.

2. Rate of Return Method:

This method involves determining the interest rate at which the annual cost of construction is just equal to the savings in road user and maintenance costs. A trial and error solution is used to determine the rate of interest that satisfies the following equation:

$$D_B - D_A = (E_A - E_B) + (M_A - M_B)$$

where subscripts A and B refer to alternatives A and B. The highway project having the highest rate of return on both a total and incremental basis is selected as the best alternative. This rate must be greater than the minimum acceptable rate of return.

3. Benefit-Cost Ratio Method:

This method is by far the most widely used in highway projects evaluation. The Benefit-Cost Ratio is the ratio of road user cost savings to the annual cost of the project.

$$R_{BA} = \frac{E_A - E_B}{(D_B - D_A) - (M_B - M_A)}$$

where R_{BA} is the benefit-cost ratio of alternative B over A. The alternative having the highest benefit-ratio on both total and incremental basis is the best.

4. Present Worth Method:

This method expresses the stream of future costs in terms of their value at the present time. In order to do this, future costs are discounted by the appropriate interest rate to provide them with the same dimensions as initial fixed costs. The "present worth" value of future cost F, j years from now is given by F/(1+i)j. The present discounted value of all futrue expenditure is determined by assuming these terms of each year in the period under consideration.

$$PWF = \sum_{j=1}^{n} \frac{F_j}{(1+i)^j}$$

where:

PWF = present worth of all future costs

F_j = annual cost in year j

i = rate of interest

n = life of the project

The total present worth of a project PW with an immediate expenditure C is given by the equation:

$$PW = C + PWM + PWE$$

where PWM and PWE are the present worth of future maintenance and road user cost respectively. The alternative having the lowest total present worth is chosen as the best.

APPENDIX B

REGRESSION ANALYSIS AND SAMPLES OF DATA COLLECTION AND ANALYSIS RESULTS

Regression Analysis:

Linear regression (used in the analysis and as discussed in the results of Chapter 4) concerns the fitting of a straight line to a given scatter of data points. The most common mathematical technique used in determining the position and slope of a regression line is the "method of least squares". The line position is determined by the method of least squares such that the sum of the squares of deviations of the observed points about the line is minimized. The form of regression equation can be expressed as follows:

$$Y = a + bx$$

The coefficient of determiantion "R^2" measures the closeness of fit of the regression equation to the observed values. R^2 values can vary in magnitude from 0 to 1. An "R^2" value of 1.00 suggests a best fit when all data points fall exactly on the regression line. R^2 can be calculated as follows:

$$R^2 = \frac{b^2\,[\Sigma x_i^2 - (\Sigma x_i)^2/n]}{\Sigma y_i^2 - (\Sigma y_i)^2/n}$$

The correlation coefficient "R" describes the relationship between the observations of the variables x and y. In the case of linear regression, when the value of "R" is either +1 or -1 the relationship between x and y is an exact linear relationship. The sign of R is the same as that of b or the slope of the regression line. R is calculated as follows:

$$R = \sqrt{R^2}$$

VEHICLE YR NO CL MK	GASOLINE GALS	GASOLINE AMT	FUEL OIL GALS	FUEL OIL AMT	MOTOR OIL QTS	MOTOR OIL AMT	MISC AMOUNT	TOTAL HOURS	TOTAL MILES	PARTS COST	LABOUR COST	AUX PARTS	AUX LABOUR	TOTAL COST
						2ND QTR - SEP 1975				DISTRICT 01				
741275 003 11	927	594.25	0	0.00	24	9.33	0.00	700	15019	75.14	218.50	0.00	0.00	897.22
741284 003 28	269	184.68	0	0.00	1	0.35	0.00	179	4054	26.45	0.00	0.00	0.00	211.49
71 103 006 40	693	362.99	0	0.00	16	6.24	0.00	532	8823	37.93	104.50	0.00	0.00	511.66
72 163 006 20	411	217.83	0	0.00	11	4.51	0.00	278	5987	71.38	304.00	0.00	0.00	597.72
74 312 006 20	880	477.50	0	0.00	27	10.14	0.00	576	13999	0.00	0.00	0.00	0.00	487.64
74 639 006 20	813	568.64	0	0.00	21	8.12	0.00	628	11138	37.67	351.50	0.00	0.00	965.93
74 640 006 20	797	434.79	0	0.00	16	6.30	0.00	390	10592	382.58	655.50	0.00	0.00	1479.17
72 645 006 40	614	331.74	0	0.00	17	6.12	0.00	326	8179	36.16	209.00	0.00	0.00	583.02
72 673 006 40	675	423.43	0	0.00	12	4.32	0.00	196	9599	70.83	332.50	0.00	0.00	831.08
70 713 006 26	465	250.38	0	0.00	17	6.45	0.00	168	5694	31.63	76.00	0.00	0.00	364.46
72 795 006 40	394	245.84	0	0.00	13	4.68	0.00	226	6528	121.81	152.00	0.00	0.00	524.33
72 797 006 40	796	456.03	0	0.00	16	13.34	18.19	393	11214	45.26	104.50	0.00	0.00	637.32
75 822 006 20	307	162.71	0	0.00	6	2.16	0.00	216	4300	0.00	0.00	109.80	370.50	645.17
75 827 006 20	307	155.82	0	0.00	6	2.16	0.00	224	4216	0.00	38.00	61.65	313.50	571.13
75 835 006 20	263	138.86	0	0.00	10	3.60	0.00	148	4384	50.00	0.00	96.97	267.00	536.43
75 839 006 20	167	88.51	0	0.00	0	0.00	0.00	104	2188	0.00	0.00	43.43	247.00	378.99
75 863 006 20	178	94.34	0	0.00	6	2.15	0.00	107	2282	0.00	19.00	74.47	418.00	607.97
75 864 006 20	213	110.63	0	0.00	2	0.72	0.00	140	2990	50.00	0.00	81.48	399.00	641.83
75 865 006 20	122	79.65	0	0.00	5	1.80	0.00	35	1413	0.00	0.00	61.41	627.00	769.85
75 866 006 20	293	159.23	0	0.00	6	2.16	0.00	209	3548	50.00	0.00	100.35	503.60	815.24
721093 006 20	526	278.88	0	0.00	13	5.04	0.00	718	9760	206.25	389.50	0.00	0.00	879.67
71 143 020 40	983	531.37	0	0.00	30	11.30	0.00	550	9757	67.35	256.50	0.00	0.00	866.52
75 165 020 11	334	177.54	0	0.00	5	1.80	0.00	89	3120	0.00	0.00	42.27	646.00	867.61
72 222 020 20	913	483.91	0	0.00	43	16.04	0.00	236	11132	247.37	541.50	0.00	114.00	1402.82
74 233 023 28	1355	723.92	0	0.00	39	14.29	0.00	372	15657	9.97	95.00	0.00	0.00	843.18
74 263 023 20	660	355.82	0	0.00	15	5.66	0.00	176	5269	6.50	96.00	0.00	0.0	463.98
74 275 023 20	707	424.16	0	0.00	19	6.97	0.00	189	7209	0.00	0.00	25.16	190.00	646.29

Table B.1 M.T.C.'s Computer Print-outs on Running Costs for Motor Vehicles, First Two Quarters (April Through September), 1975.

2ND QTD - SEP 1975 DISTRICT 01

VEHICLE YR	NO	CL	MK	GASOLINE GALS	GASOLINE AMT	FUEL OIL GALS	FUEL OIL AMT	MOTOR OIL QTS	MOTOR OIL AMT	MISC AMOUNT	TOTAL HOURS	TOTAL MILES	PARTS COST	LABOUR COST	AUX PARTS	AUX LABOUR	TOTAL COST
75	156	000	71	755	527.78	0	0.00	7	4.67	19.09	0	11840	0.00	0.00	77.13	319.09	1008.60
75	164	000	71	1183	835.72	0	0.00	21	29.76	42.57	0	19947	38.04	171.00	77.15	313.50	1507.74
75	178	000	84	17	10.59	0	0.00	0	0.00	2.50	0	195	0.00	0.00	0.00	0.00	13.09
72	216	000	28	164	93.70	0	0.00	10	4.20	5.00	0	2606	0.00	0.00	0.00	0.00	102.90
72	219	000	28	156	90.11	0	0.00	2	2.32	0.00	0	2211	54.45	0.00	0.00	0.00	146.83
72	234	000	28	312	208.59	0	0.00	5	6.24	17.08	0	5544	17.72	57.00	0.00	0.00	306.53
72	241	000	28	553	335.44	0	0.00	12	10.38	31.24	0	10338	283.44	19.60	0.00	0.00	680.10
72	252	000	28	558	354.66	0	0.00	18	16.00	31.27	0	11086	51.19	28.50	0.00	0.00	481.62
74	298	000	37	244	171.51	0	0.00	8	10.24	32.15	0	4765	30.41	38.00	10.00	0.00	292.31
74	304	000	37	232	147.94	0	0.00	6	2.16	4.00	0	5026	50.12	0.00	7.20	0.00	219.42
74	314	000	11	1148	666.82	0	0.00	58	21.23	12.00	0	15886	197.13	342.00	0.00	0.00	1239.18
74	315	000	11	742	410.13	0	0.00	21	10.37	20.60	0	10383	750.29	323.00	0.00	0.00	1514.39
73	145	001	03	653	385.39	0	0.00	26	10.02	0.00	403	9741	86.31	323.00	0.00	0.00	804.72
73	429	001	03	752	443.45	0	0.00	24	8.96	0.00	470	10948	39.01	190.00	0.00	0.00	681.42
75	018	003	20	866	458.41	0	0.00	25	9.37	0.00	390	14350	0.00	0.00	26.88	228.00	722.66
74	087	003	20	739	388.51	0	0.00	22	7.98	0.00	379	11630	13.33	38.00	0.00	0.00	447.82
74	091	003	20	762	424.04	0	0.00	32	12.00	0.00	458	14205	39.20	152.00	0.00	0.00	627.24
74	092	003	20	700	371.00	0	0.00	29	11.09	0.00	474	12248	143.49	95.00	0.00	0.00	620.58
72	363	003	26	349	185.80	0	0.00	9	3.24	0.00	259	6448	24.77	223.25	0.00	0.00	437.06
72	373	003	26	413	217.52	0	0.00	8	2.94	0.00	407	6633	102.99	161.50	0.00	0.00	484.95
72	574	003	40	598	316.94	0	0.00	33	12.38	0.00	502	8822	18.61	142.50	0.00	0.00	490.43
72	779	003	40	604	320.12	0	0.00	23	8.64	0.00	416	10550	108.14	152.00	0.00	0.00	588.90
72	1023	003	20	595	316.06	0	0.00	20	8.48	0.00	370	9744	9.11	19.00	0.00	0.00	352.65
72	1024	003	20	497	265.00	0	0.00	22	8.34	0.00	379	10390	24.45	190.00	0.00	0.00	487.79
72	1025	003	20	567	311.35	0	0.00	13	5.04	0.00	483	10710	36.22	57.00	0.00	0.00	409.61
72	1026	003	20	604	319.38	0	0.00	31	11.94	0.00	431	13593	5.85	75.00	0.00	0.00	413.17
72	1028	003	20	490	271.71	0	0.00	22	11.94	5.68	279	6293	47.89	114.00	0.00	0.00	451.22

Table B.1 M.T.C.'s Computer Print-outs on Running Costs for Motor Vehicles, First Two Quarters (April Through September), 1975 (Cont'd.).

2ND QTR - SEP 1975 DISTRICT 10

VEHICLE YR	NO	CL	MK	GASOLINE GALS	GASOLINE AMT	FUEL OIL GALS	FUEL OIL AMT	MOTOR OIL QTS	MOTOR OIL AMT	MISC AMOUNT	TOTAL HOURS	TOTAL MILES	PARTS COST	LABOUR COST	AUX PARTS	AUX LABOUR	TOTAL COST
72	265	001	03	632	386.93	0	0.00	28	10.88	0.00	542	10921	101.95	479.75	0.00	0.00	979.51
74	446	001	90	505	286.34	0	0.00	17	6.44	0.00	420	12193	15.83	318.25	0.00	0.00	639.86
75	007	003	20	374	213.49	0	0.00	8	2.99	0.00	207	6237	0.00	0.00	99.22	237.50	553.19
75	008	003	20	228	116.61	0	0.00	6	2.16	0.00	141	3933	0.00	47.50	53.78	133.00	353.05
75	129	003	20	668	405.30	0	0.00	20	7.55	0.00	340	11638	25.48	66.50	95.86	351.00	962.69
75	131	003	20	587	332.16	0	0.00	28	10.33	0.00	394	11491	0.00	123.50	96.57	304.00	866.55
70	183	003	32	15	8.70	0	0.00	0	0.00	0.00	21	394	0.00	0.00	0.00	0.00	8.70
74	210	003	20	952	556.62	0	0.00	27	10.57	0.00	797	16847	44.01	393.00	0.00	0.00	991.20
74	215	003	20	335	189.64	0	0.00	17	6.42	0.00	423	5001	57.60	190.00	0.00	0.00	443.66
72	724	003	26	483	271.62	0	0.00	17	6.67	0.00	361	8692	165.33	166.25	0.00	0.00	609.87
75	736	003	20	127	70.90	0	0.00	0	0.00	0.00	137	2400	0.00	0.00	21.69	275.50	368.09
72	749	003	26	706	490.88	0	0.00	21	8.36	3.50	529	13150	98.98	265.00	5.10	190.00	1081.82
72	750	003	20	366	210.97	0	0.00	18	7.13	0.00	273	7069	44.00	133.00	0.00	0.00	395.90
72	1030	003	20	424	253.03	0	0.00	9	3.64	0.00	275	6272	71.10	104.50	0.00	0.00	432.27
72	1054	003	20	437	252.80	0	0.00	16	6.21	0.00	376	7876	104.24	256.50	0.00	0.00	619.75
72	1071	003	26	735	440.32	0	0.00	45	18.10	0.00	416	11736	133.10	199.50	0.00	0.00	791.02
73	1114	003	28	642	471.94	0	0.00	21	8.61	0.00	369	9370	172.30	228.00	0.00	0.00	880.85
73	1115	003	28	618	333.26	0	0.00	30	12.27	0.00	466	10243	70.83	180.50	0.00	0.00	596.86
73	1116	003	28	745	531.63	0	0.00	28	11.18	0.00	467	12462	113.34	199.50	0.00	0.00	856.65
73	1137	003	28	862	510.94	0	0.00	34	13.94	0.00	419	14002	178.94	418.00	0.00	0.00	1121.92
73	1184	003	20	730	410.45	0	0.00	21	8.01	0.00	561	10872	135.47	85.50	120.67	0.00	760.10
73	1193	003	11	642	368.93	0	0.00	18	7.38	0.00	648	9461	57.50	247.00	0.00	38.00	718.51
74	1261	003	11	839	478.23	0	0.00	25	10.15	0.00	428	14412	130.02	494.00	0.00	0.00	1112.40
71	178	006	40	558	317.48	0	0.00	20	8.20	0.00	431	7818	-17.95	275.50	0.00	0.00	583.23
74	336	006	20	793	590.70	0	0.00	22	9.02	0.00	559	12464	161.39	289.75	0.00	0.00	1050.86
74	427	006	20	831	597.56	0	0.00	25	10.45	0.00	461	12937	138.73	218.50	0.00	0.00	965.24
74	495	006	20	849	503.37	0	0.00	34	13.94	0.00	464	13344	122.65	465.50	0.00	0.00	1105.46

Table B.1 M.T.C.'s Computer Print-outs on Running Costs for Motor Vehicles, First Two Quarters (April Through September), 1975 (Cont'd.).

								2ND QTR - SEP 1975						DISTRICT 10			
VEHICLE				GASOLINE		FUEL OIL		MOTOR OIL		MISC	TOTAL	TOTAL	PARTS	LABOUR	AUX	AUX	TOTAL
YR	NO	CL	MK	GALS	AMT	GALS	AMT	QTS	AMT	AMOUNT	HOURS	MILES	COST	COST	PARTS	LABOUR	COST
72	604	005	20	475	277.30	0	0.00	26	10.65	0.00	331	7324	195.50	327.75	0.00	0.00	811.51
74	644	006	20	910	522.38	0	0.00	36	13.86	0.00	464	11591	304.58	199.50	17.83	0.00	1058.15
75	759	006	20	261	156.60	0	0.00	5	1.85	0.00	193	3900	0.00	0.00	89.07	161.50	409.02
75	829	006	20	323	181.55	0	0.00	8	2.98	0.00	141	4161	0.00	0.00	73.32	301.00	558.85
75	830	006	20	233	130.46	0	0.00	5	2.05	0.00	161	3245	0.00	0.00	90.29	306.00	526.63
72	855	005	40	37	21.06	0	0.00	0	0.00	0.00	23	109	10.06	76.00	4.78	114.00	225.90
75	805	005	20	295	159.88	0	0.00	5	2.05	0.00	209	3846	0.00	0.00	103.31	180.50	445.74
73	1233	006	20	796	429.77	0	0.00	33	13.13	0.00	605	12489	140.64	147.25	0.00	0.00	730.79
69	112	016	32	355	218.87	0	0.00	12	4.47	0.00	273	3089	19.88	114.00	0.00	0.00	357.22
74	133	020	20	739	418.13	0	0.00	19	7.29	0.00	236	7476	67.60	308.75	0.00	0.00	801.77
72	229	020	20	980	550.75	0	0.00	37	14.17	0.00	346	12349	102.76	636.50	0.00	57.00	1361.18
74	264	020	20	430	243.23	0	0.00	4	1.57	0.00	116	5503	14.67	95.00	0.00	76.00	430.4[illegible]
73	380	020	20	1304	733.06	0	0.00	44	16.79	0.00	412	15681	266.69	399.00	132.19	39.00	1585.73
75	168	025	11	134	72.18	0	0.00	0	0.00	0.00	45	1259	0.00	0.00	362.92	1263.50	1698.60
73	250	025	11	977	591.23	0	0.00	19	7.39	0.00	503	10626	113.83	123.50	14.55	135.50	986.00
73	159	030	11	1384	777.56	0	0.00	38	14.73	0.00	638	10325	481.55	128.25	0.00	0.00	1402.09
75	102	031	20	237	130.35	0	0.00	1	0.36	0.00	134	2189	-61.06	0.00	523.45	2555.50	3148.61
75	114	031	20	317	249.23	0	0.00	6	2.46	0.00	130	2642	145.37	1919.00	329.57	57.00	2701.63
75	125	031	20	298	166.94	0	0.00	1	0.35	0.00	141	2153	15.70	104.50	315.60	2013.00	2636.10
75	127	031	20	170	88.40	0	0.00	0	0.00	0.00	141	1532	-23.84	228.00	224.63	2061.50	2578.69
71	141	031	20	659	371.49	0	0.00	25	10.10	0.00	484	6077	142.53	237.50	0.00	0.00	761.67
72	153	031	26	1240	727.10	0	0.00	49	19.11	0.00	539	10089	96.71	1026.00	22.55	190.00	2082.16
74	210	031	40	1117	829.13	0	0.00	30	12.15	0.00	476	8188	98.21	475.00	0.00	0.00	1414.62
70	232	031	20	356	217.82	0	0.00	21	8.51	0.00	219	3998	9.59	52.25	0.00	0.00	288.27
71	274	031	26	647	492.32	0	0.00	25	10.25	0.00	417	7344	160.03	76.00	0.00	0.00	738.60
71	285	031	20	323	464.78	0	0.00	16	6.56	0.00	477	5267	17.89	237.50	0.00	0.00	726.73
72	301	031	20	730	391.10	0	0.00	10	4.19	0.00	613	5161	0.00	76.00	0.00	0.00	471.20

Table B.1 M.T.C.'s Computer Print-outs on Running Costs for Motor Vehicles, First Two Quarters (April Through September), 1975 (Cont'd.).

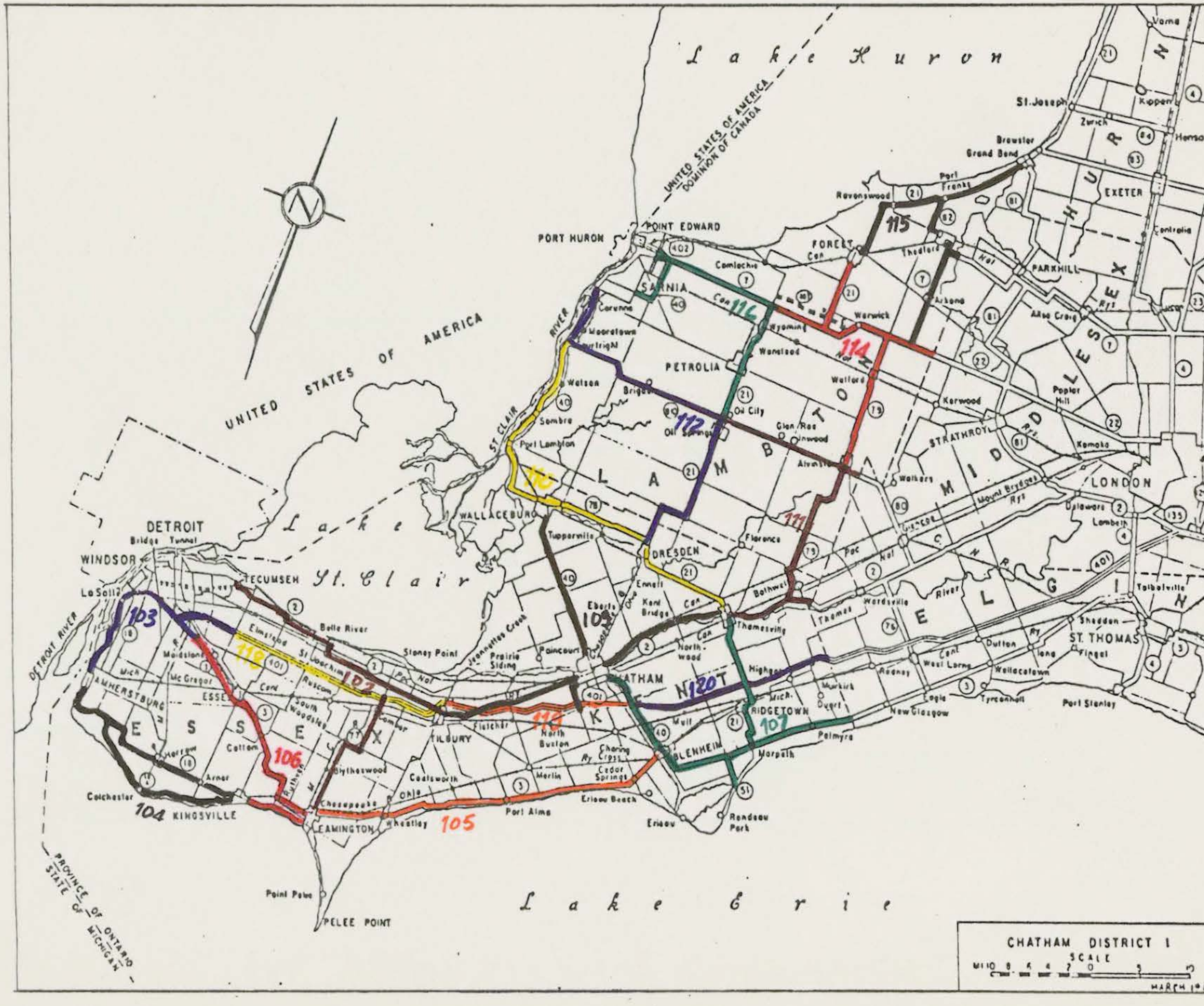


Figure B.1 Plan for District Number One with Patrol Links Shown

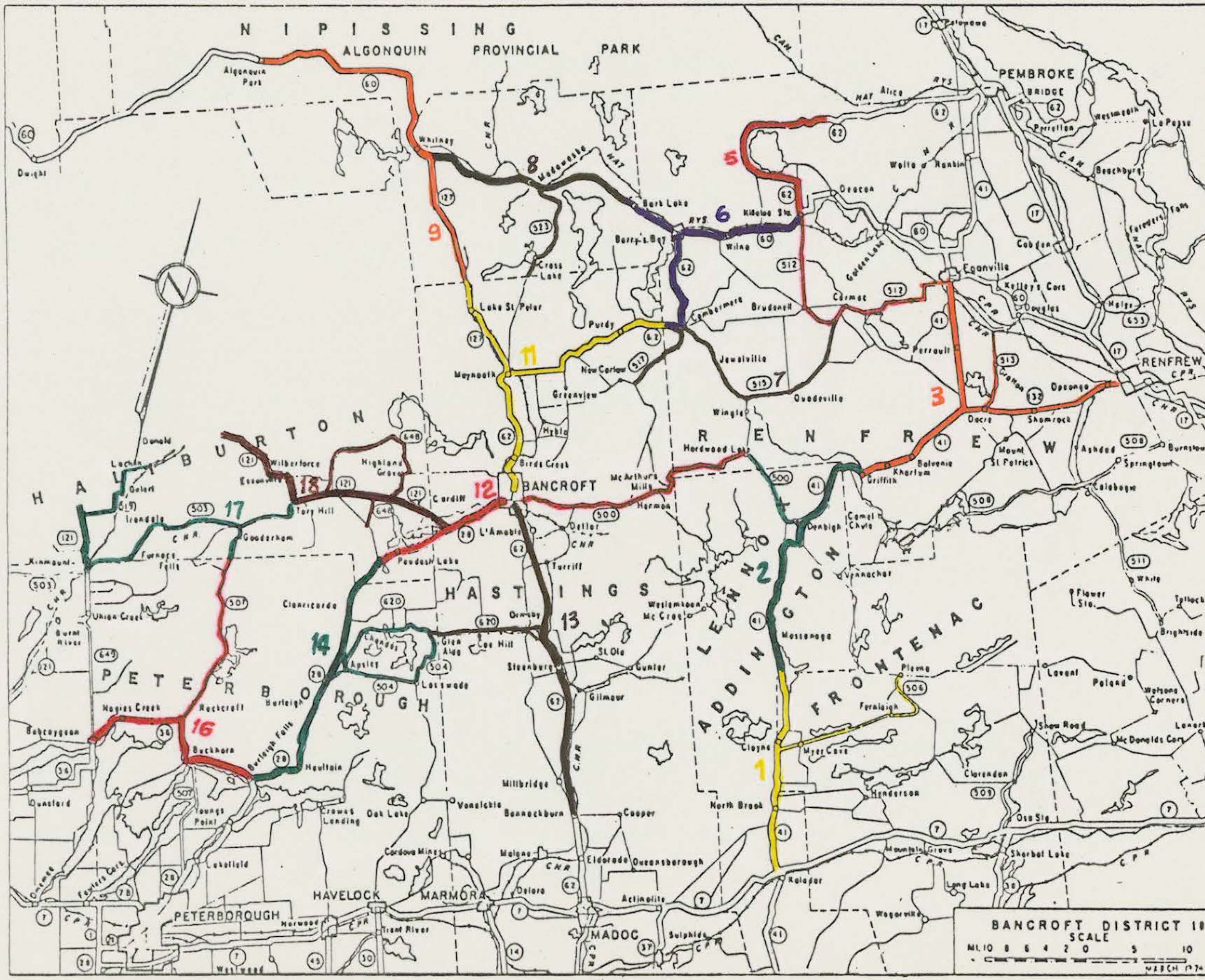


Figure B.2 Plan for District Number Ten with Patrol Links Shown

DISTRICT #: 10 COUNTY: VICTORIA TOWNSHIP: SOMERVILLE

HIGHWAY #: 121 PATROL LINK #: 17 PLAN #: C375-10

Vertical Curves			Land marks & Comments	Horizontal Curves		
Station	Slope (%)	Dist.		Station	D or Δ	L
0+00			ELEV. 925.0			
1+00	-0.8			PC 1+84.34	D=24°LT	
3+00	-2.5		(HWY 503) (KINMOUNT)	EC 2+90.17		
4+00	-1.0					
5+00	-3.0		BURNT RIVER			
6+00	-0.8					
9+00	+0.1		(HWY 503)			
10+00	-0.7			BC 10+33.52	D=11°LT	
12+00	+0.9			EC 12+57.00		
13+00	0					
15+00	-0.3			PC [illegible]	D=7°LT	
19+00	0			EC 21+41.10		
20+00	+0.3					
22+00	+2.0			BC 21+66.74	D=16°LT	
23+00	+2.6			EC 23+55.33		
24+00	+2.0		ELEV. 924.5			
26+00	+0.2			BC 25+50.24	[illegible]	
27+00	+1.0			EC 26+50.55		
28+00	+2.1					
29+00	+1.0			BC 27+63.71	D=7°RT	
30+00	-0.8			EC 30+61.33		
32+00	-6.0					
35+00	-2.1			PC 36+39.33	D=1°LT	
36+00	-0.9			EC 43+26.27		
37+00	-0.1					
39+00	+1.0			PC [illegible]	D=2°LT	
41+00	+3.5			EC 55+09.75		
42+00	+2.1					
43+00	-3.4			PC 53+89.16	D=4°RT	
44+00	-3.0			EC 72+55.27		
45+00	-2.1					
46+00	-0.5					
47+00	+1.1					
49+00	+2.0		ELEV. 923.0 Test Run #2			

Table B.2 Sample of Data Collected from Survey Plans on Geometric Characteristics of Patrol Links.

Table B.3 Details on Selected Test Run Sections

Test Run	1	2	3	4	5	6	7
Highway	519	121	503	507	62	127	62
Survey Plan #	C843-1	C375-10	C876-11	876-507	516-62	568-127	853-62
Station @ Beginning	0+00	49+00	210+40	100+00	590+00	127+00	270+00
Station @ End	264+00	212+40	356+00	321+20	695+60	242+60	448+40
Length (ft.)	26400	16340	14560	22120	10560	11560	17840
Length (mi.)	5.00	3.09	2.76	4.19	2.00	2.19	3.38
Elevation at Start	1074.7	923.0	1052.3	1166.0	1614.0	1302.0	1356.0
Elevation at End	1086.1	1071.8	1067.0	1067.1	1410.1	1302.0	1077.7
Diff. in Elev (ft)	11.4	148.8	14.7	98.9	203.9	0.0	278.3
Average Slope(ft/mile)*	2.28	48.16	5.33	23.60	101.95	0.0	82.33
Land marks located near or at test run section	Jct. Hwy 121 @ Sta. 0+00	Jct. Hwy 519 @ Sta. 256+21.0	Jct. Hwy 507 @ Sta. 356+00	Boundary of Peterboro County @ Sta. 100+00	Jct. Hwy 127 @ Sta. 695+60	Jct. Hwy 62 is at Sta. 100+00	Jct. Hwy. 62 @ Sta. 448+40

* Average slopes shown here are obtained from survey plans, and they do not completely agree with slopes (grade in ft/mi) obtained by calculation using the computer program and shown in Table 4.6A. This discrepancy is a result of inaccuracy in collecting geometric characteristics data.

DISTANCE/ROAD EFFECTS FUEL CONSUMPTION TEST.

TEST No 7 DATE. Oct 26 VEHICLE No. 74-318-000-11

FUEL Reg. API GR. ______ TIRES - GR78x15 FIRESTONE.

5TH WHEEL - LABECO - SER. 1573. - 30 PSI. INFLATION

FUEL METER - FLUIDYNE - 0104/1396 DRIVER. Bob

DIRECT. South TEST. ROAD 1215 Rt. 579 (2) SPEED 50 OBSERVER.

DIST.	RDG. ml.	DIST.	RDG. ml.	DIST.	RDG. ml.	DIST.	RDG. ML.	DIST.	RDG. ml.
0-0		1-0		2-0		3.0		4.0	
0-500	18	=	229	=	438	500	658		
0-1000	38	=	248	=	463	660	660		
0-1500	56	=	261	=	486				
0-2000	77	=	275	=	508				
0-2500	95	=	292	=	527				
0-3000	112	=	320	=	550				
0-3500	135	=	354	=	570				
0-4000	167	=	380	=	580				
0-4500	191	=	390	=	607				
0-5000	206	=	397	=	638				
1-0	211	2-0	410	3.0	648	4.0		5.0	

Wind increasing
~~Tailwind~~

Time 220.0
Fuel Temp. 22°C.
Air Temp. 66°F

DIRECTION - North.

DIST.	RDG. ml.	DIST.	RDG. ml.	DIST.	RDG. ml.	DIST.	RDG. ml.	DIST.	RDG. ml.
0-0		1-0		2-0		3.0		4.0	
0-500	41	=	316	=	596	500	864		
0-1000	76	=	339	=	626	660	868		
0-1500	86	=	369	=	662	=			
0-2000	103	=	409	=	684	=			
0-2500	153	=	432	=	698	=			
0-3000	195	=	446	=	719	=			
0-3500	220	=	462	=	748	=			
0-4000	237.	=	491	=	778	=			
0-4500	253	=	523	=	801	=			
0-5000	281	=	554	=	827	=			
1-0	293	2-0	568	3-0	840	4.0		5.0	

Wind increasing
Headwind.

Time 217.4
Fuel Temp. 22°C
Air Temp 65°F.

Table B.4 Sample of Data Collected on Gasoline Consumption Measurements.

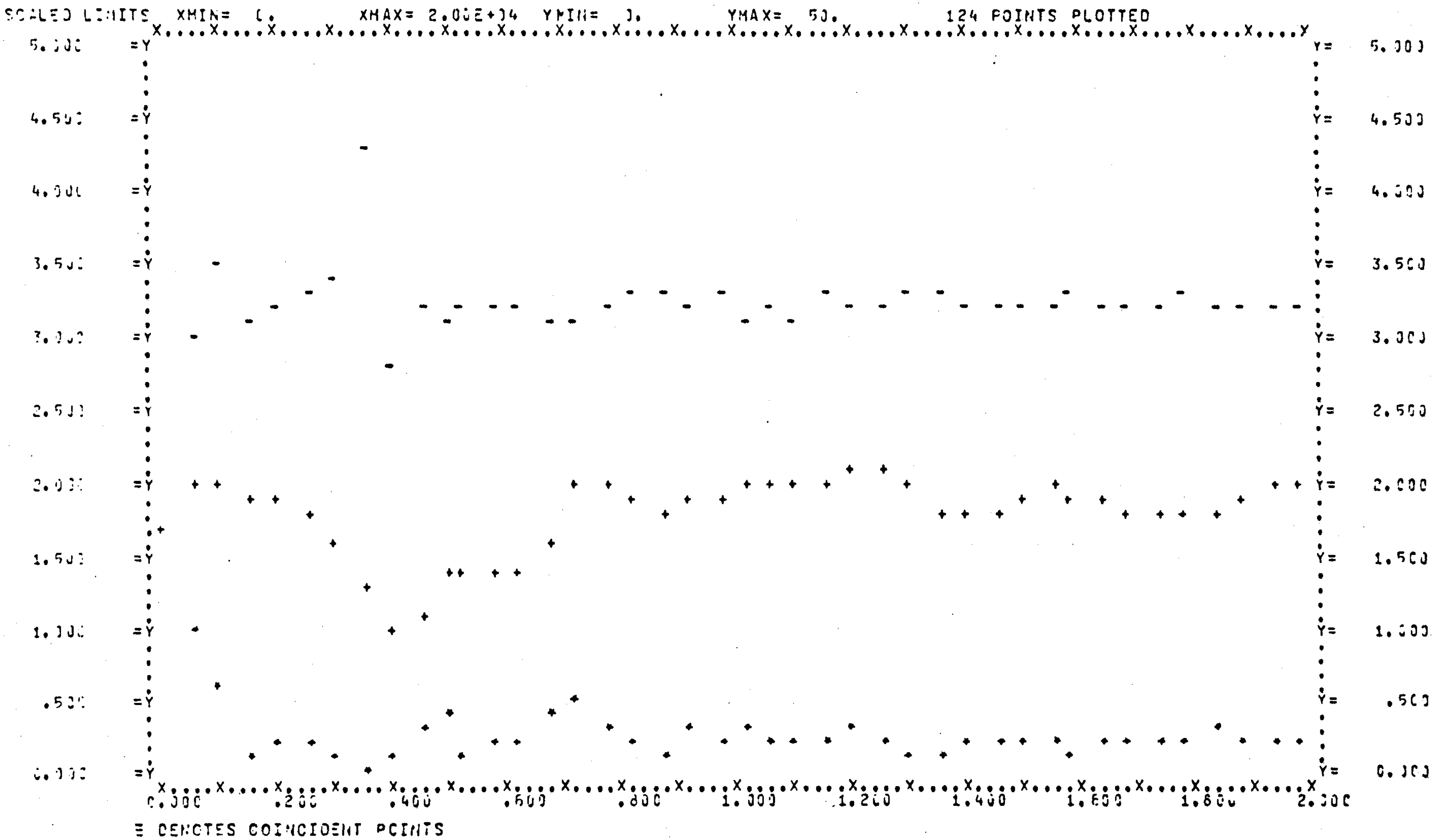


Figure B.3 Print-out on Gasoline Consumption Data for Test Run Number One

Figure B.3 Print-out on Gasoline Consumption Data for Test Run Number One (Cont'd)

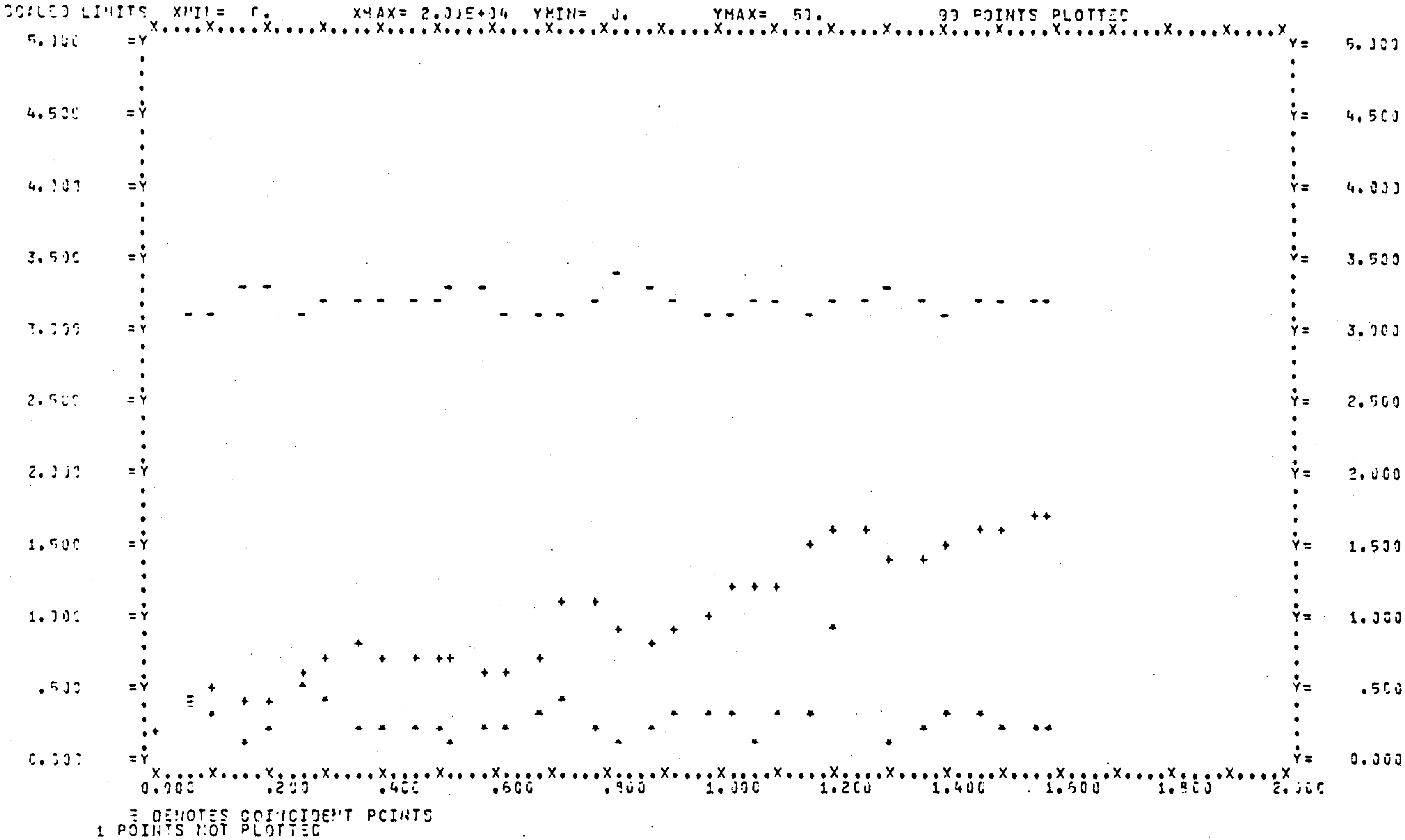


Figure B.4 Print-out on Gasoline Consumption Data for Test Run Number Two

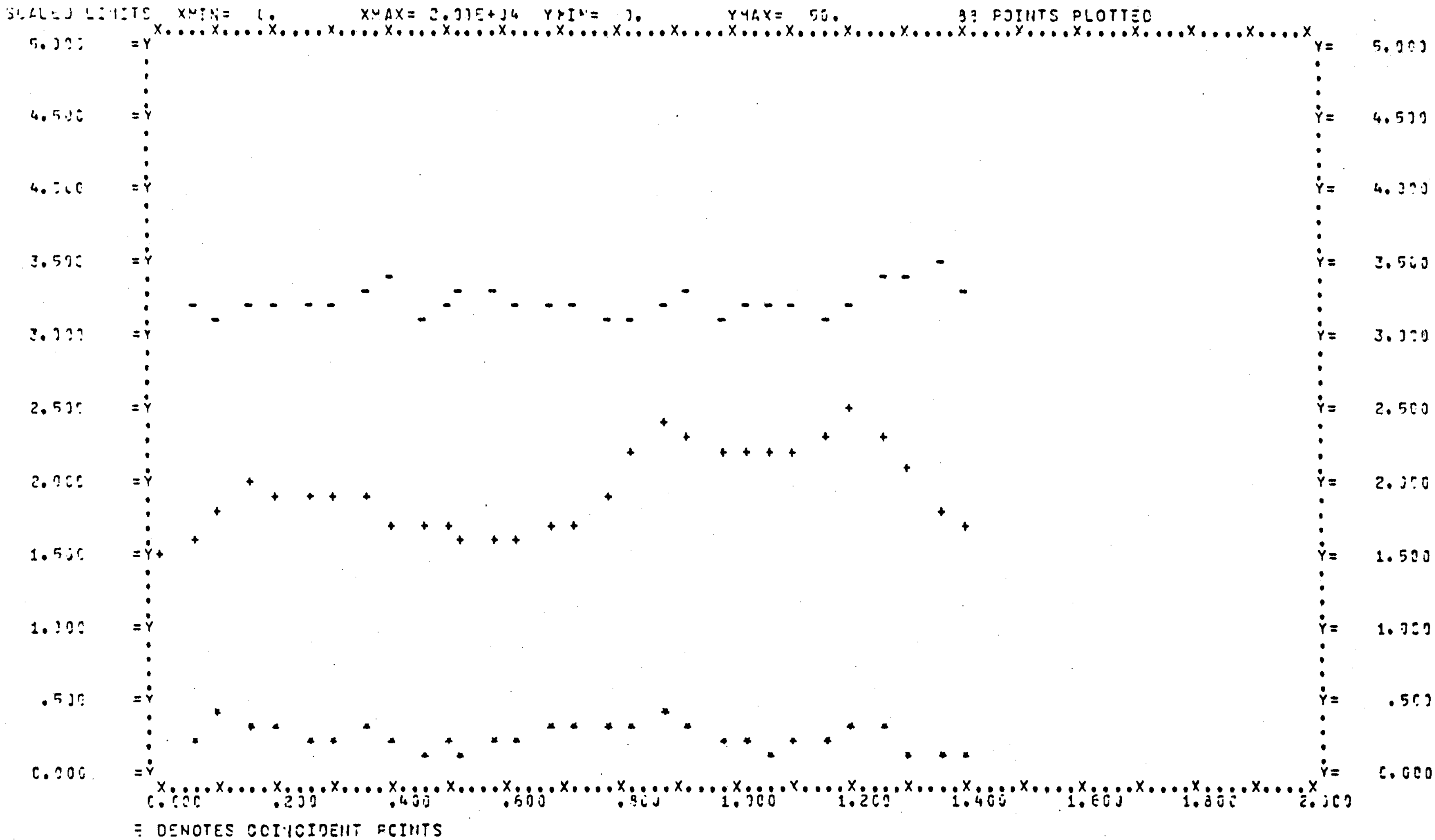


Figure B.5 Print-out on Gasoline Consumption Data for Test Run Number Three

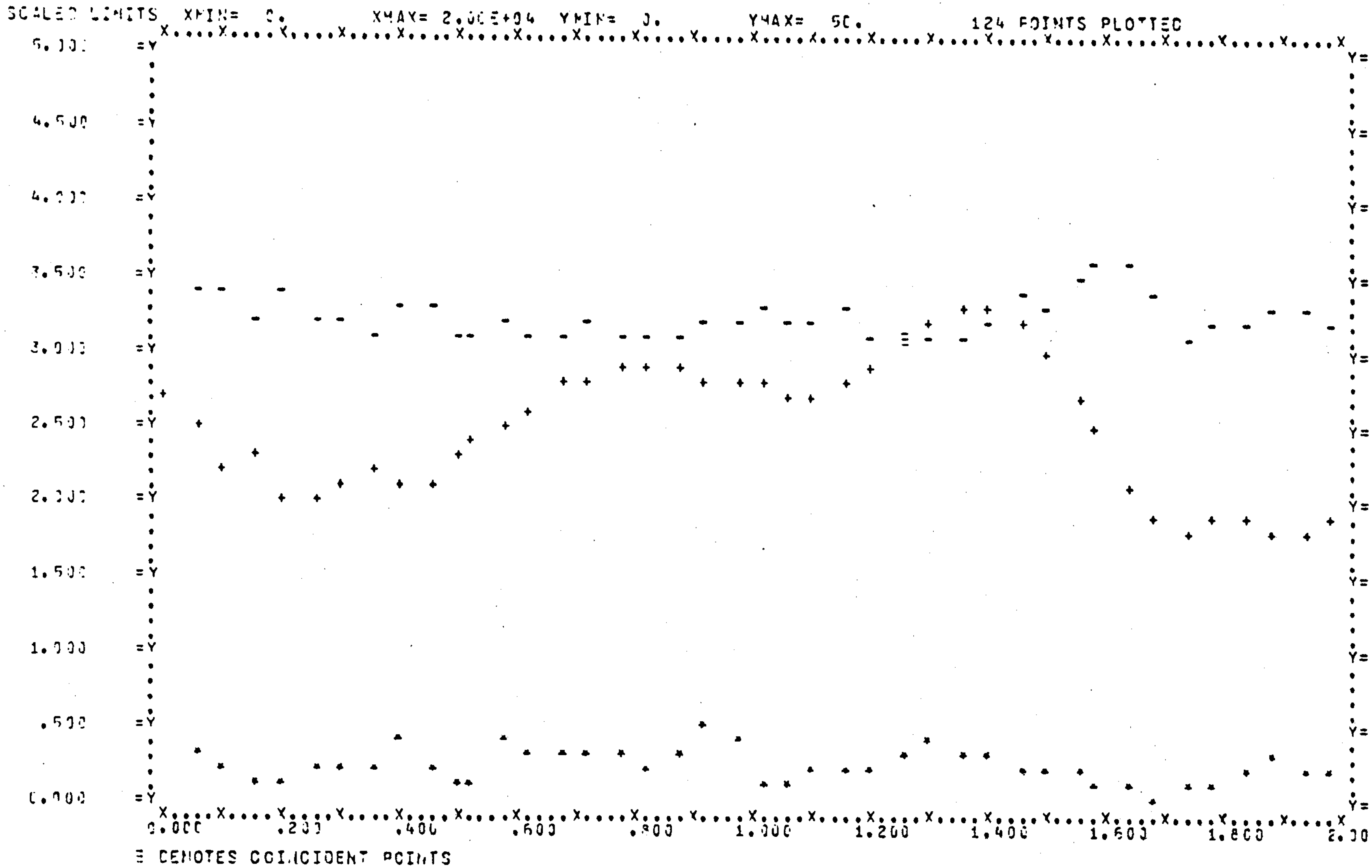


Figure B.6 Print-out on Gasoline Consumption Data for Test Run Number Four

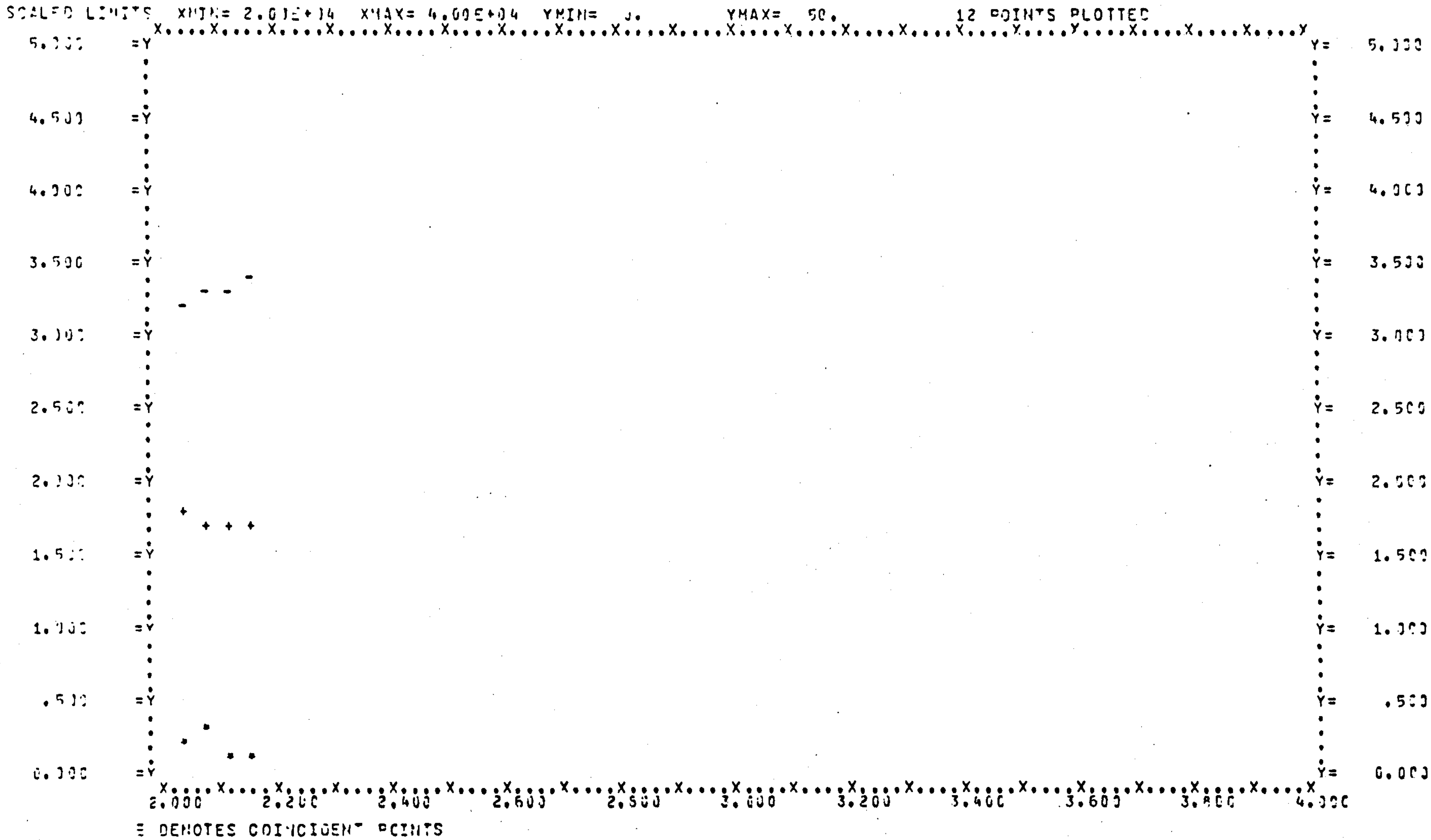


Figure B.6 Print-out on Gasoline Consumption Data for Test Run Number Four (Cont'd)

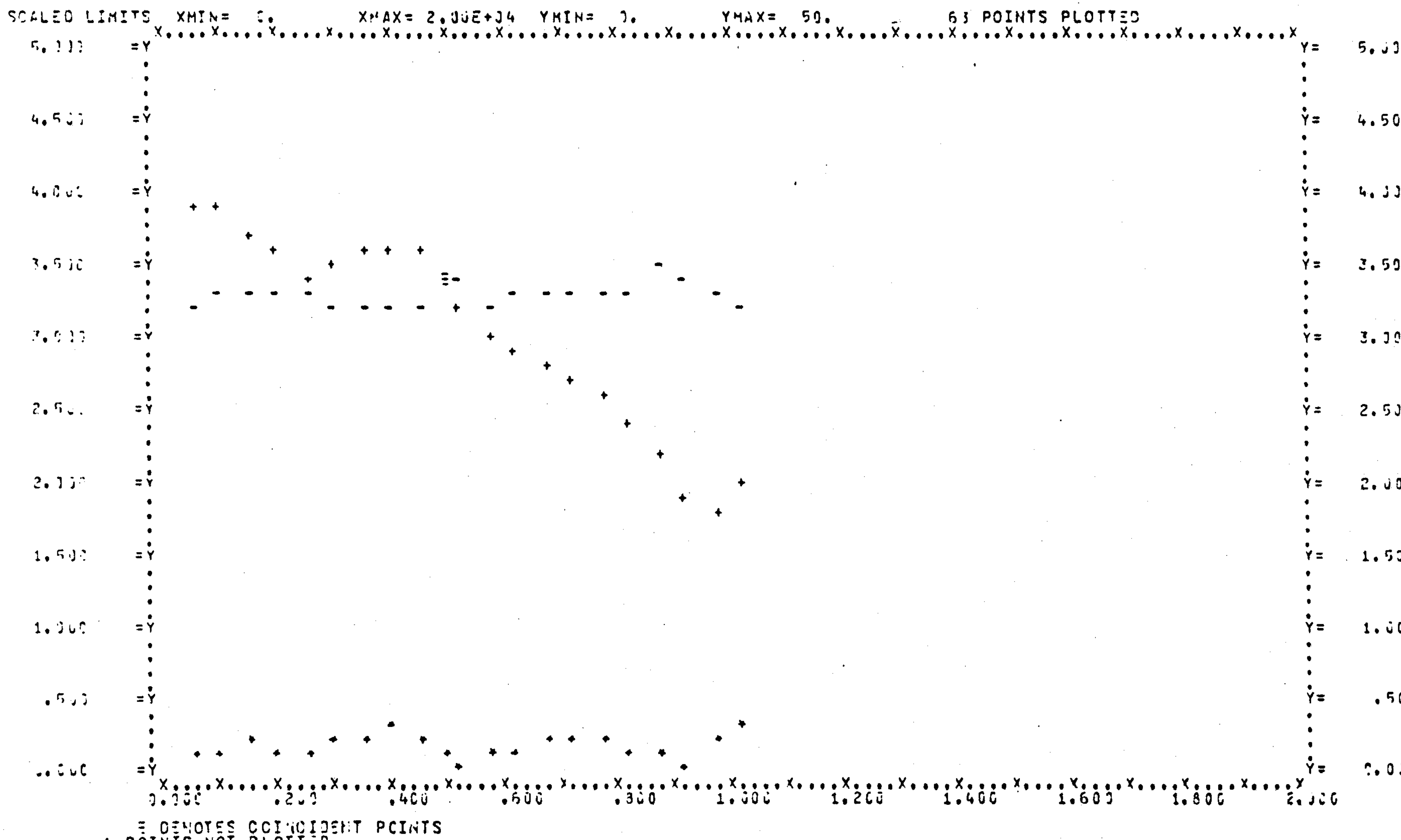


Figure B.7 Print-out on Gasoline Consumption Data for Test Run Number Five

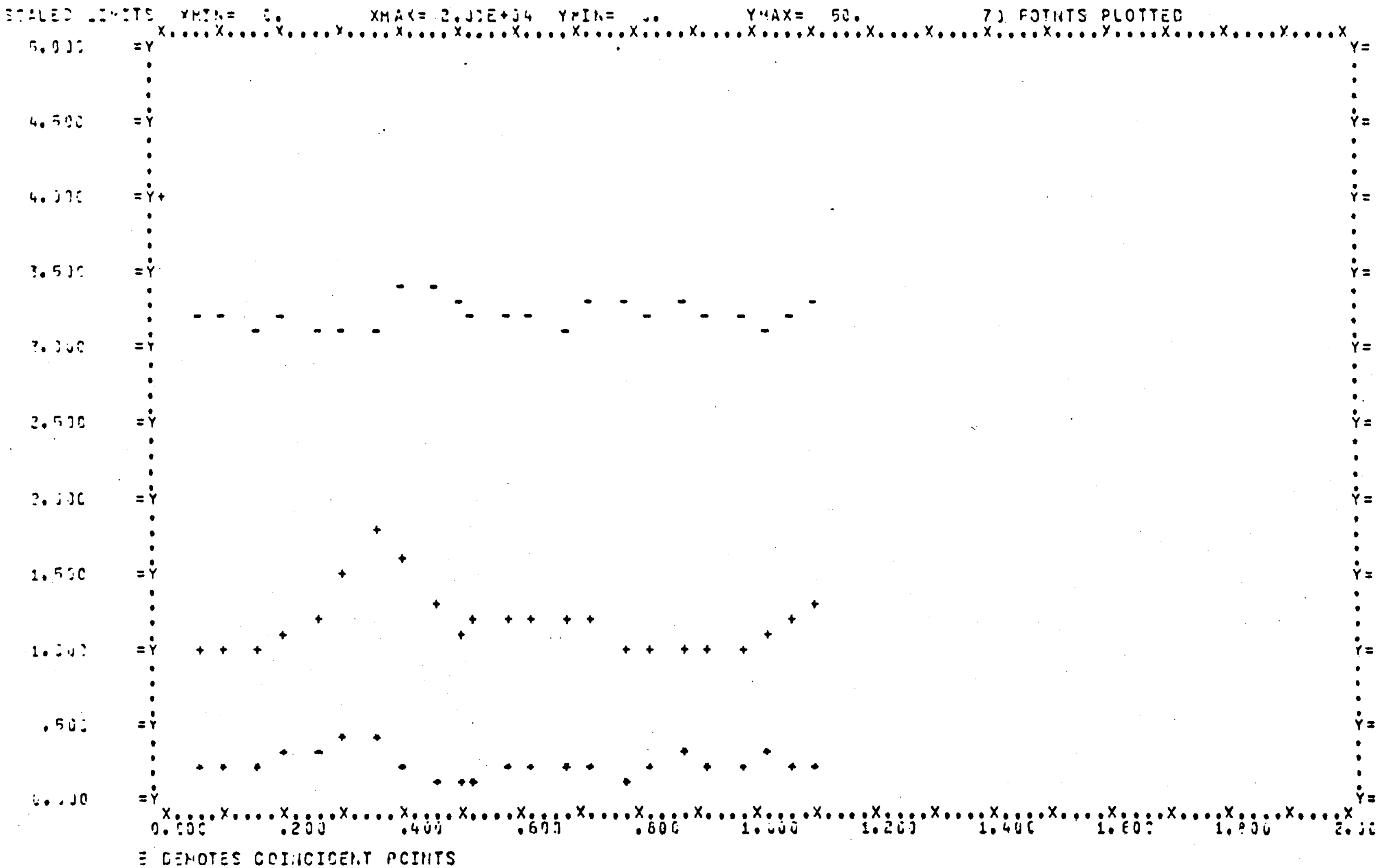


Figure B.8 Print-out on Gasoline Consumption Data for Test Run Number Six

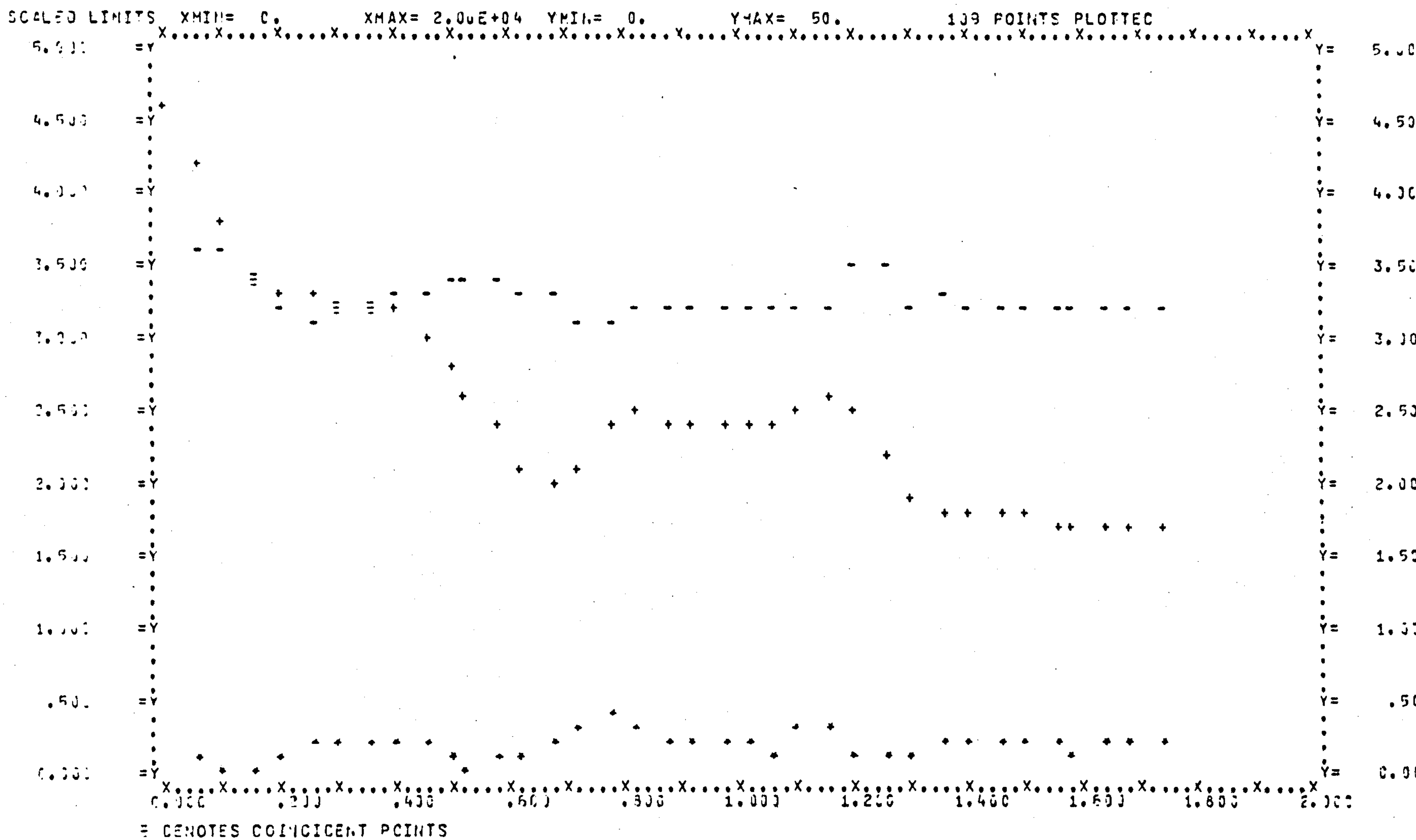
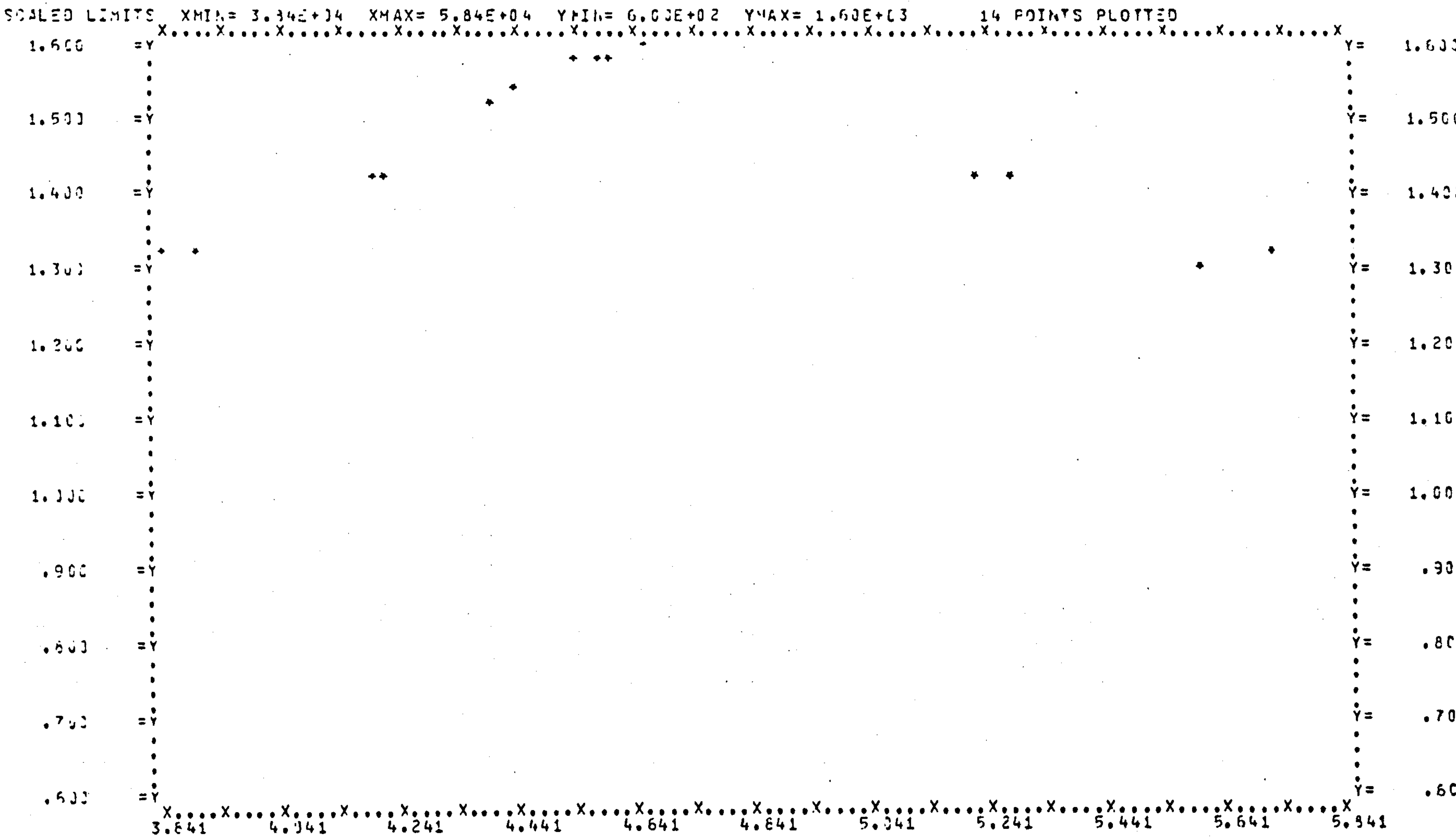


Figure B.9 Print-out on Gasoline Consumption Data for Test Run Number Seven.

DISTRICT NUMBER 10.00
HIGHWAY NUMBER 60.00
PATROL LINK 8.00



= DENOTES COINCIDENT POINTS

Figure B.10 Sample of Print-outs on Geometric Characteristics Data and Elevation Plot for Patrol Links.

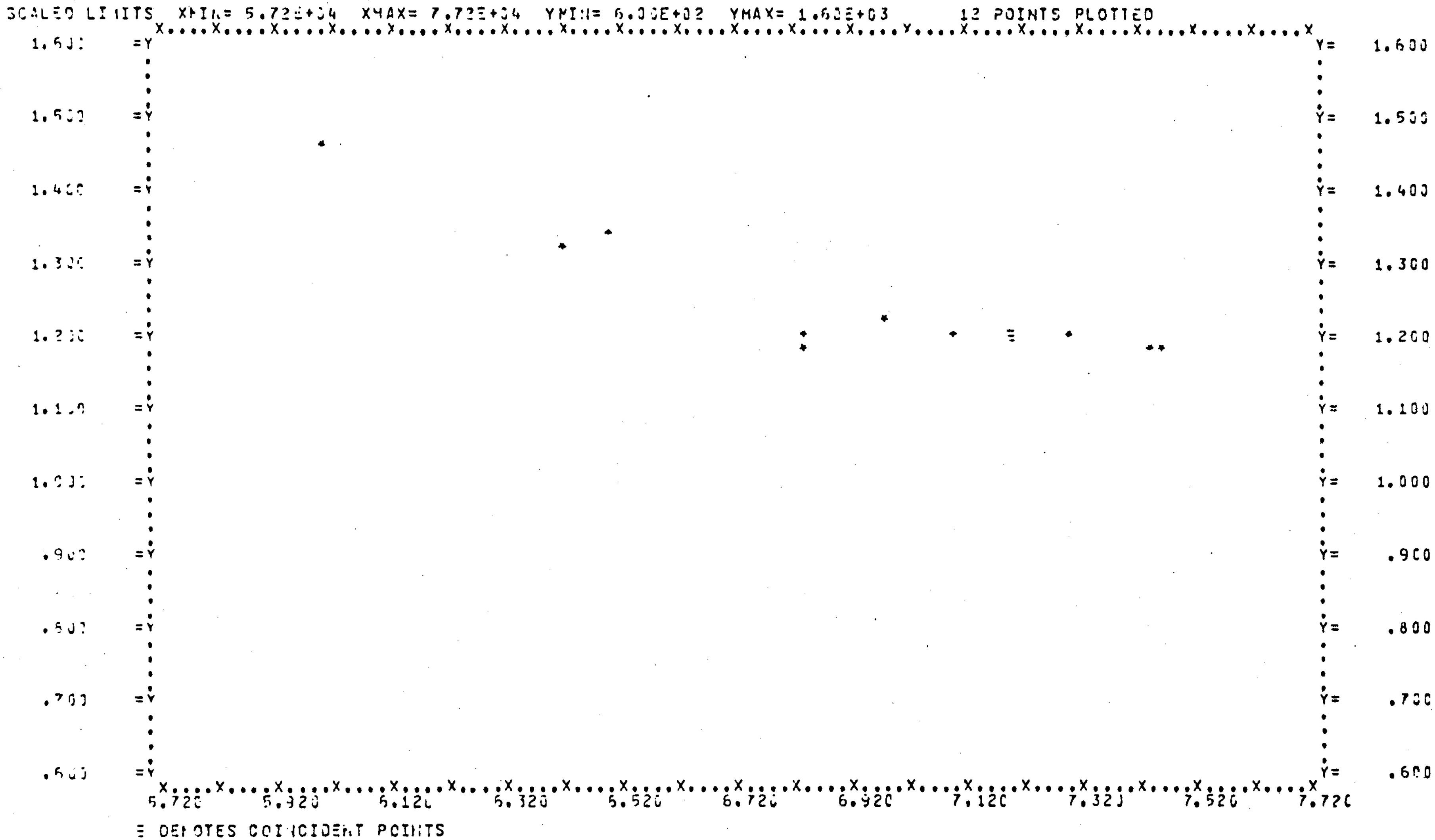
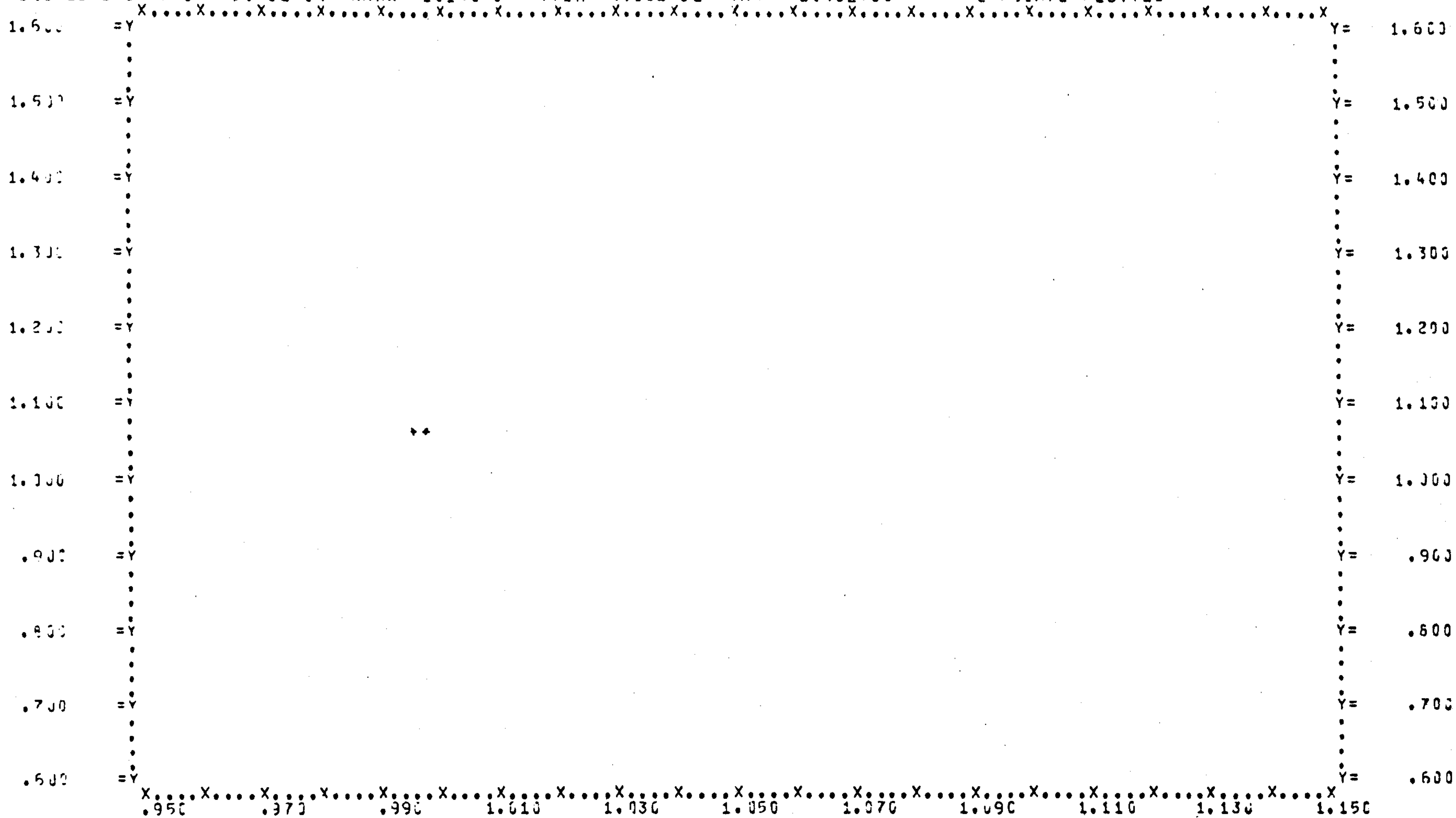


Figure B.10 Sample of Print-outs on Geometric Characteristics Data and Elevation Plot for Patrol Links (Cont'd.).

Figure B.10 Sample of Print-outs on Geometric Characteristics Data and Elevation Plot for Patrol Links (Cont'd.).

SCALED LIMITS XMIN= 9.50E+04 XMAX= 1.15E+05 YMIN= 6.00E+02 YMAX= 1.60E+03 2 POINTS PLOTTED



= DENOTES COINCIDENT POINTS

-1230.600 33800.000 989.307 24789.810 2666.390 61276.200 -192.236 -3.641 210.820 3.993 191.326 3.624 11.030

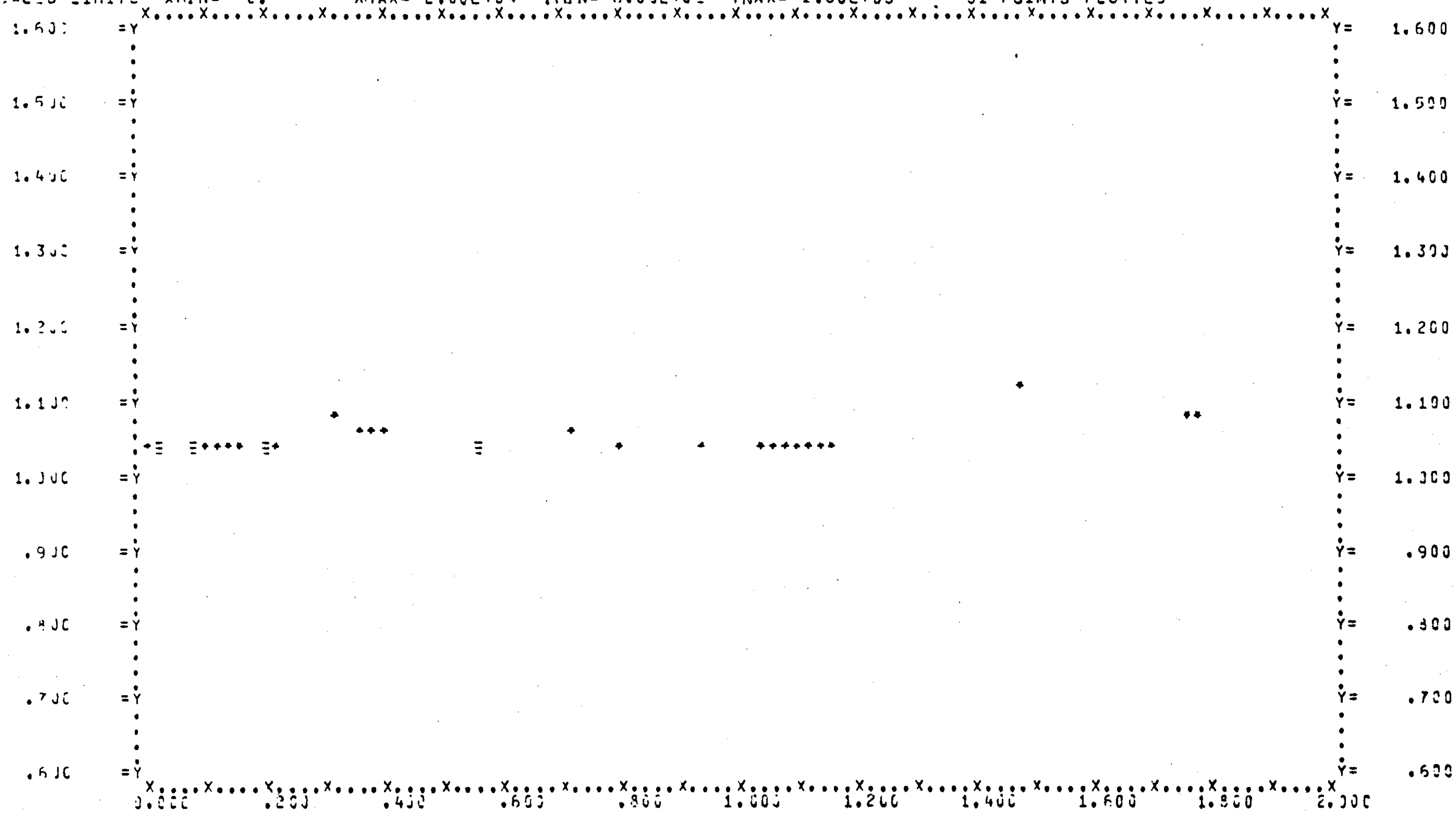
HORIZONTAL RESULTS

.41433E+01 .25396E+02 .85436E+04 .21075E+07

Figure B.10 Sample of Print-outs on Geometric Characteristics Data and Elevation Plot for Patrol Links (Cont'd.).

DISTRICT NUMBER 10.00
HIGHWAY NUMBER 523.00
PATROL LINK 8.00

SCALED LIMITS XMIN= 0. XMAX= 2.00E+04 YMIN= 6.00E+02 YMAX= 1.60E+03 31 POINTS PLOTTED



≡ DENOTES COINCIDENT POINTS

Figure B.10 Sample of Print-outs on Geometric Characteristics Data and Elevation Plot for Patrol Links (Cont'd.).

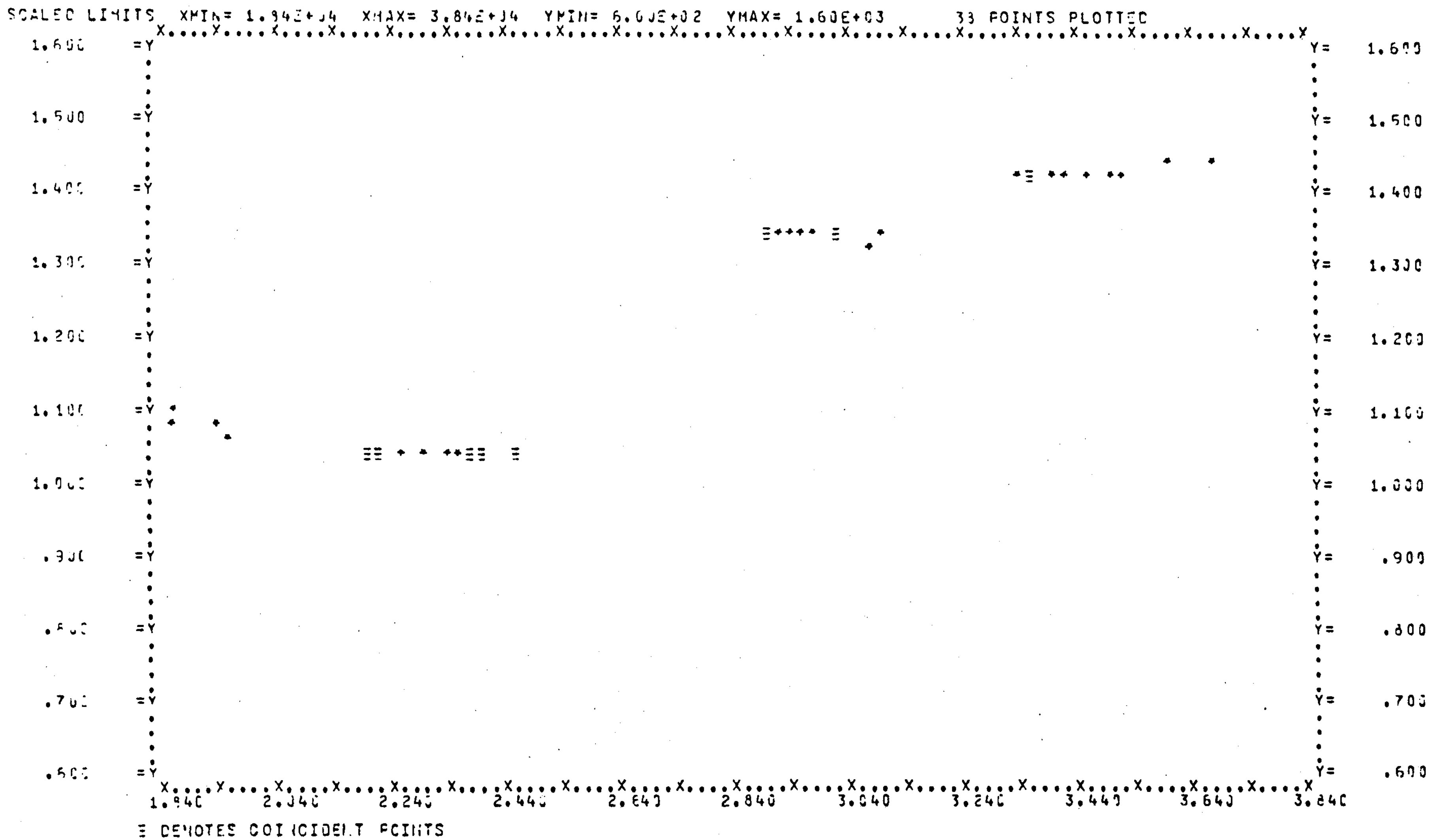
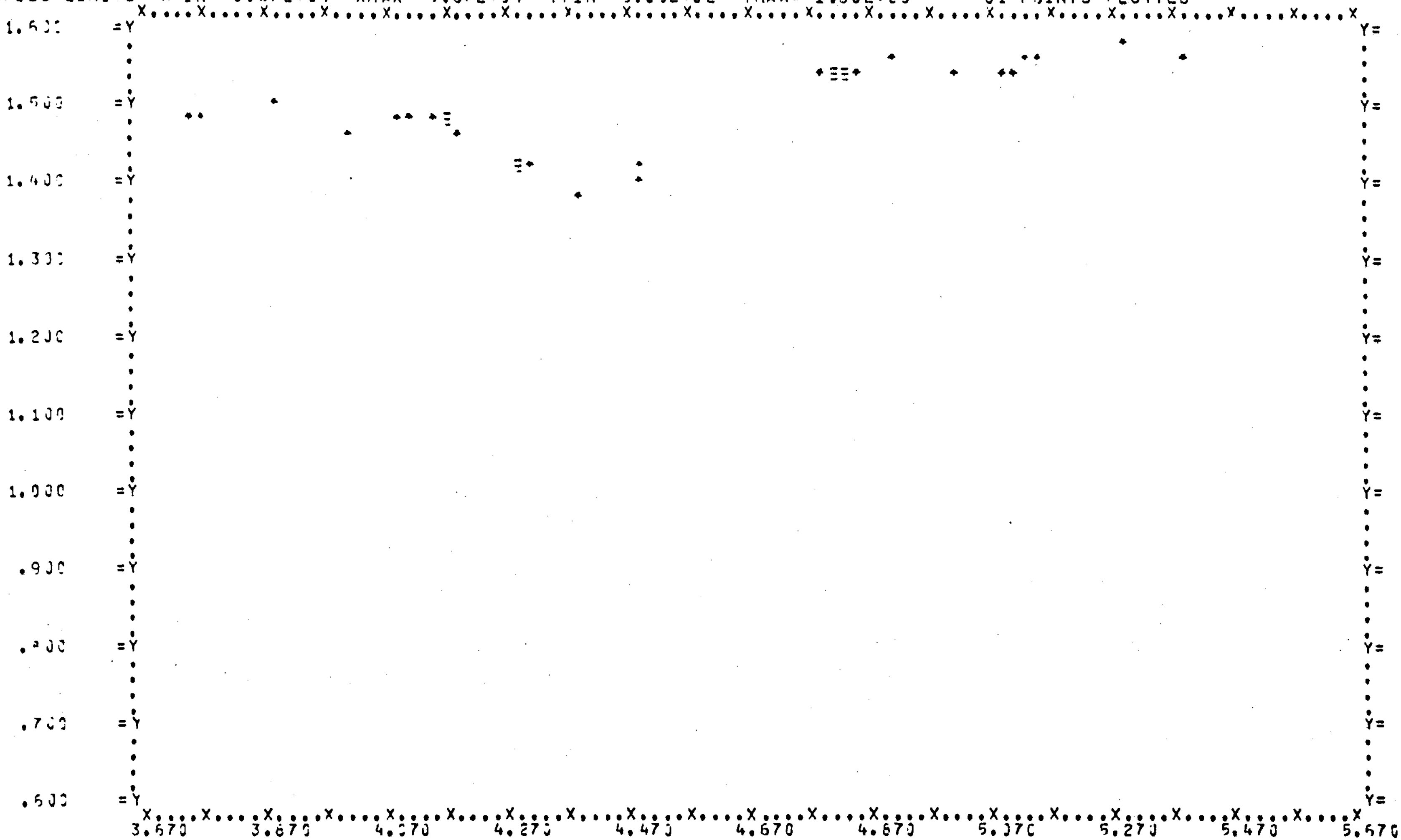


Figure B.10 Sample of Print-outs on Geometric Characteristics Data and Elevation Plot for Patrol Lins (Cont'd.).

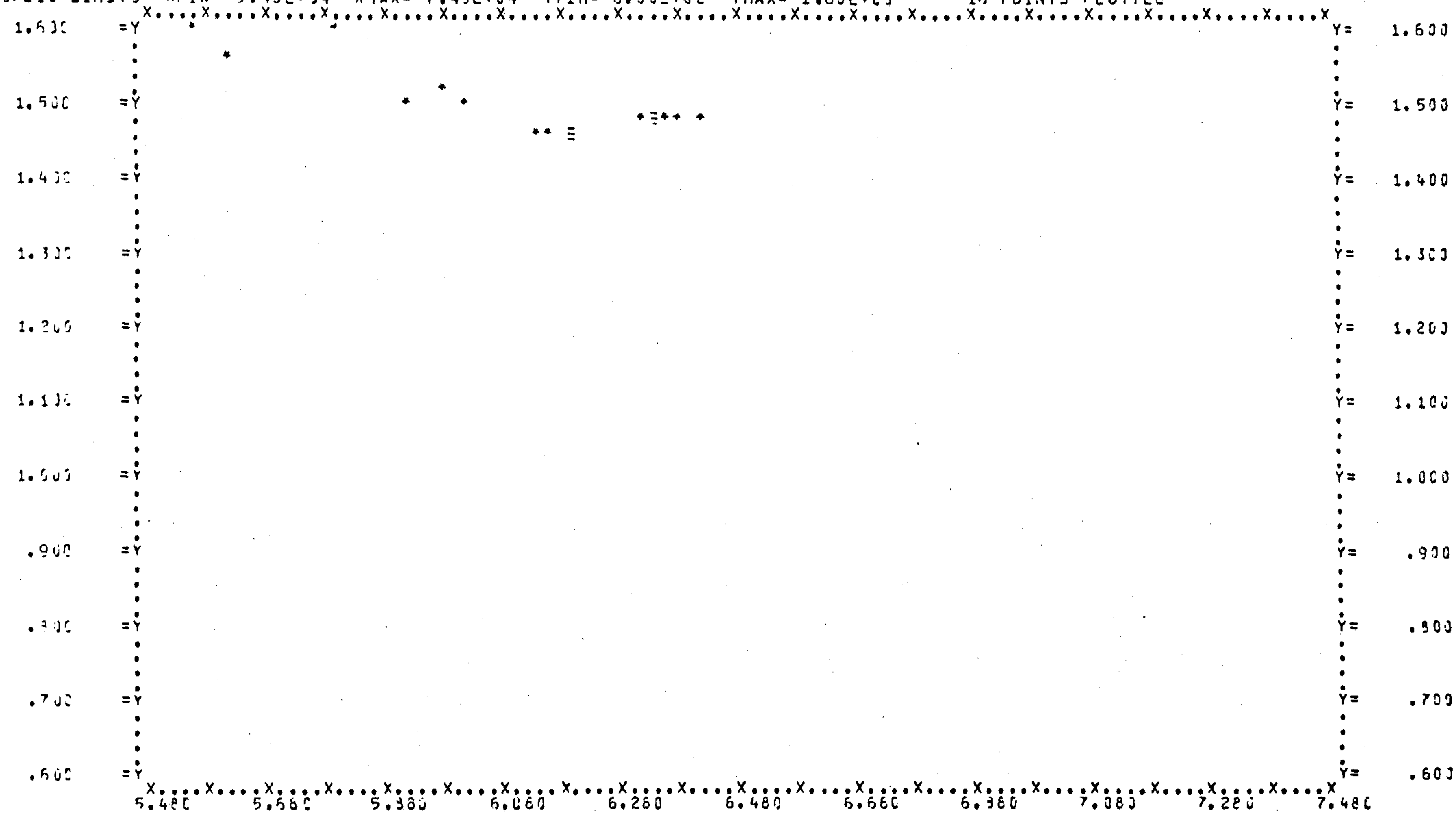
SCALED LIMITS XMIN= 3.67E+04 XMAX= 5.67E+04 YMIN= 6.00E+02 YMAX= 1.60E+03 31 POINTS PLOTTED



≡ DENOTES COINCIDENT POINTS

Figure B.10 Sample of Print-outs on Geometric Characteristics Data and Elevation Plot for Patrol Links (Cont'd.).

SCALED LIMITS XMIN= 5.48E+04 XMAX= 7.48E+04 YMIN= 6.00E+02 YMAX= 1.60E+03 16 POINTS PLOTTED



= DENOTES COINCIDENT POINTS

-653.610 22340.000 1146.669 37310.670 6400.030 66050.670 -154.479 -2.926 162.270 3.073 143.912 2.726 7.757

HORIZONTAL RESULTS

.64832E+02 .14644E+03 .29847E+06 .46320E+07

Figure B.10 Sample of Print-outs on Geometric Characteristics Data and Elevation Plot for Patrol Links (Cont'd.).