ESTIMATES OF TRANSPORTATION ENERGY SAVINGS WITH TRANSPORTATION MANAGEMENT MEASURES FOR VARYING CITY SIZE

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ABSTRACT

Since the early 1970's, fuel consumption in the transportation sector has been one of the major issues facing planners trying to conserve energy. Generally, fuel consumption is influenced directly by the number of vehicles, the distance travelled, the operating speed and the overall population of city.

Traffic engineers spent a great deal of time solving such a problem sometimes by introducing the concept of traffic management, the different actions and strategies that reduce the fuel consumption and some other times by estimating the energy saving to evaluate the effectiveness of these actions. Despite best efforts, energy savings estimation have shown wide fluctuations.

This study provides a preliminary investigation of the impact of city size, in the medium range, on potential energy savings accrued due to implementation of Transportation Energy Management Measures (TEMM's). The data sources used includes the energy savings for each of five city size groups, subjected to 23 TEMM's. These data were rearranged and regressed over city size by using the CURFIT technique. Formulae were derived for each of the TEMM's. For the purpose of verification, the Community Benefits Analysis program (CBA) was applied to test some of the obtained results. It is thus concluded that the resulting energy savings, using the regressed equations provide a reasonable way to predict potential benefits across the medium range of city sizes.

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The author wishes to dedicate this work to his parents, family and friends, whose encouragement, support, and understanding are gratefully appreciated; thank you father, thank you mother.

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1. INTRODUCTION

Since the beginning of this century, economic growth of industrial countries has been based on the availability of cheap, continuous, and abundant energy resources. Such availability can sharply increase industrial development, accelerate improvement in life styles, and also enhance the advantages and characteristics of modern communities.

In the early 1970s, due to international events, people on a world-wide basis realized that petroleum resources were finite and would not continue to be cheaper than other energy sources. In the late 70's and early 80's crude oil prices in Canada experienced a rapid increase; for example, the price of imported crude oil in Montreal increased sharply from $4 per barrel in 1973 to $43 per barrel in 1982 [1]. These sharp increases gave the indication that an energy shortage could be expected sooner or later. As a result, there was felt an essential need to identify energy saving approaches to meet the possibility of a prolonged and expected energy shortage, with resultant high costs.

Despite the rapid increases in oil prices, people still use oil as a major source of energy, particularly in the transportation sector. The transportation sector typically accounts for more than 52% of the total oil consumption in Ontario, reaching a total consumption of 191 million barrels annually (i.e., the annual bill is approximately $6 billion) [1]. Within this sector, auto and truck usage accounts for

80% of all oil consumption. Therefore, it was concluded that the urban transportation system was an important area where energy saving studies should be conducted to effect efficiency strategies, and consequently, to more effectively manage energy consumption. For example, considering only a 10% saving of consumed energy in the transportation sector, the Ontario provincial economy could be annually enhanced by hundreds of millions of dollars released for spending in other sectors. Such a saving basically depends on the adopted energy management strategies for the urban transportation system of Ontario's cities. These savings would obviously vary from city to city according to characteristics of each specific city. From the available information in the literature [2], it can be concluded that both energy consumption and savings are significantly influenced by the impact of city size. Therefore, it was deemed appropriate to study the elements of the urban transportation system that have a potential to save energy and to establish the impact of city size on such a saving.

The urban transportation system is essentially made up of three elements, the urban roadway system, the vehicles which use the roadway system and the people and goods occupying the vehicles. The complexity of an urban transportation system with associated demand patterns often introduces traffic congestion which is a major factor in increasing such urban mobility problems as energy consumption, noise, pollution, and accidents. The transportation system's function is to provide safe and efficient vehicular movement of people, goods and emergency services throughout the urban area. Unfortunately, this is often very difficult to achieve, particularly during the rush hours when demand exceeds the available capacity of that system.

In the mid-1970's, the Transportation System Management (TSM) process became a very popular response to investigate the impact of both higher costs and an unstable energy resource supply. TSM is a concept that develops strategies and actions to achieve maximum utilization of the existing roadway system with a minimum of capital-intensive additions to accommodate an increasing demand for service. Since the inception of TSM, traffic engineers have conducted numerous studies investigating the major factors that have a significant potential to reduce transportation energy consumption, identifying the interactions between these factors, and predicting how much energy could be saved through implementation.

In this regard, many specific studies have been conducted to determine the main traffic operational factors that cause additional fuel consumption such as delay, stops, and speed changes. The principal concern was to develop "new" techniques that could improve both the quantity served and service quality experienced by traffic flow on existing facilities. As one example, the Transportation Energy Management Program (TEMP) in Ontario was created to assist traffic engineers in reducing energy consumption [1]. This program summarized and focused the results of previous work and provided engineers with examples of several measures that could lead to reducing energy consumption in the urban transportation sector. TEMP also provided analytic techniques to estimate the impact, as well as documenting example applications to assist in the implementation of these measures.

Different attempts have been used by traffic engineers to estimate fuel consumption before and after implementing any Transportation Energy Management Measure (TEMM). Despite these attempts and due to the fact that only aggregate data has generally been collected during the last ten years, it was found that there was still a significant fluctuation in estimated energy saving values for specific locations and situations. Consequently, there was, and still is, a need to integrate available information on TEMM's that have a significant potential for energy savings, in a simple "model" which can guide traffic engineers to easily estimate energy savings with levels of confidence consistent for investigative planning purposes.

Therefore, the main objective of this study is to develop a simple and a flexible "model" to easily estimate energy savings for various TEMM's. This model is specifically developed for medium-sized cities ranging from a population of 50 to 350 thousands. Since the majority of commonly accepted TEMM's are generally viewed as applicable to cities in that range of sizes [2]. Ideally, potential energy savings would be simply determined as a function of city size for each measure; the extent to which this simplification is possible is implicitly addressed in this study.

The conduct of this study included a selected literature review of the findings of previous experience with transportation energy management programs which is presented in Chapter 2. This is followed by a discussion and analysis of collected data in Chapter 3. Finally, a summary of the most important results, and recommendations for further study are presented in Chapter 4.

2. LITERATURE REVIEW

This chapter contains an overview of selected studies that either dealt with fuel consumption in urban traffic or the impacts of transportation energy management. Comparisons between the results of these studies were made and conclusions as to feasibility and success are drawn accordingly.

2.1. OVERVIEW

As suggested earlier, a great deal of attention has been given to energy consumption in urban areas and specifically to the factors that have a major effect on fuel consumption efficiency. These factors are often categorized into four basic groups:

1. The vehicle characteristics such as weight, age, size, and resultant engine fuel consumption.
2. The traffic flow characteristics such as travel distance, additional or lost time during full stops, delays due to incidents, accelerations, slow downs, and travel with lower speeds in congested areas with attendant estimates of varying fuel consumption.
3. The environmental characteristics such as adverse weather and its impact on fuel consumption.
4. The traffic and network characteristics such as street system operations, type of control, impact of transit and pedestrians, and city size as related to fuel consumption.

Based on investigation of the above factors, TSM has become an important element in the urban transportation planning and system management processes. TSM procedures challenged decision makers to minimize energy consumption by improving both the quantity and quality of traffic flow. These two goals were often acomplished by maximizing the efficiency of use of existing facilities through certain traffic engineering actions. In this regard, there are several studies that have been undertaken to document the results of applications. The following sections contain reviews of a limited selection of available work on fuel consumption in urban traffic (i.e. Transportation Energy Management concepts, goals and objectives, strategies, tactics, and application of these measures). A review of the Transportation Energy Analysis Manual (TEAM) produced from the Ontario TEMP effort is also included.

2.2. FUEL CONSUMPTION IN URBAN TRAFFIC.

W. E. Fraize [3] discussed some of the energy and environmental considerations in the United States by using statistical analysis of data. This study was carried out in early 1972 to investigate the rate of growth of fuel consumption in the U.S.A. This rate was found to be 4%, while the world growth rate of fuel consumption was about 6.8%. Based on these results, he showed that the annual per capita auto ownership world-wide in the year 2000 would be significantly less than the current U.S. level (i.e. U.S. auto ownership in the year 2000 would be 1.12 autos per capita while the world ownership would only be 0.31). This study suggested that such a rapid increase in fuel consumption held a real potential for future problems and should be minimized by studying in more detail three main issues. Firstly, electrification and/or adoption of alternate fuels for transportation modes should be investigated for a wide range of applications in an attempt to conserve energy. Secondly, the possibility of using smaller sized and less powerful vehicles should be considered for use, especially in urban areas, and thirdly, the improvement of high speed ground transportation systems and increasing the use of urban mass transit should be widely encouraged.

It can be observed that the above goals provide limited basic actions for improving the quality and quantity of traffic flow. Most of these actions dealt with the possibility of altering the vehicle, the fuel, and/or developing hybrid vehicles or engines. As a result, no explicit references to other more specific TSM-type measures were made.

In 1974, Alan M. Voorhees and Associates [4] partially considered the main factors that cause this problem. That study investigated in more detail the major strategies that affect fuel consumption. The results of the study were intended to assist local traffic engineers, transporation planners, and administrators in the incorporation of energy conservation considerations into the transportation planning process. Published results identified general guidelines to reduce energy consumption through transportation actions and suggested an overall framework summarized by the following three questions:

1. How does the transportation action effectively reduce energy consumption?,

2. what are the total effects of these actions? and
3. in what size metropolitan area is the action practical for implementation? (There was ,then, an early recognition of the potential impact of city size on probable success).

In early 1976, gasoline consumption in urban traffic was also investigated and discussed by Evans, Herman, and Lam [5]. They attempted to study the main factors that increase fuel consumption. They utilized field test data of fuel consumption as related to the speed-time history of an automobile travelling in urban traffic by using regression analysis methods. They concluded that fuel consumption can be significantly affected by the following variables:

1. The average trip time per unit distance that allows the variance in fuel consumption to be more than 71% ,
2. the work done per unit distance to accelerate the vehicle, and
3. the fraction of coasting distance travelled.

In addition to addressing the factors that affect fuel consumption, this study describes different methods for sampling speed-time histories and also recommends the best method for determining fuel consumption. The results demonstrated that there are no substantial differences in the estimating methods, and the main factor that increases the fuel consumption was deemed to be the average trip time per unit distance.

Considering traffic system complexity, there was felt a need to also study the effect of traffic and network features on fuel consumption. Honeywell Inc. [6] covered some of these features. They studied fuel consumption in the urban areas of Washington D.C., and parts of the Berkeley and Los Angeles, California networks using computer simulation. The main purpose of the study was to conduct a simple simulation examining the effects of traffic conditions, network configurations, and traffic control policies on the fuel consumption in those networks. They reached the following conclusions:

1. Changing two-way streets to one-way streets results in an increase of Fuel Consumption Efficiency (FCE) of 12% measured in vehicle-miles per gallon,
2. the system performance under peak traffic conditions was slightly better than off-peak traffic conditions in terms of FCE,
3. the number of turning movements had a large effect in reducing FCE especially at off-peak hours,
4. the use of a pedestrian scramble system implemented by an all-red interval resulted in an increase in total network delay of 160% to 820%; under the same conditions, FCE decreased from 48% to 35% depending on the level of turning movements,
5. using fully actuated signals showed significant advantages over pre-timed signals with respect to FCE; this improvement was inversely related to the amount of cross street traffic volume,
6. FCE improved as the cycle length increased, for the arterials where the vehicle platoons travel relatively undisturbed,
7. FCE in an urban network is inversely related to traffic flow demand, and

8. FCE also decreased with respect to the frequency of bus services from 26% to 10%.

The study identified a number of factors that have a major effect on improving the traffic flow quality, but there are too many variables to be discussed here in more detail. The study neither selected the "best" variable that might give the largest FCE, nor discussed the possibility of improving the quantity of traffic flow.

From the above four studies it can be seen that traffic control features, as well as the impacts of urban mass transit have not been discussed. Each one of the above studies focused on specific kinds of actions that might reduce the fuel consumption. Despite these efforts, a more comprehensive framework that could be used for establishing programs to improve both quantity and quality of traffic flow was still needed.

To address this problem, the Federal Highway Administration (FHWA) [7] conducted a study in an attempt to provide a consistent framework for TSM development, resulting in a series of reports on "Measures of Effectiveness for Multimodal Urban Traffic Management." The first objective of this study was to provide a comprehensive set of goals and objectives for TSM strategies for improving both the quantity and quality of traffic flow. The second objective was to derive measures of effectiveness (MOE's) for determining the degree to which each objective was achieved. The third objective was to identify and present data collection and analysis methods for determination of TSM strategies.

The results were summarized in the format of a user's guide for practicing engineers and planners who are engaged in the development and evaluation of urban area TSM strategies. The study also recommended measures of effectivness for each TSM strategy and identified computer techniques for facilitating TSM analysis. The FHWA study was therefore considered to be one of the first major steps in the development of a comprehensive guide for assessing and implementing strategies for reducing transportation energy consumption in urban areas.

Another study in Alexandria, Virginia (1980) was conducted by Fredric A. Wagner in an attempt to determine the energy conservation impacts of eight urban transportation actions [8]. Wagner believed these actions had a major effect in realizing energy savings. He concluded the following points:

1. 3.5% of estimated energy use can be conserved by improving the traffic signal system (i.e., by applying signal coordinations, periodic optimization of signal timing, and advanced forms of master computer control);
2. 0.6% reduction of areawide automotive fuel consumption can be achieved by flashing signals and removal of traffic control signs;
3. 0.5% reduction of areawide automotive fuel consumption can be achieved by adopting the Right-Turn-On-Red-After-Stop (RTORAS) strategy instead of prohibiting vehicles from using that procedure;
4. 0.36% reduction of areawide fuel consumed by automobiles would

be achieved by freeway traffic management;

5. priority treatment for High-Occupancy vehicles can save up to 0.5% of total areawide automobile fuel consumption;
6. ridesharing programs for work trips can reduce automobile fuel consumption by as much as 3 to 4%;
7. alternative work schedules consisting of 50% of central business district workers who participate in staggered work hours, plus 10% compressed work week can save urban fuel consumption by about 0.8%; and
8. municipal programs for transit service expansion and transit management improvements would result in a 1% saving of urban transportation fuel consumption.

He suggested that these eight combined actions could save up to 7.5% of urban automobile energy consumption (i.e., annual savings of about 3.8 billion gallons, which meant 25 gallons per year for every man, woman, and child in urban America).

A study was carried out in Hamilton, Ontario by the IBI Group to investigate the impact of energy management measures in reducing fuel consumption [9]. This study involved the analysis of only a few energy saving measures to review how efficient those measures could be. The main objective was to determine whether a 33% and 20% reduction in energy consumption (a provincial objective) was possible for passenger and freight transportation respectively. Traffic operations, transit, legislative, high-occupancy vehicles, and other measures were "applied" in the Regional Municipality of Hamilton-Wentworth, where they found the following:

1. Alternative signal timing plans could provide about 4 million litres of fuel savings per year. This measure was considered the most cost-effective measure with an implementation cost per litre of fuel saved being less than 1 cent;
2. traffic signal coordination / actuation would save an estimated 1 million litres per year at a cost per litre of fuel saved between 1 and 2 cents;
3. replacing four-way stops with traffic signals could save approximately 300,000 litres per year at a cost of 12 cents per litre of fuel saved;
4. express bus service would not result in large energy savings compared to the other measures, but would provide other benefits such as reduction of pollution and noise;
5. additional promotion of carpooling and vanpooling could save from 0.7 to 1.1 million litres per year at a cost per litre of fuel saved in the range of 24-28 cents;
6. provision of fringe parking lots would result in an estimated saving of 330,000 litres per year at a cost between 19 and 23 cents per litre of fuel saved; and
7. flexible hours or a compressed work week had significant potential to effect energy savings between 400,000 to 800,000 litres per year, with a cost between 10 and 20 cents per litre of fuel saved.

Each of the last three studies reviewed were carried out for urban locations with different populations (city sizes). This author could find no other study which explicitly investigated the effect of population on fuel consumption. However, the IBI Group study referred to earlier [2], included a comprehensive Canada-wide study to assess the national energy impact of various urban transportation management measures, taking into account the suitability of measures by size of urban centre. They developed a conceptual framework for urban transportation energy management measures considering transportation system characteristics for passengers and goods. These characteristics were indentified for five city size groups to estimate the base energy consumption as well as the potential savings that could arise from implementing specific energy management measures. A long list of some 50 potential measures were subjected to preliminary screening, from which a short list of 23 of the most promising measures were subjected to detailed analyses. Both the short and long lists are presented in Appendix A for reference purposes.

The IBI study introduced and applied both quantitative and qualitative analyses by the type of measure to estimate the potential national energy saving for each city size group. Potential regional savings were estimated by taking into account the number of cities in five major regions of the country. Finally, they introduced by rank the ten best measures for each city size grouping. Such ranking provided a preliminary indication of the preferred measure(s) that could be selected by transporation planners, traffic engineers, and municipal decision makers in developing a comprehensive energy management program. Deficiencies and anticipated implementation problems were also introduced. Solution programs were proposed to overcome these problems, and the recommendations reached are summarized below:

1. Traffic measures are ranked first for all city sizes, accounting for more than 70% of the total potential energy savings;
2. high-occupancy vehicle measures ranked second and account for about 15% of the total potential energy savings;
3. other measures ranked third and accounted for 9%-11% of the potential energy savings;
4. urban goods movement measures ranked fourth and accounted for 3%-5% of the total potential energy savings; and
5. transit measures ranked fifth and accounted for less than 1% of the total potential energy savings.

Furthermore, it was concluded that not all of the above measures were suitable for application across all city sizes. For example, transit measures would not be as suitable in smaller cities (i.e., less than 50,000) as they might be in larger cities. However, it was noted that such traffic control measures as optimized signal timing plans and removal of stop signs might be applicable for all city sizes.

Finally, as the last item in this literature review, the Province of Ontario introduced the Transportation Energy Management Program (TEMP) [1] for Ontario munincipalities, which is compiled in a comprehensive manual, the Transportation Energy Analysis Manual (TEAM). The contents of that manual are summarized in the next section.

2.3. TRANSPORTATION ENERGY ANALYSIS MANUAL (TEAM)

The concepts, strategies, tactics, and application measures of

TEMP are presented comprehensively in the TEAM and represent the joint efforts of the Ministry of Transportation and Communications and the Ministry of Energy of the Province of Ontario. The focus of the work was to achieve reduction of energy consumption in the transportation sector through the following objectives:

1. Improving the efficiency of transportation technology.
2. Improving the efficiency of transportation operations.
3. Using more efficient modes.
4. Developing and promoting alternatives to oil.
5. Reducing travel requirements.

Principally, the manual focuses on municipal transportation energy conservation intending to guide these municipalities in implementing actions that can save energy. TEAM deals with all of the transportation aspects that relate to energy consumption and is intended to be a comprehensive reference that describes energy conservation opportunities and measures, presents data on impacts, and documents experience and implementation techniques. A complete summary of the main strategies, actions and measures that can increase energy savings is presented in Appendix A.

2.4 REMARKS

This literature review primarily included studies which show evaluation of procedures used by traffic engineers for dealing with the rapid increase in energy consumption in the transportation sector. This review leaves one with the impression that it is the task of traffic engineers to establish the main factors that have a potential for decreasing urban energy consumption and to establish strategies, actions, methods of estimation and measures of effectiveness for each factor. The studies also showed that all of the proposed TEMM's reduce energy consumption, pollution, noise and travel time, but may decrease safety (it was noticed that safety decreases slightly during the replacing of stop signs with yield signs and implementation of flashing signals). As stated earlier, there was no defined way to etimate energy saving for varying city sizes except the rough estimations for population ranges provided by the IBI Group.

The following chapter includes a description of the data used, and the analytic techniques adopted for developing a simple model to investigate the impact of city size on energy saving. For the purpose of partial verification, an independent fuel savings prediction method was applied to compare results obtained with the proposed procedure. Based on that comparison, a brief discussion of the results is presented.

3. DATA ANALYSIS

A description of the data used in this analysis and the adopted analysis techniques is contained in this chapter. A portion of the data collected by the IBI Group, under contract with Transport Canada [2], was selected for the analysis. The purpose of this selection is discussed and presented in section 3.1. From these data, the relationships between energy savings and the TEMM's for different city size groups were obtained by using standard regression analysis techniques. The CURFIT technique description and the obtained equations that describe these relationships are detailed in section 3.2. The only alternate technique known to the author for independent comparison of energy saving predictions was the Community Benefits Analysis (CBA) program. This program is also discussed and applied for the purposes of validating and testing regression results. A summary of the analysis results is given in section 3.3.

3.1 DESCRIPTION AND DISCUSSION OF SELECTED DATA

The basic data used in this study were selected from the IBI Group final report "A National Framework For Urban Transportation Energy Management" [2]. This report was prepared for both the Transportation Development Centre of Transport Canada and the Departement of Energy, Mines and Resources in September 1983. The data were classified by IBI into five groups of city size ranges. All of the data compiled for each of these groups is reproduced in Appendix A.

Table 3.1 is a sample of that data which includes 23 TEMM's against evaluation criteria for the population range of 100,000 to 350,000.

As noted in Table 3.1, the TEMM's were generally categorized by traffic operations, transit, high occupancy vehicles, urban goods movement, and complementary measures identification. Each category also contains a number of specific measures which are also detailed in Appendix A. The evaluation criteria comprises the four main groups of areawide energy savings, annual expenditure, other impacts and implementation considerations. The annual expenditure group includes capital costs, operating costs and cost-effectiveness (i.e., expenditure required per unit of fuel saved). The other impacts group mainly consists of safety, environmental, and spatial travel impacts. The implementation considerations group consists of public response, regulatory problems and interaction with other measures.

As an example using Table 3.1, and considering the implementation of improved signal timing plans, the annual saving of fuel is shown to be 2,210,000 litres, while the annual expenditure required to obtain that saving is 36,500 dollars. Accordingly, this measure costs 2-3 cents per litre of fuel saved for this population range. During implementation of this measure, the Table shows that safety and environmental impacts are improved, public response is positive, and no regulatory problems are expected.

The five city size ranges available from the IBI study are shown in Table 3.2 along with the number of Canadian cities in each range. It is clear that the ranges are quite different in size, and also that the number of cities varies significantly from range to range.

TABLE 3.1 Energy savings against TEMM's for the third group of city size classifications (100,000-350,000).

TRANSPORTATION ENERGY MANAGEMENT MEASURES	ENERGY SAVINGS AREA-WIDE		COST			OTHER IMPACTS			IMPLEMENTATION CONSIDERATIONS		
	1,000's	$	ANNUAL EXPENITURE 1,000's $	COST EFFECTIVENESS ¢/LITRE	COST EFFECTIVENESS $/BARREL	SAFETY	TRANSPORTATION SYSTEM	ENVIRONMENT	PUBLIC RESPONSE	INSTITUTIONAL/REGULATORY	INTERACTION WITH OTHER MEASURES
TRAFFIC MEASURES											
1. Turning Mov't Restr.	3.1	0.00	0.6	20	31.80	improved	none	minor	minor	enforcement	none
2. Replace Stop with Yield	878.0	0.26	9.8	1	1.59	pot. decrease	none	improved	mixed	enforcement	none
3. Replace Stop with Signal	130.0	0.04	16.5	13	20.67	possible reduction	none	improved	positive	none	none
4. Actuated Signals	450.0	0.13	30.0	7	11.13	none	none	improved	positive	none	none
5. Flashing Signals	7.3	0.00	0.5	7	11.13	decrease	none	improved	mixed	enforcement	none
6. Improved Signal Timings	2210.0	0.65	36.5	23	3.10	improved	none	improved	positive	none	none
7. Interconnect Signals	916.0	0.27	145.0	16	25.44	improved	none	improved	positive	none	sig. timing
8. Computerized Signals	787.0	0.23	61.5	8	12.70	improved	none	improved	positive	none	none
9. Increase Park Enforce	78.0	0.02	85.0	109	173.31	none	mode shift	improved	negative	enforcement	transit/HOV
10. Parking Prohibitions	281.0	0.08	267.0	95	151.05	none	mode shift	improved	negative	enforcement	transit/HOV
11. Freeway Surveillance			-	-	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TRANSIT MEASURES											
12. Bus Scheduling	68.2	0.02	45.0	66	105.00	none	none	negligible	none	none	none
13. Transit Priority	2.3	0.00	15.6	680	709.14	minor	mode shift	minor	mixed	traffic/ enforcement	transit service
14. Optimiz. Transit Routes	66.8	0.02	25.0	37	58.83	none	mode shift	minor	positive	none	bus sched.
15. Aut. Vehicle Monitor	105.0	0.03	217.0	210	329.00	none	none	minor	minor	none	none
HOV MEASURES											
16. Carpool/Vanpool	330.0	0.10	75.0	23	36.57	none	mode shift	positive	positive	transit/new agency	transit/ parking
17. Fringe Parking Lots	329.0	0.10	41.6	15	23.85	n.a	n.a	n.a	n.a	n.a	n.a
18. Shared Ride Taxis	313.0	0.09	70.0	22	34.98	none	mode shift	improved	positive	none	carpool/ vanpool
URBAN GOODS MOV'T MEASURES											
19. Driver Training	798.0	0.23	32.0	4	636	improved	none	improved	positive	private sec.	none
20. Improved Veh. Dispatch	430.0	0.13	795.0	140	223.00	none	none	improved	none	private	none
21. Truck Route Networks	471.0	0.14	155.0	32	50.90	marginal	none	improved	significant	traffic	none
OTHER MEASURES											
22. Variable Work Hours	26.2	0.01	40.0	466	740.94	none	less congestion	improved	positive	new agency	)carpool/)vanpool/
23. Compressed Work Week	408.0	0.12	95.0	23	36.57	positive	less congestion	improved	positive	new agency	)transit)

Reproduced from IBI Group study [2]

IBI Group

Table 3.2
IBI Group City Size Classificatiion

group number	Number of cities in each group	population from	to
1	118	Under 50,000	
2	15	50,000	100,000
3	15	100,000	350,000
4	6	350,000	1,000,000
5	3	Over 1,000,000	

Although the IBI data encompasses a wide overall variation in city size, the stratification is very coarse. It does not seem likely that the suggested savings would apply equally across all city sizes in a given range. Implicitly, the data given by the IBI Group only permits energy savings estimation for a given range of population, not for a specific city size. It should be noted that the IBI Group used a hypothetical "typical" city for each city size range which was assumed to represent a city with characteristics averaged over all other Canadian cities in its range. No more information was given in the IBI report as to how the characteristics of the "typical" city were determined. Therefore, due to lack of more disaggregate data, it seemed appropriate to attempt to provide a simple, yet more flexible method to help estimate energy savings for any medium city size. The following section contains a description of the analysis used to accomplish that goal.

3.2. DATA ANALYSIS

This section includes a full description of the analysis approach, method of solution, and the analysis techniques that were adopted to establish expressions for estimating energy savings for varying city size.

For this study, a standard regression analysis was carried out in order to provide a systematic technique for estimating the coefficients used in the development of descriptive mathematical expresions. The CURFIT subroutine developed by Smith [11] for regression analysis was selected for its availability and simplicity. A complete listing of the subroutine is presented in Appendix B, and the technique is explained in more detail in the following section.

3.2.1 CURVE FITTING TECHNIQUE (CURFIT)

The main objective of regression analysis is to determine the best equation(s) that describe(s) the data; the CURFIT subroutine was chosen for this purpose. This subroutine attempts to find the equation of the curve that best fits the data by minimizing the errors using the least-square method for four attempted equation forms. In CURFIT, the equation may take one of the following forms: linear, exponential, logarithmic, or power.

Input to the subroutine is a number of data pairs (NO). In this instance, each pair was denoted by a city size (X-axis), and the associated energy saving in litres of fuel saved per year (Y-axis) for each TEMM. Also necessary as input is the type of equation attempted to fit the data. The output provides the squared value of the coefficient of correlation (R^2), the standard error (STERR), sum of squares, and cross products of variables. R^2 and STERR are defined and explained in more detail in Appendix B.

In order to determine the appropriate city size to represent a given range, an example comparison was carried out. This comparison in Figure 3.1 used the IBI energy savings plotted against both the hypothetical "typical" cities (solid line) and mid-points of the first four city size ranges (dashed line) for TEMM # 6 which gives the highest energy saving. It can be noticed that the maximum difference in the resulting prediction of energy savings does not exceed 10% for the largest city size and is much closer for smaller city sizes.

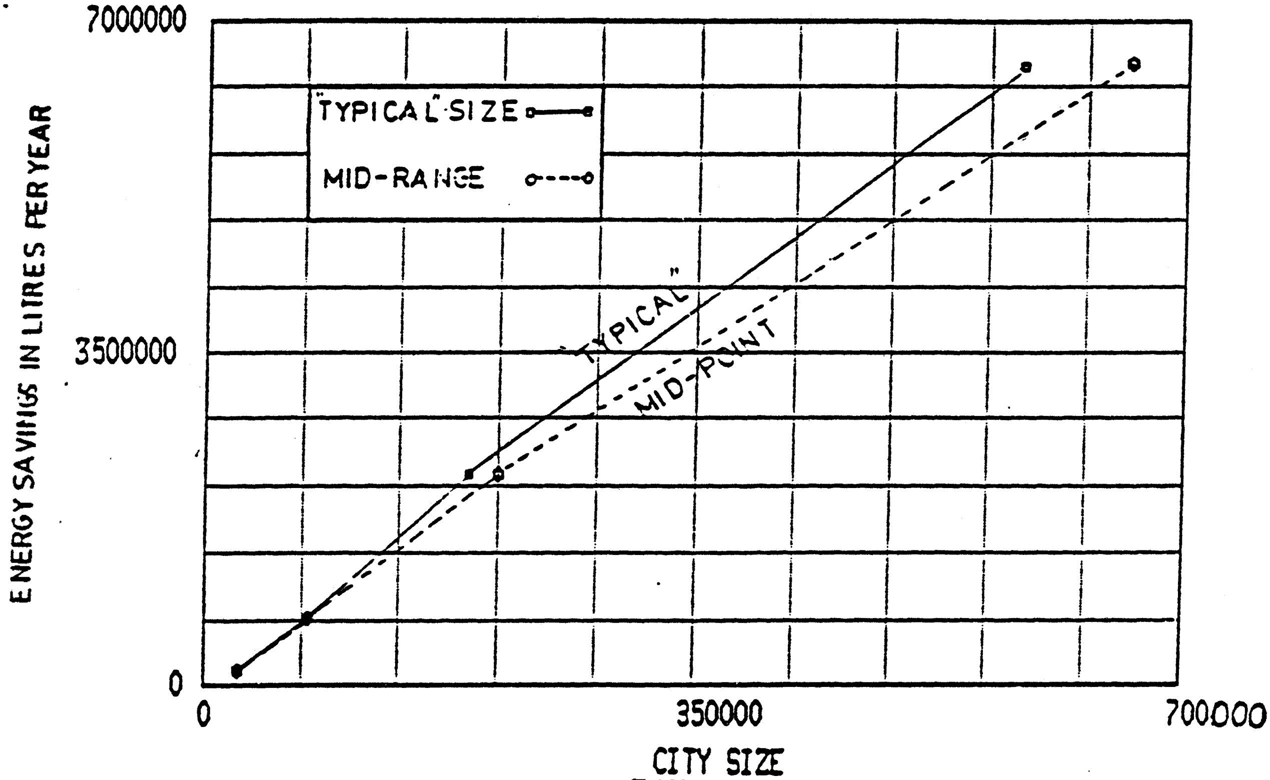

FIGURE 3.1 Comparison between energy savings for TEMM # 6 obtained by using the hypothetical typical cities and Mid-point of city size ranges.

The difference lies in the range of 7-9% for medium city sizes (which is the main concern of this study) and approaches zero for small cities. In addition to the simplicity of using the mid-points of city size ranges, the example comparison in Figure 3.1 shows that use of mid-points provides an acceptable estimation of energy savings compared to the hypothetical typical cities with an average difference of 8% for the medium city size. For all practical purposes, then, since details are not known for the typical cities (i.e., where are they in the range?), it is assumed that using mid-points will yield prediction results of acceptable confidence. Furthermore, since use of the mid-points results in slightly lower savings prediction, the results should generally be considered to be conservative.

In order to provide approximate trends of energy savings against city sizes due to implementation of any TEMM, the IBI data were therefore assumed to be adequately and conservatively representative of the mid-point of each city size range as shown in Table 3.3. Since the information in Tables 3.2 and 3.3 show that the majority of Canadian cities are located within the first three ranges in which the difference between these ranges is fairly small, and, since this study is concerned with the medium city size ranges where most of the TEMM's are applicable, the assumption was considered reasonable. However, this assumption leads to the exclusion of the fifth group on basis of not having an upper limit. This deletion also provides better regression compared to the observed values of energy savings as detailed later in this chapter.

A preliminary analysis was therefore performed using the mid-points of the first four lower ranges to investigate trends of the

Table 3.3
Mid-points of City Size Ranges.

Group #	Range of city size from	to	Mid-point of city size ranges
1	0 -	49,999	25,000
2	50,000 -	99,999	75,000
3	100,000 -	349,999	225,000
4	350,000 -	999,999	675,000
5	Over	1,000,000	—

relationship between energy saving and city size. For most TEMM's, the linear regression equations showed positive intercept values of Y at zero population. Intuitively one would expect that the curves should either pass through (0,0), or have a negative Y intercept (i.e., many TEMM's would not likely have a savings impact for very small population, say less than 20,000). Therefore, to reduce the tendency for positive Y intercepts for the linear case, a (0,0) data point was added. (Further implications of the addition of this data point are raised later in this chapter).

Refering to the deletion of the fifth point, it was noted that the first four points are relatively close on the population scale (i.e., 21,910 to 561,196) while the fifth point is far away from them (i.e., over 2.25 million). Attempting the linear equation, two cases of curve fitting for TEMM # 6 (which gives the highest energy savings) were performed to investigate whether the deletion of the fifth point provides a better regression fit or not for the lower population ranges. Since the upper limit of the fifth range is unknown, the hypothetical "typical" cities were used in this case for only the availability of all the points. The results were as shown in Table 3.4 and the plots shown in Figures 3.2 and 3.3. The fifth point is included in Case #1 (Figure 3.2), while it is excluded from Case #2 (Figure 3.3). As noted in Table 3.4, the residuals for the first four ranges in Case #1 are much more than those in Case #2, the STERR is much lower when the fifth population range is deleted, and as might be expected due to the nature of the data, R^2 improves marginally. From the plots in Figures 3.2 and 3.3, one can also visually observe that the "fit" to the fourth

Table 3.4
Curve Fitting Results using
different number of data pairs

Case # 1. (The fifth range is included)

NO	TYPE	A	B	R^2	STERR
6	Linear	-602064	15.55774	0.997	799391.8

Xi	Y ob.	Y pr.	Res.
0	0	-602,064	0.6248×10^{11}
21,910	152,000	-260,763	1.7037×10^{11}
71,150	730,000	506,268	5.0056×10^{10}
184,281	2,210,000	2,268,555	3.4287×10^{9}
561,196	6,560,000	8,139,911	2.4961×10^{12}

Summation of residuals = 3.0824×10^{12}

Case # 2. (The fifth range is excluded)

NO	TYPE	A	B	R^2	STERR
5	Linear	-50370	11.81057	0.999	64549.1

Xi	Y ob.	Y pr.	Res.
0	0	-50,370	2.5371×10^{9}
21,910	152,000	208,400	3.1810×10^{9}
71,150	730,000	789,952	3.5942×10^{9}
184,281	2,210,000	2,126,094	7.0462×10^{9}
561,196	6,560,000	6,577,675	3.1241×10^{8}

Summation of the residuals = 1.6671×10^{10}

NO = Number of data pairs used (includes (0,0))
A = Intercepted value of X on Y
B = Slope of linear equation.
R^2 = Squared value of Coefficient of correlation.
STERR = Standard error.

The attempted equation in Case # 1 takes the following form

$$Y = -602064 + 15.55774\ X$$

The attempted equation in Case # 2 takes the following form

$$Y = -50370 + 11.81057\ X$$

Y ob. and Y pr. = observed and predicted values of energy savings

Res. = residuals = $(Y\ ob. - Y\ pr.)^2$

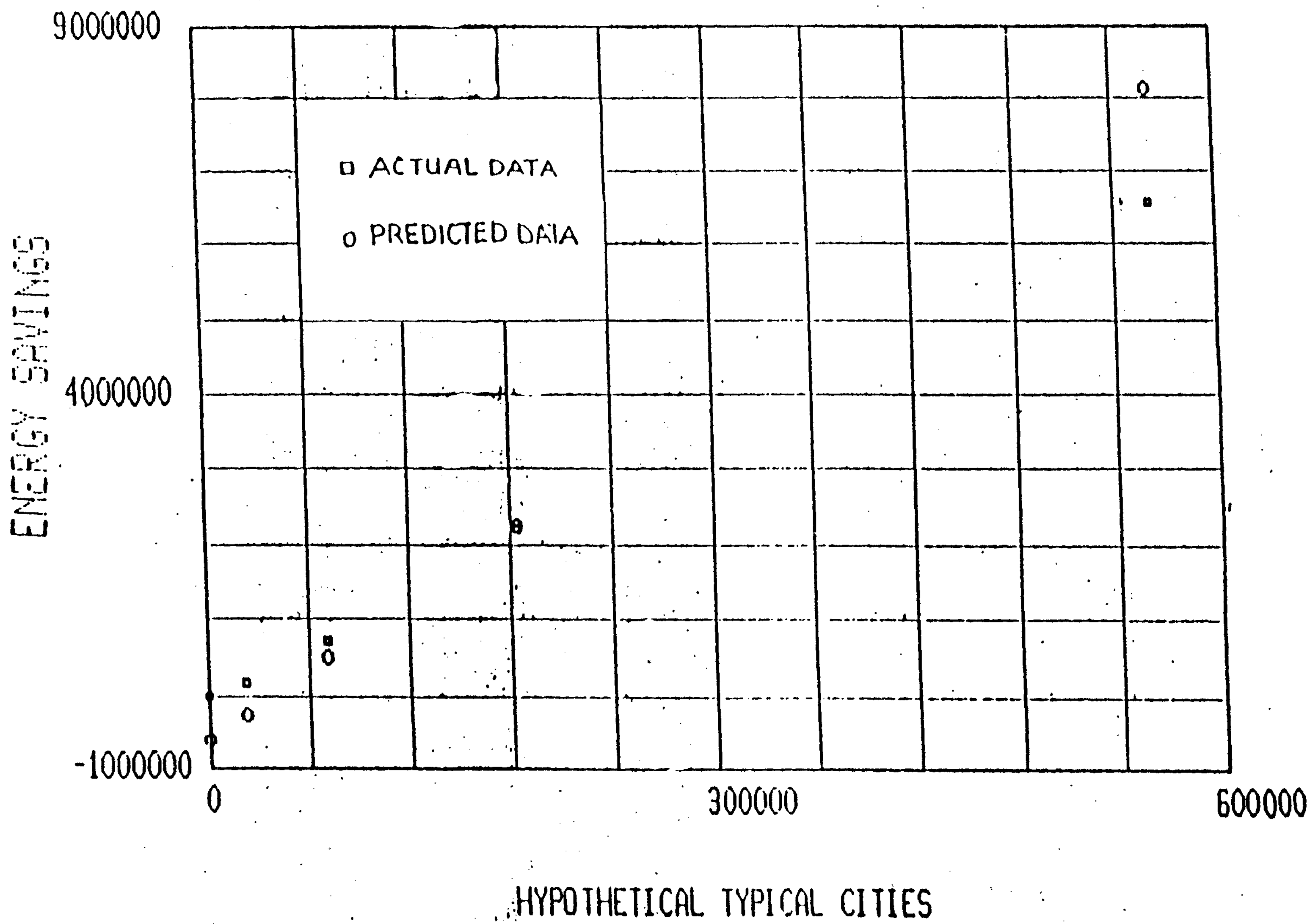

FIGURE 3.2 The regressed linear equation of TEMM # 6 including the fifth range.

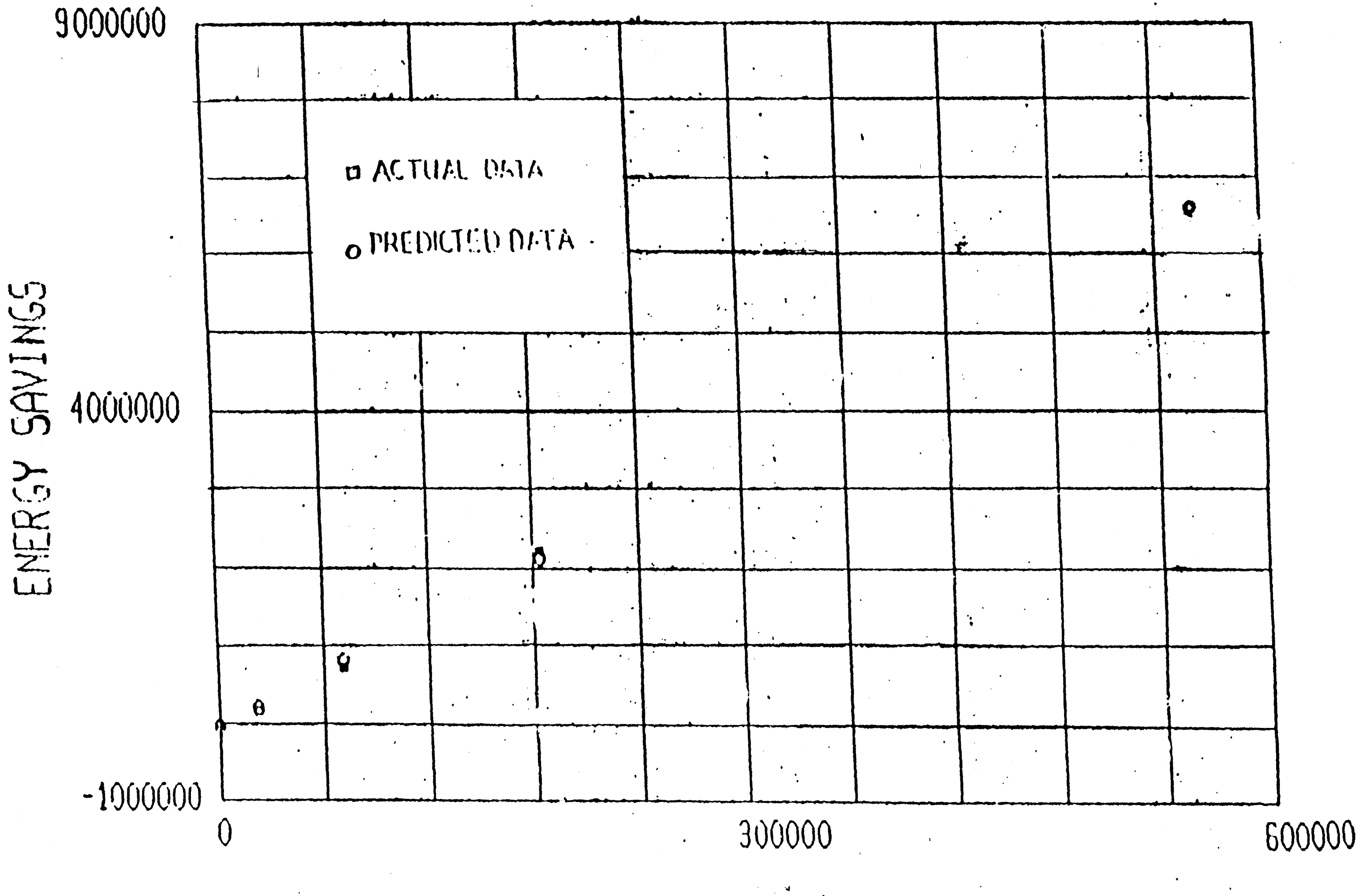

FIGURE 3.3 The regressed linear equation of TEMM # 6 excluding the fifth range.

range is better. Consequently, it was concluded that the deletion of the fifth population range results in a better fit to the observed data in the population ranges of the greatest interest, even if the overall sample size is reduced.

For the purpose of subsequent analysis, the basic data in the four appropriate IBI tables were rearranged into twenty three tables comprising data for the chosen city size ranges for each TEMM and are shown as Tables A1 through A23 in Appendix A. Table 3.5 is an example of the reorganized data representing the estimated energy savings against four mid-range city sizes, along with the (0,0) data point, for the TEMM of implementation of optimized signal timing plans.

Subsequently, these energy savings were plotted against the mid-point of city size ranges for all twenty three measures. Figure 3.4 is an example plot for one of the TEMM's; all plots are shown as Figures A1 through A23 in Appendix A. It can be noticed that two TEMM's are not applicable for small to medium city sizes; freeway surviellance (Figure A11) and fringe parking lots (Figure A17). Therefore, those data sets were excluded from further consideration. Figure 3.4 shows that potential energy saving increases with increasing city size under the effect of optimized signal timing plans. The remaining figures in the Appendix show that the energy saving also increases with increasing city size at different rates based on the effect of each TEMM.

The remaining 21 TEMM's were used in the regression analysis. The results obtained from application of the subroutine CURFIT on the basic data (5 pairs including the (0,0) point) are shown in Table 3.6. Each of the 21 data sets was regressed using all four forms

Table 3.5
Summary of Energy Savings against City Sizes under the implementation of Optimized Signal Timing Plans

Optimized signal timing plans	
Mid-point of city size ranges	energy savings in litres/year
0	0
25,000	152,000
75,000	730,000
225,000	2,210,000
675,000	6,560,000

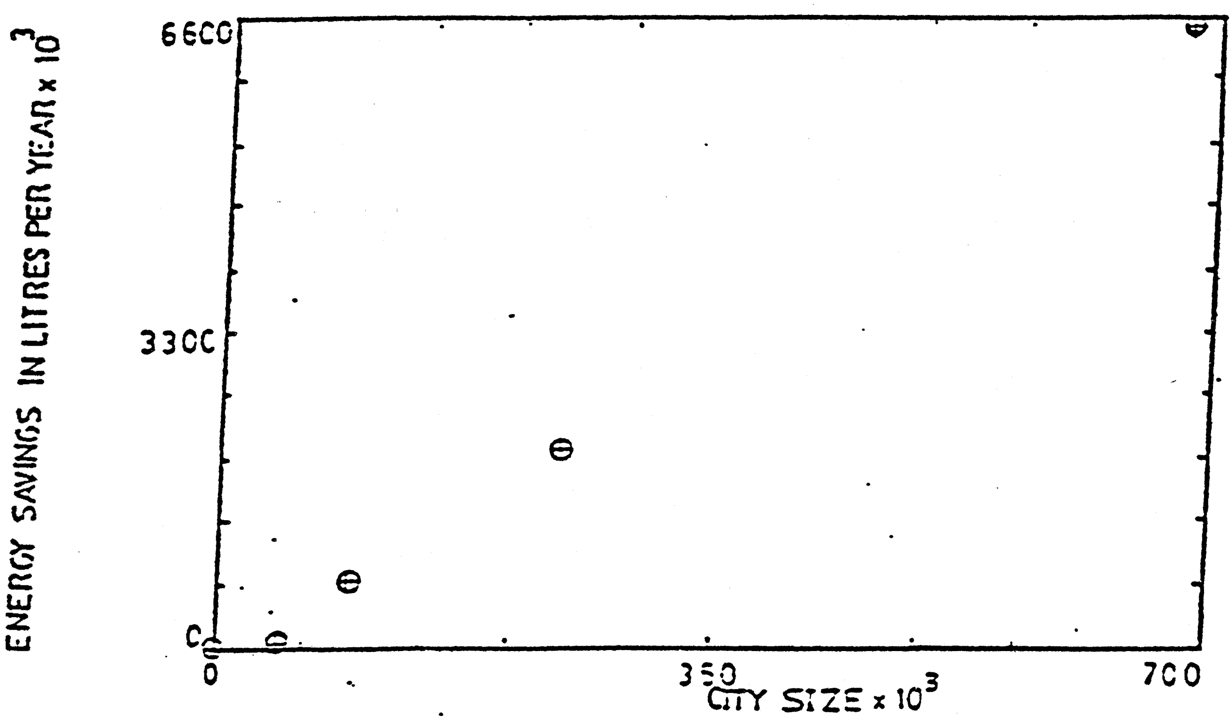

FIGURE 3.4 City sizes against energy savings due to the effect of optimized signal timing plans.

of equations. Generally, the coefficient of correlation ranges from 0.215 to 1.000 for the regressed cases. Several cases provided very close coefficients of correlation between equations, such as TEMM's 2, 6 and 18 (R^2 for the linear equation is 0.999 and for the power equation is 1.000). However, despite the fact that inclusion of (0,0) was considered to be a reasonable action from a pragmatic standpoint, associating it with the small number of data pairs used in this analysis biases the results. For example, addition of (0,0) makes R^2 for the power function higher than it would have been otherwise. Similarily, since most of the linear equations showed positive intercepts in the preliminary testing, (0,0) inclusion would tend to decrease R^2 for that situation. Therefore, R^2 cannot reliably be used to distinguish between the descriptive capability of the linear and power equations especially when R^2 values are very close. Also noted is the fact that the power of X in most of the power equations is very close to unity (i.e., almost linear). It therefore became apparent that more than one form can describe the relationships equally well, or at worst, it is not possible to identify the "best" descriptor.

To test the difference in descriptive capability of the equations, a graphical representation was used to investigate which one of the regressed equations for TEMM # 3 was closer to the actual data. The observed and the predicted values of energy savings resulting from the four attempted equations for replacing stop signs with signals are shown in Figure 3.5. It is noted that due to the relatively wide variations of population ranges and the small number of data pairs used, a prediction error is expected with the results. However, this

Table 3.6
Output of CURFIT technique

TEMM#	NO	TYPE	A	B	R^2	STERR
1	5	LIN	216.000	.010	.981	383.404
	5	EXP	6.583	.000	.302	5.409
	5	LOG	707.503	185.678	.314	2318.694
	5	PWR*	.179	.675	.996	.424
2	5	LIN	-30028.770	4.080	.999	20693.170
	5	EXP	292.683	.000	.271	7.699
	5	LOG	239017.900	68038.820	.254	985205.800
	5	PWR*	1.579	1.068	1.000	.060
3	5	LIN	11172.000	.640	.989	18736.910
	5	EXP	145.205	.00001476	.244	7.255
	5	LOG	45970.290	11605.960	.297	150960.800
	5	PWR*	.993	.988	.998	.346
4	5	LIN	43447.970	1.372	.976	60740.070
	5	EXP	208.500	.000	.254	7.499
	5	LOG	104325.900	26557.820	.334	316859.400
	5	PWR*	1.234	1.028	.999	.212
5	5	LIN	629.600	.024	.986	794.481
	5	EXP	13.839	.000	.280	5.846
	5	LOG	1782.319	457.532	.323	5592.351
	5	PWR*	.268	.816	.999	.222
6	5	LIN	-23775.760	9.771	.999	42048.810
	5	EXP	540.601	.000	.265	8.078
	5	LOG	593698.900	166295.900	.255	2342695.000
	5	PWR*	2.217	1.116	1.000	.131
7	5	LIN	116508.800	2.062	.897	194803.000
	5	EXP	291.932	.000015953	.250	7.716
	5	LOG	177913.300	43662.950	.367	483859.400
	5	PWR*	1.477	1.055	.999	.326
8	4	LIN	94133.340	2.887	.993	74468.920
	4	EXP	36.752	.000	.349	8.312
	4	LOG	337363.300	61254.600	.456	645946.600
	4	PWR*	1.644	1.046	.999	.285
9	5	LIN	5900.000	.244	.980	9846.313
	5	EXP	62.525	.000	.267	6.762
	5	LOG	17701.460	4597.926	.318	56858.820
	5	PWR*	.631	.935	1.000	.133

Table 3.6 (continued)

10	5	LIN	24772.810	.837	.973	38822.990
	5	EXP	153.285	.000	.255	7.304
	5	LOG	62847.180	16082.530	.328	194317.600
	5	PWR*	1.038	1.002	1.000	.148
11	2	This set is omitted due to insufficient data				
12	5	LIN	-86.401	.238	.983	8743.449
	5	EXP	37.961	.000	.303	6.472
	5	LOG	14498.961	4118.023	.268	57519.400
	5	PWR*	.509	.917	.997	.454
13	5	LIN	58.400	.010	.998	113.998
	5	EXP	6.222	.000012724	.305	5.364
	5	LOG	648.944	175.546	.280	2374.940
	5	PWR*	.175	.761	.996	.387
14	5	LIN	13644.000	.158	.934	11712.840
	5	EXP	87.483	.000	.227	6.948
	5	LOG	16295.780	3598.395	.443	34075.380
	5	PWR*	.707	.934	.997	.413
15	5	LIN	-11355.190	.583	.996	10732.590
	5	EXP	65.377	.000	.297	6.785
	5	LOG	31013.530	9244.296	.228	143558.200
	5	PWR*	.697	.958	.999	.281
16	5	LIN	-11279.990	1.730	.997	28578.830
	5	EXP	174.389	.000	.272	7.385
	5	LOG	102733.400	28870.870	.253	418691.700
	5	PWR*	1.167	1.025	1.000	.164
17	3	This set is also omitted due to insufficient data				
18	5	LIN	8768.029	1.408	.999	10252.930
	5	EXP	201.121	.000	.255	7.458
	5	LOG	92356.370	24638.150	.279	334260.000
	5	PWR*	1.225	1.023	1.000	.188
19	5	LIN	-70535.890	4.778	.992	118133.200
	5	EXP	339.824	.000	.266	7.778
	5	LOG	266964.900	76888.310	.235	1172884.000
	5	PWR*	1.712	1.075	1.000	.138
20	5	LIN	-30734.390	2.271	.997	31861.540
	5	EXP	187.209	.000	.278	7.424
	5	LOG	127142.900	36876.560	.240	554191.900
	5	PWR*	1.237	1.034	1.000	.097

Table 3.6 (continued)

21	5	LIN	49783.210	1.684	.994	35447.200
	5	EXP	290.784	.000	.239	7.681
	5	LOG	128903.300	32061.940	.329	386713.400
	5	PWR*	1.461	1.042	.998	.344
22	5	LIN	-4795.509	.178	.985	5603.745
	5	EXP	22.681	.000	.326	6.171
	5	LOG	8620.703	2550.177	.215	41119.460
	5	PWR*	.422	.890	.997	.414
23	5	LIN	-36103.990	2.839	.978	109556.300
	5	EXP	222.890	.000	.271	7.561
	5	LOG	157979.000	43055.470	.240	64681.000
	5	PWR*	1.454	1.050	.999	.241

* = The asterisk indicates the equation that was chosen to describe the data.

NO = Number of data pairs used in this analysis (including (0,0))

TYPE = Type of attempted equation

A = Intercept of Y in linear and product of X in power equation

B = Power of X in power equation or slope of Y on X

R^2 = Squared value of coefficient of correlation

STERR = Standard error

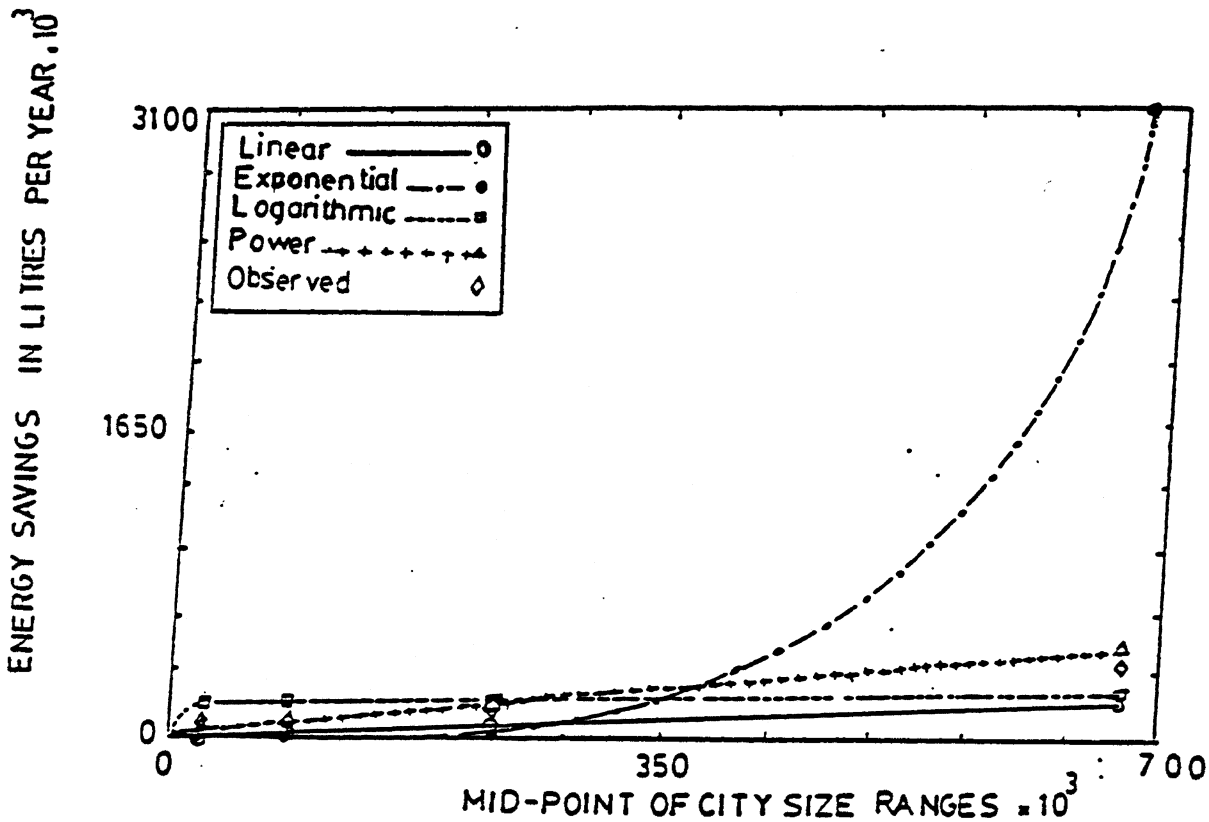

FIGURE 3.5 Observed and predicted values of energy savings resulting from the four attempted equations against mid-point of city size ranges for TEMM # 3.

error is quite small in the first three ranges, but can be relatively large in the fourth range as shown in Figure 3.5. It is also noted that the power equation gives closer results to the observed values. Although this type of testing was not carried out for other TEMM's, the power equation was adopted as the appropriate descriptor for the results, and identified by an asterisk in Table 3.6. The equation takes the form:

$Y = A \cdot X^B$ where,

Y = energy savings (litres/year),

A = product of X,

X = city size (population), and

B = power of X.

Table 3.7 contains a summary of the results of the regression analysis. For each TEMM, the power equation that was selected to describe the relationship between city sizes and energy savings is shown. These regressed relationships were plotted and are displayed in Figure 3.6. The relative positioning provides a crude ranking, indicating the potential of a TEMM to save energy. To evaluate the extent to which such an implicit ranking has been "incorrectly" assigned due to the regression process, the raw data were plotted for all TEMM's in Figure 3.7. As an example, the curve that gives the highest energy saving is the improved signal timing plans (TEMM 6), while the curve that gives the lowest energy saving is the turning movement restrictions (TEMM 1). These two curves have the same rank to save energy in both cases (before and after regression and at any city size). In fact, all but TEMM's 7, 8, 20, 21, 12, 14, 23 and 4 follow the

Table 3.7
Regressed Power Equation
for each TEMM

TEMM #	TEMM Name	Equation form
1.	Turning Movement Restriction	$Y = 0.179 \cdot X^{0.765}$
2.	Replace stop with yield sign	$Y = 1.579 \cdot X^{1.068}$
3.	Replace stop with signals	$Y = 0.993 \cdot X^{0.988}$
4.	Actuated signals	$Y = 1.234 \cdot X^{1.028}$
5.	Flashing signals	$Y = 0.268 \cdot X^{0.816}$
6.	Improved signal timing	$Y = 2.217 \cdot X^{1.116}$
7.	Interconnection of signals	$Y = 1.477 \cdot X^{1.055}$
8.	Computerized signal control	$Y = 1.644 \cdot X^{1.046}$
9.	Increased parking enforcment	$Y = 0.631 \cdot X^{0.935}$
10.	Parking prohibition	$Y = 1.038 \cdot X^{1.002}$
11.	This measure was not applicable	
12.	Bus scheduling	$Y = 0.509 \cdot X^{0.917}$
13.	Transit priority	$Y = 0.175 \cdot X^{0.761}$
14.	Optimization of transit routes	$Y = 0.707 \cdot X^{.934}$
15.	Automatic vehicle monitoring	$Y = 0.697 \cdot X^{.958}$
16.	Carpooling/Vanpooling	$Y = 1.167 \cdot X^{1.025}$
17.	This measure was not applicable	
18.	Shared ride taxis	$Y = 1.225 \cdot X^{1.023}$
19.	Driver training	$Y = 1.712 \cdot X^{1.075}$
20.	Improved vehicle dispatching	$Y = 1.237 \cdot X^{1.034}$
21.	Truck route networks	$Y = 1.461 \cdot X^{1.042}$
22.	Variable work hours	$Y = 0.422 \cdot X^{.890}$
23.	Compressed Work week	$Y = 1.454 \cdot X^{1.050}$

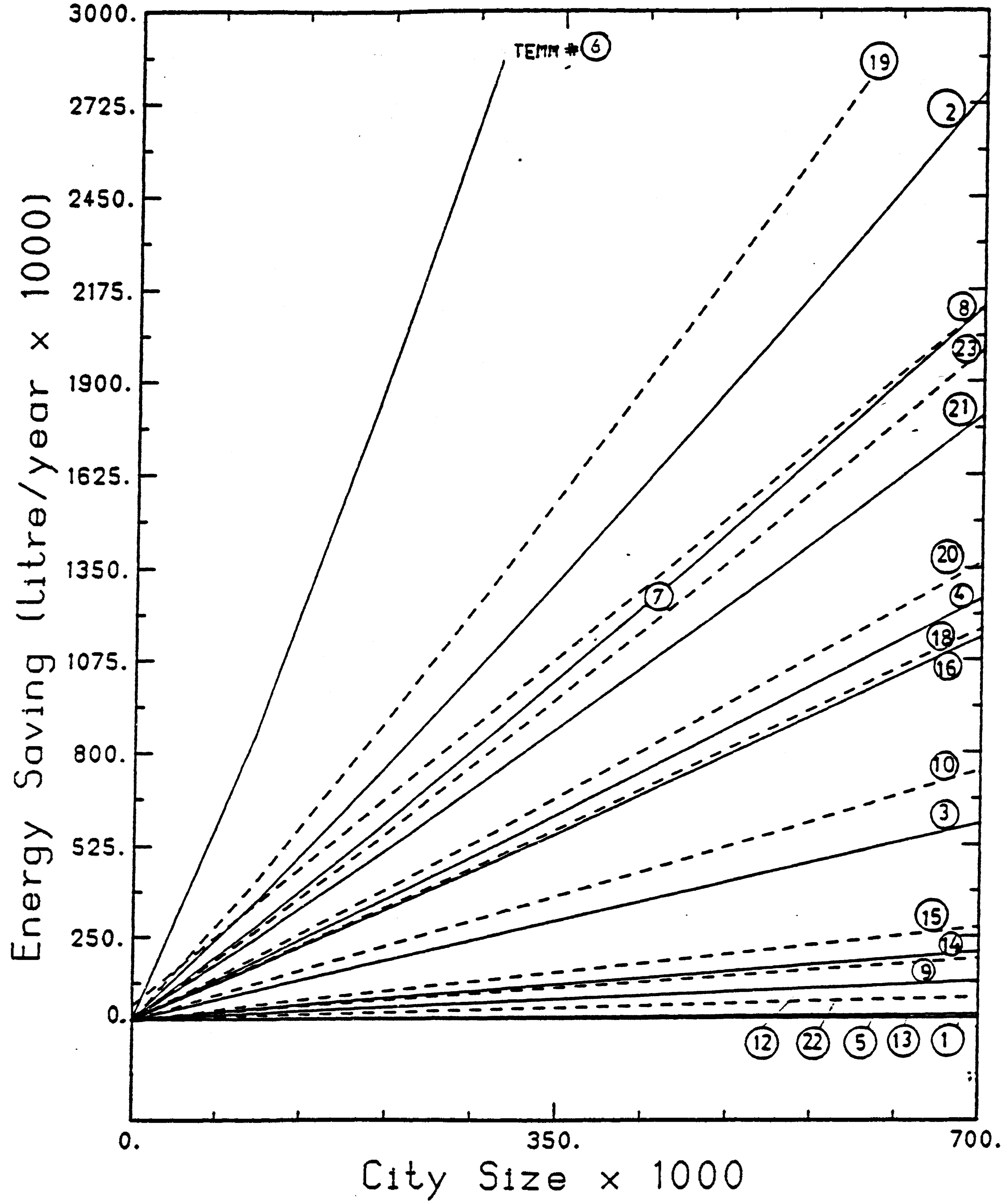

FIGURE 3.6 Summary of resulting curves representing the relationship between the energy saving and city size under the effect of all 21 TEMM obtained by the regression analysis.

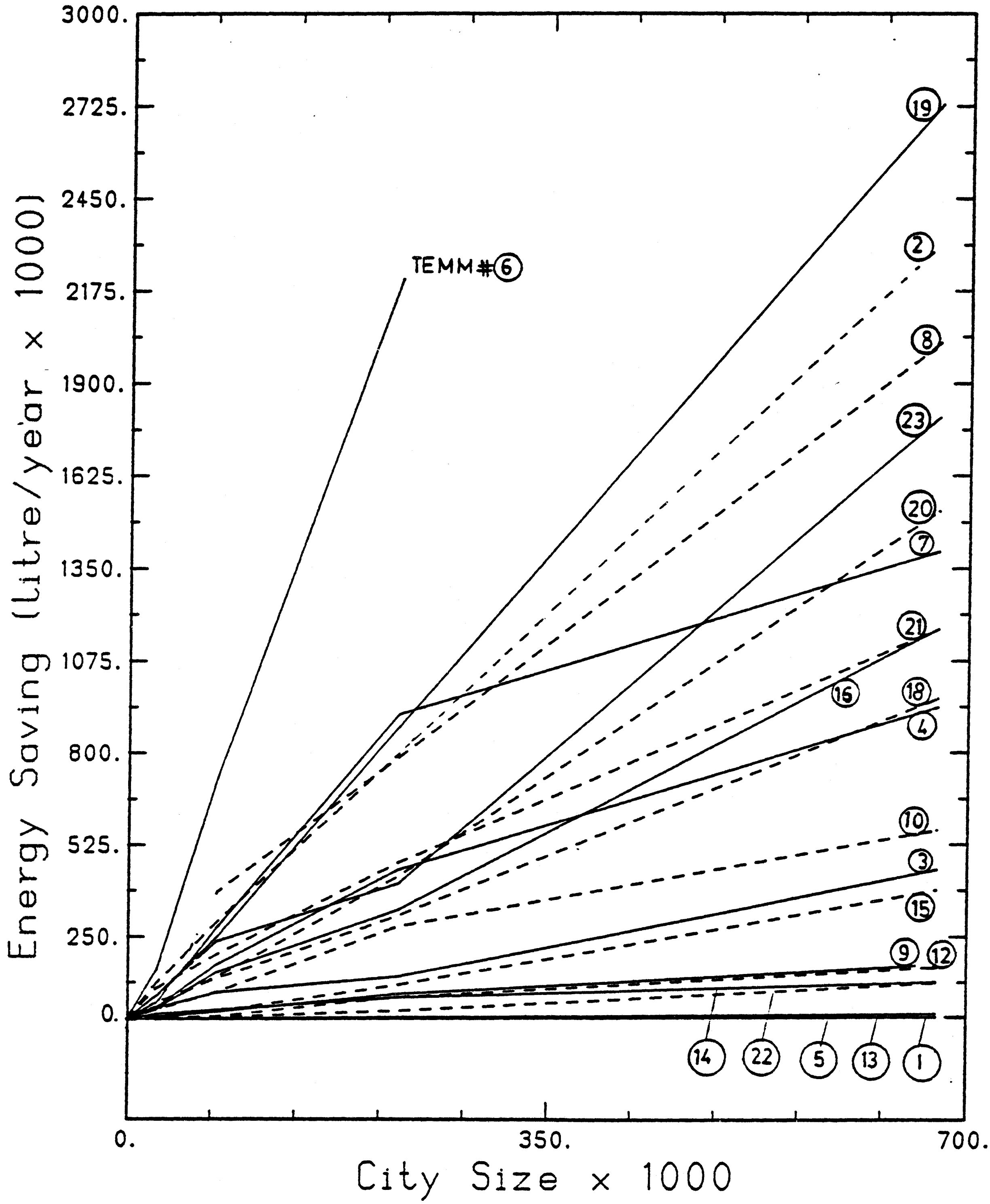

FIGURE 3.7 Summary of curves representing the relationship between the energy saving and city size under the effect of all 23 TEMM before peroforming the regression analysis.

same rank in Figures 3.6 and 3.7 across all the population ranges. Of these exceptions, four curves (7, 8, 23 and 4) significantly change ranks, while the remaining four curves (12, 14, 20 and 21) are changed to a minor extent.

Given the qualifications and restrictions mentioned previously, the energy saving for any city size can be simply predicted either by using a plot like Figure 3.6 or by direct calculation from each TEMM's equation (perhaps in a computer algorithm). This will hopefully encourage traffic engineers, planners, and municipal decision makers to at least initially estimate how much energy can be saved for their particular city size.

However, it would still be useful to test whether these predictions are within acceptable ranges of estimation by comparing results with those from an alternative technique. The only available program that could be found to estimate energy savings based on population was the Community Benefits Analysis technique (CBA). For the purpose of comparison, the CBA program was used to "evaluate" the results implied by the previous equations.

3.2.2. THE CBA TECHNIQUE

The CBA program was developed as an informal demonstration tool by personnel from the Ministry of Transportation and Communications and Canadian General Electric in 1984. This program was designed to interactively perform a cost/ benefit analysis for optimized signal timing plans, coordinated signals, and actuated signal systems based on city size and pertinent traffic control information.

The output of this program provides estimates of implementation cost (dollar/ year), energy saving (dollar/year), and pay back period (years). The annual energy saving depends on the energy consumption before and after implementing any TEMM, and its calculations are based on the following variables as determined from city population:

1. arterial travel distances,
2. annual average daily traffic, and
3. average speed.

The implementation cost is another variable that is included in this program, determined by the following factors:

1. type of interconnection used for coordinated signals,
2. intersection equipment age (less or greater than 10 years), and
3. the period of time elapsed since signal timing optimization was last updated (years).

This cost is also divided into several subcosts such as: communication cost, which may include telephone lines or coaxial cables (leased or owned), control room, detectors, construction, consulting, contingency, and other major capital costs of the adopted system. All cost computations are based on the number of signals in the community network, which is also determined as a function of population.

3.2.3. COMPARISION OF REGRESSION RESULTS WITH CBA ESTIMATES

To directly compare the regression results with CBA estimates, the energy saving as well as the pay back period for given city sizes were obtained using both methods. Although both estimating procedures rely primarily on city size, it is important to note that the

CBA formulation is a much more detailed treatment of energy savings estimations, but only for a very limited number of possible TEMM's. As a consequence of the calculation procedures, comparisons between the two techniques can only be approximate, and only a limited range of variation was attempted for the appropriate TEMM's.

For example, following almost the same assumptions that the CBA program used, only three city sizes and three TEMM's were used for the purpose of this comparison. Since this study is primarily concerned with medium-sized cities, the sizes chosen were 100,000 , 200,000 and 300,000. To accomodate the CBA format, the selected TEMM's were coordinated signals, optimized signal timing plans and actuated signals.

Table 3.8 shows the results of this comparison and includes the IBI-Regression (IBI-Reg.) and the Community Benefits Analysis (CBA) energy saving values in dollars per year, with the percentage difference between estimates. The gasoline price was assumed to be $ 0.5 per litre for both studies. Considering the implementation of a coordinated signal system, IBI-Reg. gives annual energy savings of $666,750 , $1,453,925 and $2,283,350 respectively for city sizes of 100,000 , 200,000 and 300,000 , compared to the CBA estimates of $736,700 , $1,310,700 and $2,075,300. The diferences between energy saving estimates were approximately 9%, 10% and 9% respectively for those city sizes chosen. In the other two cases, the diference in results between the two studies ranges between 4 and 22%. It is clear that the IBI-Reg. method generally gives higher estimates of energy savings than does the CBA program, but the differences are considered quite acceptable for planning purposes.

To assess the impact of the largest differences in fuel saving

Table 3.8
Comparison of Energy Savings ($/year)
between CBA and IBI-Reg. Results.

Energy saved by implementing coordinated signals (dollars/years)			
City Size	IBI-Reg.	CBA study	difference (%)
100,000	666,750	736,700	9
200,000	1,453,925	1,310,700	10
300,000	2,283,350	2,075,300	9
Energy saved by implementing improved signal timing plans (dollars/year)			
City Size	IBI-Reg.	CBA study	difference (%)
100,000	530,550	509,500	4
200,000	1,170,825	914,500	22
300,000	1,849,050	1,435,200	22
Energy saved by implementing actuated signals (dollars/year)			
City Size	IBI-Reg.	CBA study	difference (%)
100,000	615,650	641,600	4
200,000	1,344,525	1,151,600	14
300,000	2,112,550	1,864,700	12

estimates, a comparison of anticipated pay back periods is shown in Table 3.9. This comparision was made for the three city sizes, for implementation of four different optimized signal timing plans. For the purpose of CBA input, the assumed durations of updated optimization of timing plans were: one, two, three, and five years. Table 3.9 shows that under implementation of a one year optimized signal timing plan, given city sizes of 100,000 , 200,000 and 300,000 people, the pay back periods estimated by IBI-Reg. were 3.4, 1.7 and 1.2 years, and with CBA are 3.3, 1.8, and 1.2 respectively. It is interesting to notice that the pay back periods decrease as city size increases and that the results are very close despite some of the apparently high differences in energy saving estimations between methods.

The comparison was only made between one year updated optimized plans due to the availability of this period in both studies and to simply determine where this study's pay back periods are located among the range of the CBA results. The differences of pay back periods in both studies were approximately 3.0%, 5.5% and 0% respectively. The results in Table 3.9 indicate the pay back periods for the other durations to provide information on anticipated trends of pay back with longer durations between updating.

Table 3.10 contains the results for the same three city sizes under implementation of a coordinated signal system. The percentage of traffic signals which are coordinated was varied from 1- 99% in CBA, while IBI-Reg. presumably incorporates only a completely coordinated system (100%). Based on IBI-Reg. estimation, the pay back periods for city sizes of 100,000 , 200,000 and 300,000 are 2.8, 1.7 and 1.3 while

Table 3.9
Pay back Period Comparison For Signal Timing Plans

Population	Implementation duration (years)	CBA pay back (years)	IBI-Reg. (years)	difference (%)
100,000	1	3.3	3.4	3.0
	2	2.5		
	3	2.1		
	5	2.0		
200,000	1	1.8	1.7	5.5
	2	1.4		
	3	1.2		
	5	1.1		
300,000	1	1.2	1.2	0.0
	2	0.9		
	3	0.8		
	5	0.7		

Table 3.10
Pay back Period Comparison for Coordinated Signals

Population	% of Coord.	CBA pay back (years)	IBI-Reg. (years)	difference (%)
100,000	1	2.1		
	15	2.3		
	30	2.4		
	45	2.5		
	60	2.6		
	75	2.7		
	90	2.8		
	99	2.9	2.8	3.0
200,000	1	1.2		
	15	1.3		
	30	1.4		
	45	1.5		
	60	1.6		
	75	1.7		
	90	1.8		
	99	1.8	1.7	5.5
300,000	1	0.7		
	15	0.8		
	30	0.9		
	45	0.9		
	60	1.0		
	75	1.1		
	90	1.2		
	99	1.3	1.3	0.0

for CBA they are 2.9, 1.8 and 1.3 years respectively. The pay back periods still decrease with increasing of city size, and the results remain suprisingly close with the same percentage differences. The differences between pay back periods of both studies were only 3.0%, 5.5% and 0% for the three city sizes respectively.

Table 3.11 gives the pay back results for the effect of varing percentages (1%-99%) of actuated signals. Based on the IBI-Reg. estimation, with city sizes of 100,000 , 200,000 and 300,000 the pay backs for implementation of completely actuated signal systems are 3.1, 1.9 and 1.6 years respectively, and the equivalent CBA results are 3.3, 1.9 and 1.7 years respectively. As noticed in the two previous cases, the results are very close to each other. In the same way, the differences between pay back periods of both studies were only 6.0%, 0% and 6.0% for the three respective city sizes.

Although some high differences were associated with the energy saving estimation, the differences between pay back periods are insignificant (i.e., not higher than 6.0% in these three cases). Therefore, it was concluded that the regression estimations for these cases could be used with reasonable confidence for planning purposes.

In general, then, even with the high diference in fuel savings, all TEMM's provided almost no difference in pay back periods and the results were considered conservative (the obtained energy savings are not over estimated). It is noted that the energy saving obtained by this study is located between the energy saving obtained by the IBI Group and those obtained by the CBA program. Therefore, as noted previousely the majority of the regressed equations (13 out of 21)

Table 3.11
Pay back Period Comparison for Actuated Signals

Population	% of Actuation	CBA pay back (years)	IBI-REG. (years)	difference (%)
100,000	1	2.5		
	15	2.6		
	30	2.7		
	45	2.9		
	60	3.0		
	75	3.1		
	90	3.3		
	99	3.3	3.1	6.0
200,000	1	1.5		
	15	1.5		
	30	1.5		
	45	1.6		
	60	1.7		
	75	1.8		
	90	1.9		
	99	1.9	1.9	0.0
300,000	1	1.2		
	15	1.2		
	30	1.3		
	45	1.4		
	60	1.5		
	75	1.6		
	90	1.7		
	99	1.7	1.6	6.0

presented in Table 3.7 or the plots shown in Figure 3.6 can be used with reasonable confidence to estimate energy saving for any city in the medium-sized range. The equations 4, 7, 8, and 23 may misrepresent the situation due to the wide variation of data.

3.3 SUMMARY

Generally, the relationship between energy saving and city size was established by using standard regression analysis. The power equation was chosen to represent the relationship. It is important to conclude that the resulting expressions permit a simple and flexible method of estimating energy savings in terms of city size. Despite the differences imposed by the manner in which the data was manipulated, and those associated with alternative fuel saving estimations, this analysis suggests that the difference between pay back periods is insignificant for all practical purposes. The prediction capability of the equations chosen appears be acceptable based on the tests and cpmarisons made.

Furthermore, city size can now be used as the sole parameter for predicting energy saving with the implementation of many TEMM's. Planners can use the results presented in Table 3.7 or Figure 3.6 with reasonable confidence to estimate energy savings as discussed earlier, care must be excercised in the application of those equations whose ranks are significantly changed by the regression analysis (such as TEMM's 4, 7, 8, and 23). In these cases, direct implication from figure 3.7 could be used.

In the following chapter, a brief summary and statement of conclusion and recommendations is presented.

4. CONCLUSIONS AND RECOMMENDATIONS.

A brief summary and conclusions emanating from this study is contained in 4.1. Recommendations for future work are presented in 4.2.

4.1. Summary of Conclusions

The main findings of this study fall into two major categories: general observations and specific issues. A summary of the more general observations follows:

1. Although the literature on previous experience described useful ways for estimating energy savings, most of the work described procedures that were relatively specific in application and generally did not deal with area-wide applications. In this regard, previous work could be used to estimate in more detail the change in energy consumption by implementing a specific TEMM for a specific location, such as an intersection approach or single road link (microscopic treatment).

2. The IBI Group study results [2] provide the only "macroscopic" research results found that can be used to estimate area-wide energy savings for a rather extensive range of TEMM's. The CBA program provided energy saving estimates for only a very few TEMM's, but was structured with area-wide city size as a basic input parameter.

3. The IBI data was presented only in a very few aggregate and apparently arbitrarily established arrangement of city size ranges. Consequently, energy savings estimates for TEMM's could not necessarily be confidently applied to a specific city size within a specific range.

In additional, the tabular forms in which the data was presented, precluded easy use for prediction purposes.

4. Since the main purpose of this study was to develop a simple analytic method to estimate energy savings in terms of city size, a standard regression process was adopted, using the IBI data for city sizes up to approximately 700,000 population. Based on the analysis conducted, it was shown that for planning purposes, and for the majority of TEMM's, potential energy savings could be confidently predicted using the regressed formulae or by simply using the plots of those formulae as presented in Chapter 3. By implication, the identified relationships allow one to roughly compare potential effectiveness among TEMM's with the exceptions noted in Chapter 3.

Emanating from experience gained in the conduct of the analysis, the following specific observations were made:

1. Given the time and/or opportunity to repeat this analysis, the author would choose a slightly different approach. First, the (0,0) data point would not be included so that potential bias was avoided. Second, more attention would be given to selecting alternative regression forms which might better represent the characteristics of the relationship between city size and fuel savings. Regardless, the author also feels that the results obtained are useful and can be used with some confidence, noting the qualifications given in Chapter 3.

2. The study results are considered most applicable for small (50,000) to medium (less than 350,000) city sizes where the variations between

population ranges of basic data were not very large and the "fit" between predicted and actual data on energy savings was quite close.

3. The regressed IBI data provides reasonable results for estimating energy savings for the majority of TEMM's, as based on the comparisons with the CBA program estimates. Although comparisons were carried out with the CBA for only a few TEMM's, the pay back results were so similar that it was assumed the formulae for other TEMM's were equally useful for energy saving prediction and subsequent estimations of pay back periods (with the exceptions noted in Chapter 3).

4. As noted in Figure 3.6, and ignoring cost-effectiveness issues, the traffic operational measures generally provide the highest potential for energy savings while transit measures and other demand-based TEMM's give the lowest. On the other hand, It is noted that the first eight traffic operational measures given in Table 3.7 were not considered highly cost effective by the IBI Group [2].

5. It can be concluded that 13 of the 21 regressed equations provide confident estimation for energy savings with appropriate ranking of effectiveness, four provide approximate, but very close results, while the remaining four equations marginally misrepresent the situation, at least with respect to relative ranking.

6. The magnitude of energy saving among traffic related TEMM's depends upon the influence of the specific implemented TEMM. For example, optimized signal timing plans appears to be the most effective measure, while turning movement restrictions provides much lower

potential for energy saving.

As a general conclusion, this study has shown that traffic engineers can use the regressed equations for the majority of TEMM's to predict energy savings for small - medium sized cities with reasonable confidence. Consequently, for the first time, a simple analytic technique is available to permit easy estimation of energy savings over a wide selection of TEMM's, using city size as the only input parameter.

4.2. Recommendations For Future Work

If additional research in this area is contemplated, consideration should be given to the following remarks:

1. In light of this research effort, more disaggregate data should be collected to reduce the wide variations in large population ranges and to provide a larger data sample for analysis.

2. Since this study has only dealt with a preliminary analysis of the impact of city size on estimation of energy savings, additional studies should be conducted to estimate the effect of city size on the other evaluation criteria such as implementation cost, cost effectiveness, noise, pollution and safety to prepare appropriate strategies that can achieve the most desirable traffic conditions.

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APPENDIX A

STUDY DATA

APPENDIX A-STUDY DATA

This appendix contains 1) both the short and long lists of Transportation Energy Management Measures (TEMM's) considered by the IBI Group [8], 2) the basic data as classified by the IBI-Group [8], 3) the data as rearranged by the auther for the purpose of analysis, 4) graphics showing energy savings by city size for 23 TEMM's, and 5) a summary of the basic strategies for energy savings as presented in Transportation Energy Analysis Manual (TEAM) [10].

1. SHORT AND LONG LISTS OF TEMM's

Transportation Energy Management became very popular in the early 1970's. The main task identified for Transportation Energy Management is to effectively improve urban transportation systems by altering the supply and / or demand for transportation services. The majority of TEMM's are relatively inexpensive and easy to implement. For this study, the TEMM's used were classified into two lists by the IBI Group; 1) the short list and 2) the long list.

1. The Short List of TEMM's

The short list used in this study contained 23 TEMM's deemed to be most cost effective, identified within the five areas listed below:

A. Traffic operation measures

B. Transit measures

C. Paratransit measures

D. Urban good movement measures

E. Other measures

For each area, more specific TEMM's were identified.

A.Traffic operation measures:

1. Turning movement restrictions at intersections,
2. replace stop signs with yield signs,
3. replace stop signs with traffic signals,
4. actuated signals versus fixed time signals,
5. flashing signals in off-peak periods,
6. improved signal timing,
7. interconection of signals,
8. computerized signals control,
9. increased parking enforcement,
10. parking prohibtions and rate increases, and
11. freeway survillance and control.

IBI Group noted that by implementing such measures, the energy consumption, travel time, pollution, and delay can be reduced automatically; the benefits can accumulate 24 hours per day even if the improvements per unit time are very small.

B. Transit measues:

The second important group is transit, which is divided into subgroups as follows:

1. Bus scheduling,
2. transit priority,
3. optimization of transit routes, and
4. automatic vehicle monitoring.

C. Paratransit measures:

By improving paratransit modes, it is assumed that the number of riders will increase and the quality of traffic will be improved. Paratransit measures are divded as follows:

1. Carpooling / Vanpooling,
2. fringe parking lots, and
3. shared ride taxis.

D. Urban good movements measures:

Urban good movements can have a large impact on saving energy based on the following measures:

1. Driver training,
2. improved vehicle dispatch, and
3. truck route networks.

E. Other measures:

By shifting the masses of people during the rush hours the delay time could be decreased. Therefore, energy saving will be increased due to the effect of the following measures:

1. Variable (staggared) work hours, and
2. compressed work week.

2. The Long List of TEMM's

The long list contains the same five basic groups with additional specific measures:

A. Traffic operation measures group contains the following:

1. Geometric improvements,
2. turning movement restrictions at intersections,
3. replace stop signs with yield signs,
4. replace stop signs with traffic signals,
5. actuated signals versus fixed time signals,
6. interconnection of signals,
7. computerized signal control,
8. improved signal timings,
9. freeway surveillance and control,
10. increasing parking inforcement,
11. parking prohibitions and rate increases,
12. flashing signals in off-peak,
13. higher initial investment on highways,
14. right turn on red after stop,
15. one-way streets,
16. reversible lanes,
17. auto-area restriction, and
18. pedestrian control.

B. Transit measures group contains the following:

1. Express bus service,
2. stop spacing,
3. bus scheduling,
4. exclusive bus lanes,
5. bus actuated signals,
6. transit priority,
7. alternate vehicle size,
8. optimization of transit route,
9. improved transit markting,
10. transit park-and-ride,
11. transit fare reduction, and
12. automatic vehicle monitoring.

C. Paratransit measures group consists of the following:

1. Carpool/vanpool matching,
2. high occupancy vehicle preferential parking,
3. fringe parking lots,
4. shared ride taxis,
5. high occupancy vehicle preferential treatment,
6. improved dispatching, and
7. eliminate taxi cruising.

D. Urban goods movement measures group contains the following:

1. Goods movement loading restrictions,
2. driver training,
3. consolidation of goods movements,

4. improved dispatching, and

5. truck route networks.

E. Other measures group consists of the following:

1. Bikeways,

2. bike storage facilities,

3. telecommunications,

4. computerized transit,

5. variable work hours,

6. compressed work week,

7. pedestrian malls, and

8. increased fuel tax.

2. The following five tables contain the original IBI Group data that was used throughout this report.

TABLE AA1 Energy savings against TEMM's for the first group of city size classifications (under 50,000).

TRANSPORTATION ENERGY MANAGEMENT MEASURES	ENERGY SAVINGS AREA-WIDE		COST			OTHER IMPACTS			IMPLEMENTATION CONSIDERATIONS		
	1,000's	%	ANNUAL EXPENITURE 1,000's $	COST EFFECTIVENESS ¢/LITRE	COST EFFECTIVENESS $/BARREL	SAFETY	TRANSPORTATION SYSTEM	ENVIRONMENT	PUBLIC RESPONSE	INSTITUTIONAL/REGULATORY	INTERACTION WITH OTHER MEASURES
TRAFFIC MEASURES											
1. Turning Mov't Restr.	0.2	0.00	0.1	22	34.98	improved	spat. shift	minor	minor	enforcement	none
2. Replace Stop with Yield	71.6	0.12	0.8	1	1.59	pot. decrease	none	improved	mixed	enforcement	none
3. Replace Stop with Signal	34.5	0.06	1.5	13	20.67	possible reduction	none	improved	positive	none	none
4. Actuated Signals	36.0	0.06	2.4	7	11.13	none	none	improved	positive	none	none
5. Flashing Signals	0.7	0.00	0.0	7	11.13	decrease	none	improved	mixed	enforcement	none
6. Improved Signal Timings	152.0	0.26	4.0	3	4.77	improved	none	improved	positive	none	none
7. Interconnect Signals	50.4	0.09	10.0	20	31.80	improved	none	improved	positive	none	sig. timing
8. Computerized Signals	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
9. Increase Park Enforce	7.0	0.01	20.0	287	456.3	none	mode shift	improved	negative	enforcement	transit/HOV
10. Parking Prohibitions	27.9	0.05	75.0	269	427.71	none	mode shift	improved	negative	enforcement	transit/HOV
11. Freeway Surveillance	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TRANSIT MEASURES											
12. Bus Scheduling	3.4	0.01	17.5	509	809.00	none	none	negligible	none	none	none
13. Transit Priority	0.2	0.00	2.5	1,157	1,839.63	minor	mode shift	minor	mixed	traffic/ enforcement	transit service
14. Optimiz. Transit Routes	16.4	0.03	4.0	24	38.16	none	mode shift	minor	positive	none	bus sched.
15. Aut. Vehicle Monitor	8.4	0.01	15.6	187	297.00	none	none	minor	minor	none	none
HOV MEASURES											
16. Carpool/Vanpool	30.0	0.05	5.0	17	20.03	none	mode shift	positive	positive	transit/new agency	transit/ parking
17. Fringe Parking Lots	-	-	-	-	-	n.a	mode shift	n.a	n.a	n.a	n.a
18. Shared Ride Taxis	52.0	0.09	10.0	19	30.21	none	mode shift	positive	positive	municipalities	transit
URBAN GOODS MOV'T MEASURES											
19. Driver Training	111.0	0.19	6.0	5	7.95	improved	none	improved	positive	private sec.	none
20. Improved Veh. Dispatch	38.8	0.07	150.0	386	614.00	none	none	improved	none	private	none
21. Truck Route Networks	94.1	0.16	56.4	60	95.40	marginal	none	improved	significant	traffic	none
OTHER MEASURES											
22. Variable Work Hours	2.1	0.00	5.0	714	1,135.26	none	less congestion	improved	positive	new agency	)carpool/)vanpool/
23. Compressed Work Week	72.0	0.12	10.0	12	19.08	positive	less congestion	improved	positive	new agency	)transit)

Reproduced from IBI Group study [2]

TABLE AA2 Energy savings against TEMM's for the second group of city size classifications (50,000-100,000).

TRANSPORTATION ENERGY MANAGEMENT MEASURES	ENERGY SAVINGS AREA-WIDE		COST			OTHER IMPACTS			IMPLEMENTATION CONSIDERATIONS		
	1,000's	%	ANNUAL EXPENITURE 1,000's $	COST EFFECTIVENESS ¢/LITRE	$/BARREL	SAFETY	TRANSPORTATION SYSTEM	ENVIRONMENT	PUBLIC RESPONSE	INSTITUTIONAL/REGULATORY	INTERACTION WITH OTHER MEASURES
TRAFFIC MEASURES											
1. Turning Mov't Restr.	1.0	0.00	0.2	22	34.98	improved	none	minor	minor	enforcement	none
2. Replace Stop with Yield	250.0	0.20	2.8	1	1.59	pot. decrease	none	improved	mixed	enforcement	none
3. Replace Stop with Signal	82.8	0.07	10.5	13	20.67	possible reduction	none	improved	positive	none	none
4. Actuated Signals	167.0	0.13	11.2	7	11.13	none	none	improved	positive	none	none
5. Flashing Signals	2.8	0.00	0.2	7	11.13	decrease	none	improved	mixed	enforcement	none
6. Improved Signal Timings	730.0	0.58	18.5	3	4.77	improved	none	improved	positive	none	none
7. Interconnect Signals	278.0	0.22	50.0	18	28.62	improved	none	improved	positive	none	sig. timing
8. Computerized Signals	384.0	0.30	30.0	8	12.72	improved	none	improved	positive	none	none
9. Increase Park Enforce	23.3	0.02	40.0	180	273.48	none	mode shift	improved	negative	enforcement	transit/HOV
10. Parking Prohibitions	83.7	0.07	180.0	215	341.85	none	mode shift	improved	negative	enforcement	transit/HOV
11. Freeway Surveillance	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TRANSIT MEASURES											
12. Bus Scheduling	9.4	0.01	32.5	346	550.00	none	none	negligible	none	none	none
13. Transit Priority	1.0	0.00	7.5	728	1,157.52	minor	mode shift	minor	mixed	traffic/enforcement	transit service
14. Optimiz. Transit Routes	28.9	0.02	10.0	35	55.65	none	mode shift	minor	positive	none	bus sched.
15. Aut. Vehicle Monitor	25.2	0.02	48.0	191	304.00	none	none	minor	minor	none	none
HOV MEASURES											
16. Carpool/Vanpool	144.0	0.11	30.0	21	33.39	none	mode shift	positive	positive	transit/new agency	transit/parking
17. Fringe Parking Lots	-	-	-	-	-	n.a	n.a	n.a	n.a	n.a	n.a
18. Shared Ride Taxis	125.0	0.10	20.0	16	25.49	none	mode shift	positive	positive	municipalities	transit
URBAN GOODS MOV'T MEASURES											
19. Driver Training	296.0	0.23	15.0	5	7.95	improved	none	improved	positive	private sec.	none
20. Improved Veh. Dispatch	129.0	0.10	285.0	220	350.00	none	none	improved	none	private	none
21. Truck Route Networks	198.0	0.16	85.6	44	70.00	marginal	none	improved	significant	traffic	none
OTHER MEASURES											
22. Variable Work Hours	7.1	0.01	20.0	850	1,372.17	none	less congestion	improved	positive	new agency	)carpool/)vanpool/)transit)
23. Compressed Work Week	237.0	0.19	40.0	16	25.44	positive	less congestion	improved	positive	new agency	

Reproduced from IBI Group study [2]

IBI Group

TABLE AA3 Energy savings against TEMM's for the third group of city size classifications (100,000-350,000).

TRANSPORTATION ENERGY MANAGEMENT MEASURES	ENERGY SAVINGS AREA-WIDE		COST			OTHER IMPACTS			IMPLEMENTATION CONSIDERATIONS		
	1,000's	%	ANNUAL EXPENITURE 1,000's $	COST EFFECTIVENESS ¢/LITRE	$/BARREL	SAFETY	TRANSPORTATION SYSTEM	ENVIRONMENT	PUBLIC RESPONSE	INSTITUTIONAL/REGULATORY	INTERACTION WITH OTHER MEASURES
TRAFFIC MEASURES											
1. Turning Mov't Restr.	3.1	0.00	0.6	20	31.80	improved	none	minor	minor	enforcement	none
2. Replace Stop with Yield	878.0	0.26	9.8	.1	1.59	pot.decrease	none	improved	mixed	enforcement	none
3. Replace Stop with Signal	130.0	0.04	16.5	13	20.67	possible reduction	none	improved	positive	none	none
4. Actuated Signals	450.0	0.13	30.0	7	11.13	none	none	improved	positive	none	none
5. Flashing Signals	7.3	0.00	0.5	7	11.13	decrease	none	improved	mixed	enforcement	none
6. Improved Signal Timings	2210.0	0.65	36.5	23	3.18	improved	none	improved	positive	none	none
7. Interconnect Signals	916.0	0.27	145.0	16	25.44	improved	none	improved	positive	none	sig. timing
8. Computerized Signals	787.0	0.23	61.5	8	12.70	improved	none	improved	positive	none	none
9. Increase Park Enforce	78.0	0.02	85.0	109	173.31	none	mode shift	improved	negative	enforcement	transit/HOV
10. Parking Prohibitions	281.0	0.08	267.0	95	151.05	none	mode shift	improved	negative	enforcement	transit/HOV
11. Freeway Surveillance			-	-	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TRANSIT MEASURES											
12. Bus Scheduling	68.2	0.02	45.0	66	105.00	none	none	negligible	none	none	none
13. Transit Priority	2.3	0.00	15.6	680	709.14	minor	mode shift	minor	mixed	traffic/ enforcement	transit service
14. Optimiz. Transit Routes	66.8	0.02	25.0	37	58.83	none	mode shift	minor	positive	none	bus sched.
15. Aut. Vehicle Monitor	105.0	0.03	217.0	210	329.00	none	none	minor	minor	none	none
HOV MEASURES											
16. Carpool/Vanpool	330.0	0.10	75.0	23	36.57	none	mode shift	positive	positive	transit/new agency	transit/ parking
17. Fringe Parking Lots	329.0	0.10	41.6	15	23.85	n.a	n.a	n.a	n.a	n.a	n.a
18. Shared Ride Taxis	313.0	0.09	70.0	22	34.98	none	mode shift	improved	positive	none	carpool/ vanpool
URBAN GOODS MOV'T MEASURES											
19. Driver Training	798.0	0.23	32.0	4	636	improved	none	improved	positive	private sec.	none
20. Improved Veh. Dispatch	430.0	0.13	795.0	140	223.00	none	none	improved	none	private	none
21. Truck Route Networks	471.0	0.14	155.0	32	50.90	marginal	none	improved	significant	traffic	none
OTHER MEASURES											
22. Variable Work Hours	26.2	0.01	40.0	466	740.94	none	less congestion	improved	positive	new agency	carpool/ vanpool/ transit
23. Compressed Work Week	408.0	0.12	95.0	23	36.57	positive	less congestion	improved	positive	new agency	

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TABLE AA4 Energy savings against TEMM's for the fourth group of city size classifications (350,000-1,000,000).

TRANSPORTATION ENERGY MANAGEMENT MEASURES	ENERGY SAVINGS AREA-WIDE		COST			OTHER IMPACTS			IMPLEMENTATION CONSIDERATIONS		
	1,000's	$	ANNUAL EXPENITURE 1,000's $	COST EFFECTIVENESS ¢/LITRE	COST EFFECTIVENESS $/BARREL	SAFETY	TRANSPORTATION SYSTEM	ENVIRONMENT	PUBLIC RESPONSE	INSTITUTIONAL/REGULATORY	INTERACTION WITH OTHER MEASURES
TRAFFIC MEASURES											
1. Turning Mov't Restr.	6.7	0.00	1.3	20	31.80	improved	none	minor	minor	enforcement	none
2. Replace Stop with Yield	2730.0	0.30	30.3	1	1.59	pot.decrease	none	improved	mixed	enforcement	none
3. Replace Stop with Signal	.449.0	0.05	97.0	13	20.67	possible reduction	none	improved	positive	none	none
4. Actuated Signals	936.0	0.10	62.4	7	11.13	none	none	improved	positive	none	none
5. Flashing Signals	-16.5	0.00	1.1	7	11.13	decrease	none	improved	mixed	enforcement	none
6. Improved Signal Timings	6560.0	0.72	114.5	(2)	3.18	improved	none	improved	positive	none	none
7. Interconnect Signals	1400.0	0.15	207.5	15	23.85	improved	none	improved	positive	none	sig. timing
8. Computerized Signals	2020.0	0.22	157.5	8	12.72	improved	none	improved	positive	none	none
9. Increase Park Enforce	165.0	0.02	140.0	85	135.15	none	mode shift	improved	negative	enforcement	transit/HOV
10. Parking Prohibitions	568.0	0.06	380.0	67	106.53	none	mode shift	improved	negative	enforcement	transit/HOV
11. Freeway Surveillance	622.0	0.07	216.0	35	55.70	improved	none	improved	positive	multi	HOV's
TRANSIT MEASURES											
12. Bus Scheduling	157.0	0.02	65.0	41	65.20	none	none	negligible	none	none	none
13. Transit Priority	. 6.8	0.00	40.6	594	944.46	minor	mode shift	minor	mixed	traffic/ enforcement	transit service
14. Optimiz. Transit Routes	114.0	0.01	50.0	44	69.96	none	mode shift	minor	positive	none	bus sched.
15. Aut. Vehicle Monitor	388.0	0.04	741.0	191	304.00	none	none	minor	minor	none	none
HOV MEASURES											
16. Carpool/Vanpool	1170.0	0.13	200.0	17	27.03	none	mode shift	positive	positive	transit/new agency	transit/ parking
17. Fringe Parking Lots	823.0	0.09	104.0	13	20.67	none	mode shift	improved	positive	none	)
18. Shared Ride Taxis	962.0	0.11	100.0	10	15.90	none	mode shift	improved	positive	none	) carpool/) vanpool
URBAN GOODS MOV'T MEASURES											
19. Driver Training	3220.0	0.35	100.0	3	4.77	improved	none	improved	positive	private sec.	none
20. Improved Veh. Dispatch	1520.0	0.17	2175.0	79	126.00	none	none	improved	none	private	none
21. Truck Route Networks	1170.0	0.13	353.0	30	47.70	marginal	none	improved	significant	traffic	none
OTHER MEASURES											
22. Variable Work Hours	.110.0	0.01	70.0	198	311.64	none	less congestion	improved	positive	new agency	)carpool/)vanpool/
23. Compressed Work Week	1800.0	0.20	165.0	9	14.31	positive	less congestion	improved	positive	new agency	)transit)

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TABLE AA5 Energy savings against TEMM's for the fifth group of city size classifications (over 1,000,000).

TRANSPORTATION ENERGY MANAGEMENT MEASURES	ENERGY SAVINGS AREA-WIDE		COST			OTHER IMPACTS			IMPLEMENTATION CONSIDERATIONS		
	1,000's	$	ANNUAL EXPENITURE 1,000's $	COST EFFECTIVENESS ¢/LITRE	$/BARREL	SAFETY	TRANSPORTATION SYSTEM	ENVIRONMENT	PUBLIC RESPONSE	INSTITUTIONAL/REGULATORY	INTERACTION WITH OTHER MEASURES
TRAFFIC MEASURES											
1. Turning Mov't Restr.	32	0.00	5.1	16	25.44	improved	none	minor	minor	enforcement	none
2. Replace Stop with Yield	5670	0.22	63.0	1	1.59	pot.decrease	none	improved	mixed	enforcement	none
3. Replace Stop with Signal	993	0.04	126.0	13	20.67	possible reduction	none	improved	positive	none	none
4. Actuated Signals	3710	0.14	247.5	7	11.13	none	none	improved	positive	none	none
5. Flashing Signals	64	0.00	4.3	7	11.13	decrease	none	improved	mixed	enforcement	none
6. Improved Signal Timings	34900	1.34	525.0	2	3.18	improved	none	improved	positive	none	none
7. Interconnect Signals	2060	0.08	250.0	12	19.00	improved	none	improved	positive	none	sig. timing
8. Computerized Signals	5760	0.22	450.0	8	12.72	improved	none	improved	positive	none	none
9. Increase Park Enforce	794	0.03	400.0	50	79.50	none	mode shift	improved	negative	enforcement	transit/HOV
10.Parking Prohibitions	2740	0.07	1300.0	47	74.73	none	mode shift	improved	negative	enforcement	transit/HOV
11.Freeway Surveillance	1250	0.05	360.0	29	46.10	improved	none	improved	positive	multi	HOV's
TRANSIT MEASURES											
12.Bus Scheduling	284	0.01	115.0	41	65.20	none	none	negligible	none	none	none
13.Transit Priority	47	0.00	187.5	398	632.82	minor	mode shift	minor	mixed	traffic/ enforcement	transit service
14.Optimiz.Transit Routes	334	0.01	100.0	30	47.70	none	mode shift	minor	positive	none	bus sched.
15.Aut. Vehicle Monitor	1670	0.06	3180.0	190	302.00	none	none	minor	minor	none	none
HOV MEASURES											
16.Carpool/Vanpool	6800	0.26	600.0	9	14.31	none	mode shift	positive	positive	transit/new agency	transit/ parking
17.Fringe Parking Lots	1370	0.05	173.4	13	20.67	none	mode shift	improved	positive	none	)
18.Shared Ride Taxis	3870	0.15	300.0	8	12.72	none	mode shift	improved	positive	none	) carpool/) vanpool
URBAN GOODS MOV'T MEASURES											
19.Driver Training	9090	0.35	160.0	2	3.18	improved	none	improved	positive	private sec.	none
20.Improved Veh. Dispatch	6340	0.24	7830.0	62	98.58	none	none	improved	none	private	none
21.Truck Route Networks	2800	0.11	813.0	29	46.10	marginal	none	improved	significant	traffic	none
OTHER MEASURES											
22.Variable Work Hours	776	0.03	100.0	39	62.01	none	less congestion	improved	positive	new agency	)carpool/)vanpool/)transit
23.Compressed Work Week	8500	0.33	200.0	2	3.18	positive	less congestion	improved	positive	new agency	)

Reproduced from IBI Group study [2]

3. The data in the following twenty three tables were selected from the previous four IBI Group tables and rearranged in accordance with the 23 TEMM's. The (0,0) data point as discussed in Chapter 3, is added to all of these Tables.

TABLE A1

Summary of energy savings against city sizes under the implementation of turning movement restrictions.

TURNING MOVEMENT RESTRICTIONS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	200
75,000	1,000
225,000	3,100
675,000	6,700

TABLE A2

Summary of energy savings against city sizes under the implementation of replacing stop signs with yield signs.

REPLACING STOP SIGNS WITH YIELD SIGNS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	71,600
75,000	250,000
225,000	878,000
675,000	2,730,000

TABLE A3

Summary of energy savings against city sizes under the implementation of replacing stop signs with signals.

REPLACING STOP SIGNS WITH SIGNALS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	34,500
75,000	82,800
225,000	130,000
675,000	449,000

TABLE A4

Summary of energy savings against city sizes under the implementation of actuated signals.

ACTUATED SIGNALS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	36,000
75,000	167,000
225,000	450,000
675,000	936,000

TABLE A5

Summary of energy savings against city sizes under the implementation of flshing asignals.

FLASHING SIGNALS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	700
75,000	2,800
225,000	7,300
675,000	16,500

TABLE A6

Summary of energy savings against city sizes under the implementation of optimized signal timing plans.

OPTIMIZED SIGNALS TIMING PLANS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVING (IN LIT./YEAR)
0	0
25,000	152,000
75,000	730,000
225,000	2,210,000
675,000	6,560,000

TABLE A7

Summary of energy savings against city sizes under the implementation of interconnected signals.

INTERCONNECTED SIGNALS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	50,400
75,000	278,000
225,000	916,000
675,000	1,400,000

TABLE A8

Summary of energy savings against city sizes under the implementation of computerized signals.

COMPUTERIZED SIGNALS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	N.A
75,000	384,000
225,000	787,000
675,000	2,020,000

TABLE A9

Summary of energy savings against city sizes under the implementation of the increased parking inforcement.

INCREASE PARKING INFORCMENT	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	7,000
75,000	23,300
225,000	78,000
675,000	165,000

TABLE A10

Summary of energy savings against city sizes under the implementation of parking prohibition.

PARKING PROHIBTIONS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	27,900
75,000	83,700
225,000	281,000
675,000	568,000

TABLE A11

Summary of energy savings against city sizes under the implementation of freeway surveillance.

FREEWAY SURVEILLANCE	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	N.A
75,000	N.A
225,000	N.A
675,000	622,000

TABLE A12

Summary of energy savings against city sizes under the implementation of bus scheduling.

BUS SCHEDULING	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	3,400
75,000	9,400
225,000	68,200
675,000	157,000

TABLE A13

Summary of energy savings against city sizes under the implementation of transit priority.

TRANSIT PRIORITY	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	200
75,000	1,000
225,000	2,300
675,000	6,800

TABLE A14

Summary of energy savings against city sizes under the implementation of optimized transit routes.

OPTMIZATION OF TRANSIT ROUTES	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./TEAR)
0	0
25,000	16,400
75,000	28,900
225,000	66,800
675,000	114,000

TABLE A15

Summary of energy savings against city sizes under the implementation of automatic vehicle monitoring.

AUTOMATIC VEHICLE MONIOTOR	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	8,400
75,000	25,200
225,000	105,000
675,000	388,000

TABLE A16

Summary of energy savings against city sizes under the implementation of carpool/vanpool preferred parking scheme.

CARPOOLING / VANPOOLING	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	30,000
75,000	144,000
225,000	330,000
675,000	1,170,000

TABLE A17

Summary of energy savings against city sizes under the implementation of fringe parking lots.

FRINGE PARKING LOTS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	N.A
75,000	N.A
225,000	329,000
675,000	823,000

TABLE A18

Summary of energy savings against city sizes under the implementation of shared ride taxis.

SHARED RIDE TAXIS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	52,000
75,000	125,000
225,000	313,000
675,000	962,000

TABLE A19

Summary of energy savings against city sizes under the implementation of driver training.

DRIVER TRAINING	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	111,000
75,000	296,000
225,000	798,000
675,000	3,220,000

TABLE A20

Summary of energy savings against city sizes under the implementation of improved vehicle dispatching.

IMPROVED VEHICLE DISPATCH	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	38,800
75,000	129,000
225,000	430,000
675,000	1,520,000

TABLE A21

Summary of energy savings against city sizes under the implementation of truck route networks.

TRUCK ROUTE NETWORK	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	94,100
75,000	198,000
225,000	471,000
675,000	1,170,000

TABLE A22

Summary of energy savings against city sizes under the implementation of variable work hours.

VARIABLE WORK HOURS	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	2,100
75,000	7,100
225,000	26,200
625,000	110,000

TABLE A23

Summary of energy savings against city sizes under the implementation of a compressed work week.

COMPRESSED WORK WEEK	
AVERAGE VALUE OF CITY SIZE	ENERGY SAVINGS (IN LIT./YEAR)
0	0
25,000	72,000
75,000	237,000
225,000	408,000
625,000	1,800,000

4. Using the data in the previous 23 tables, 23 figures were plotted to display the relationship between the energy savings and city sizes for 23 TEMM's.

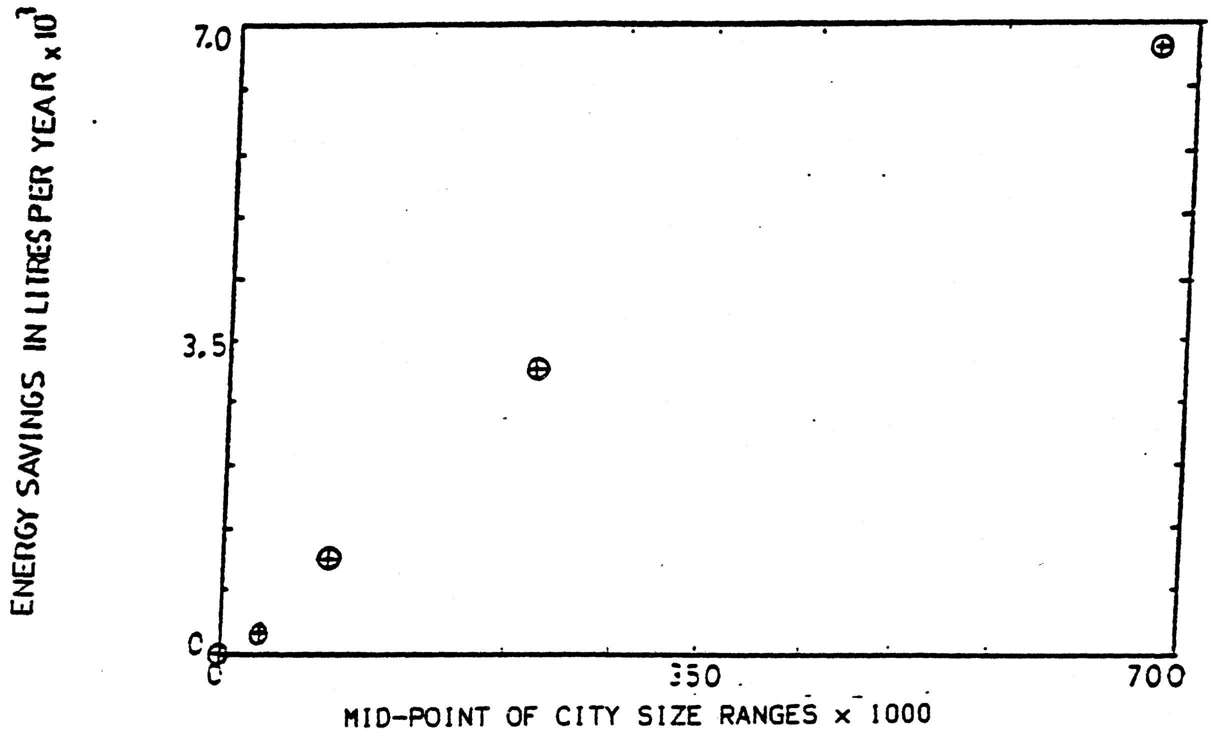

FIGURE A1 Observed energy savings against mid-point of city size ranges due to implementation of turning movement restrictions.

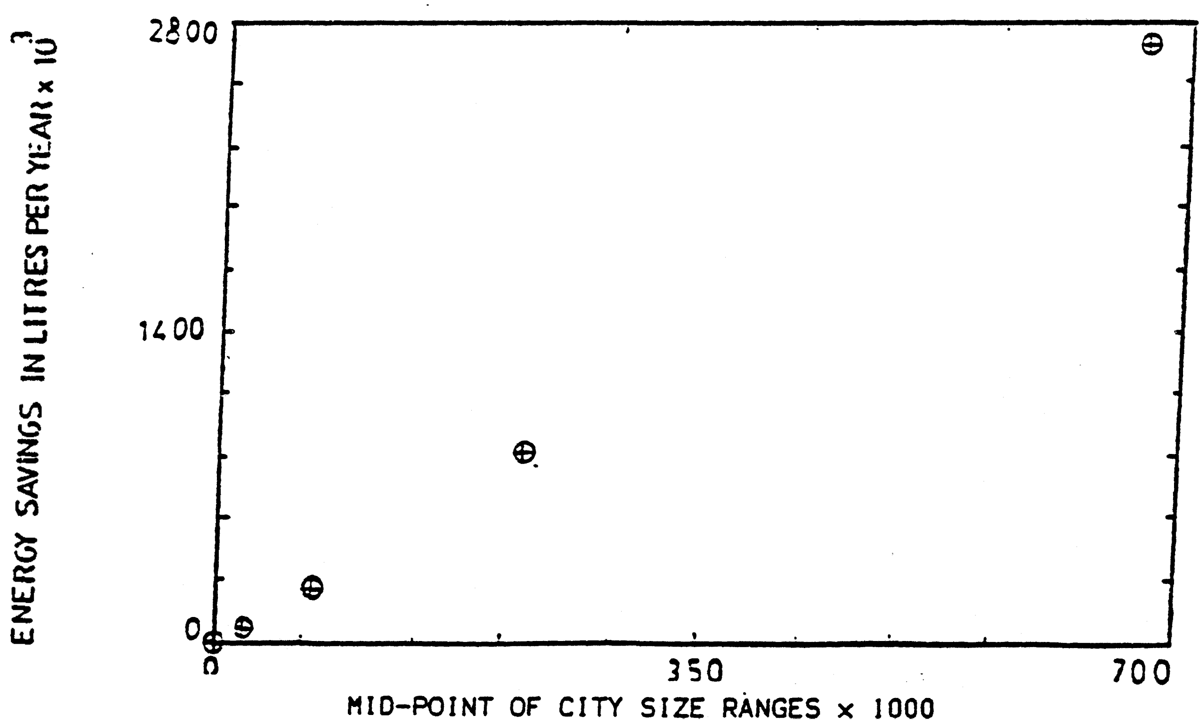

FIGURE A2 Observed energy savings against mid-point of city size ranges due to implementation of replacing stop signs with yield signs.

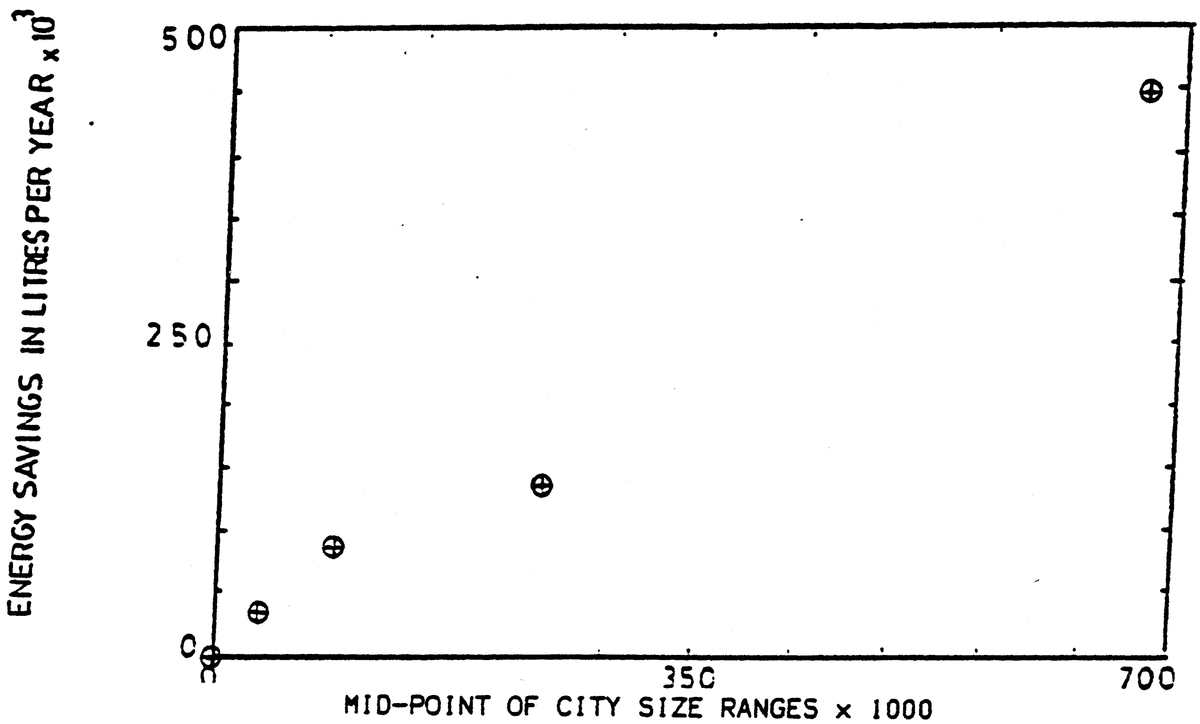

FIGURE A3 Observed energy savings against mid-points of city size ranges due to implementation of replacing stop signs with signals.

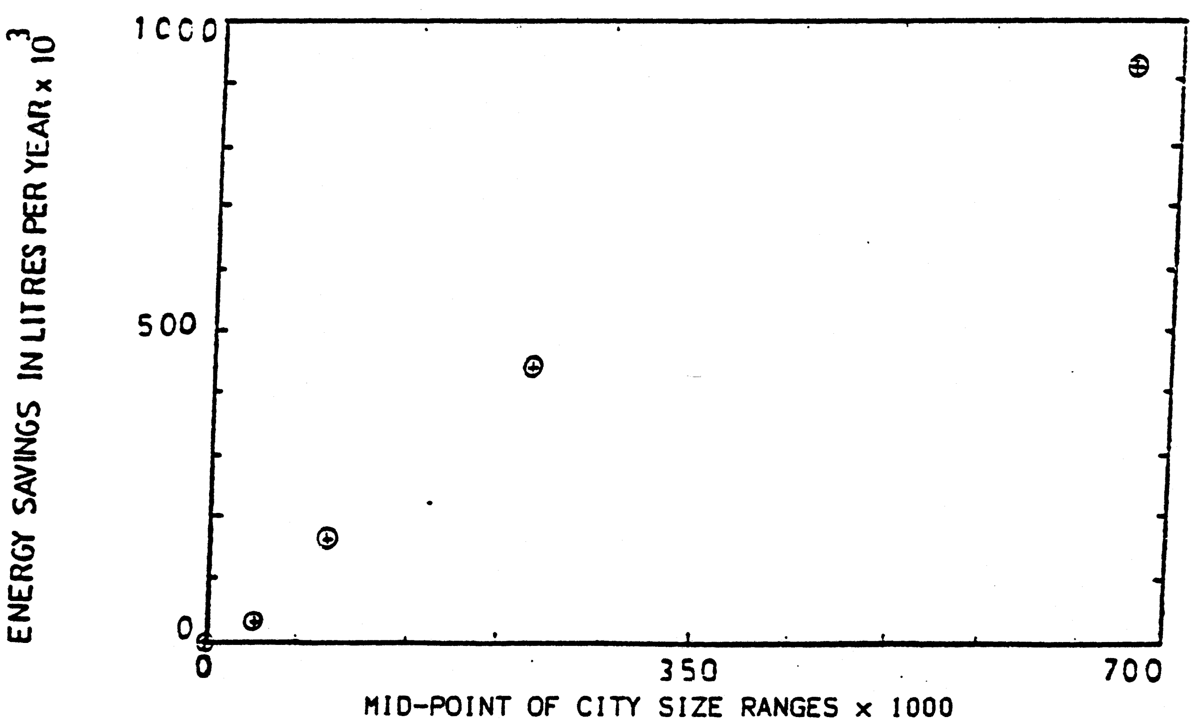

FIGURE A4 Observed energy savings against mid-point of city size ranges due to implementation of actuated signals.

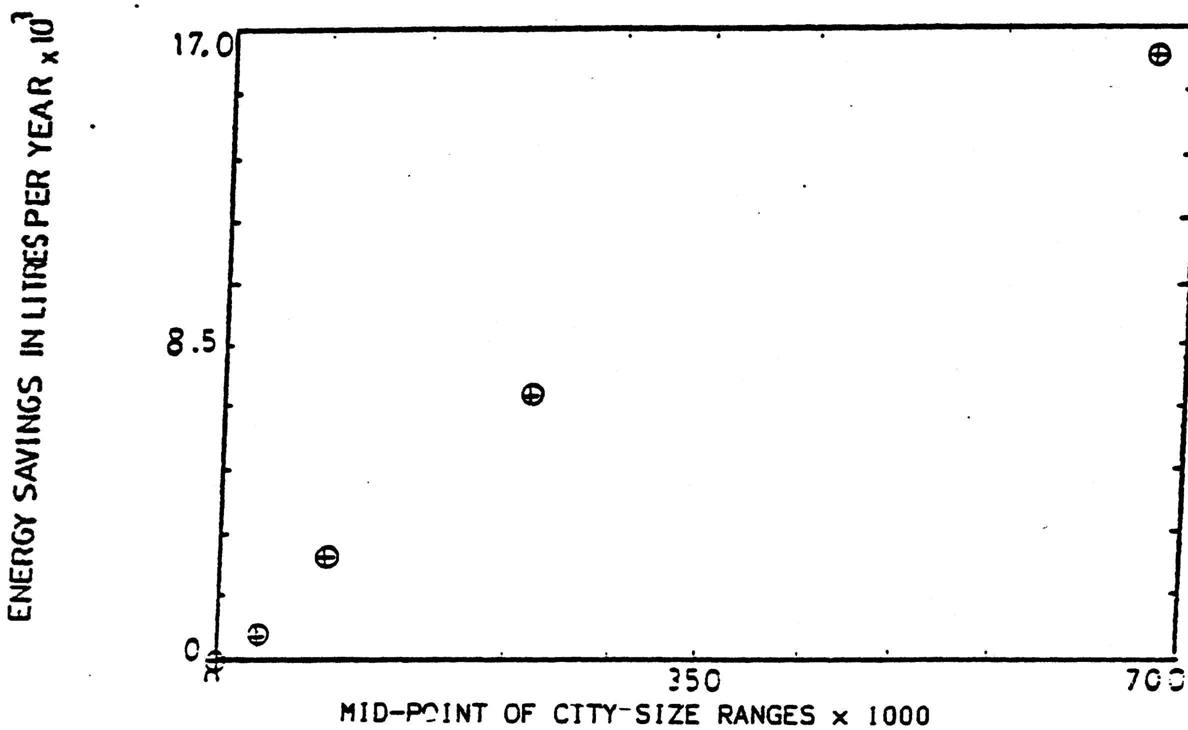

FIGURE A5 Observed energy savings against mid-point of city size ranges due to implementation of flashing signals.

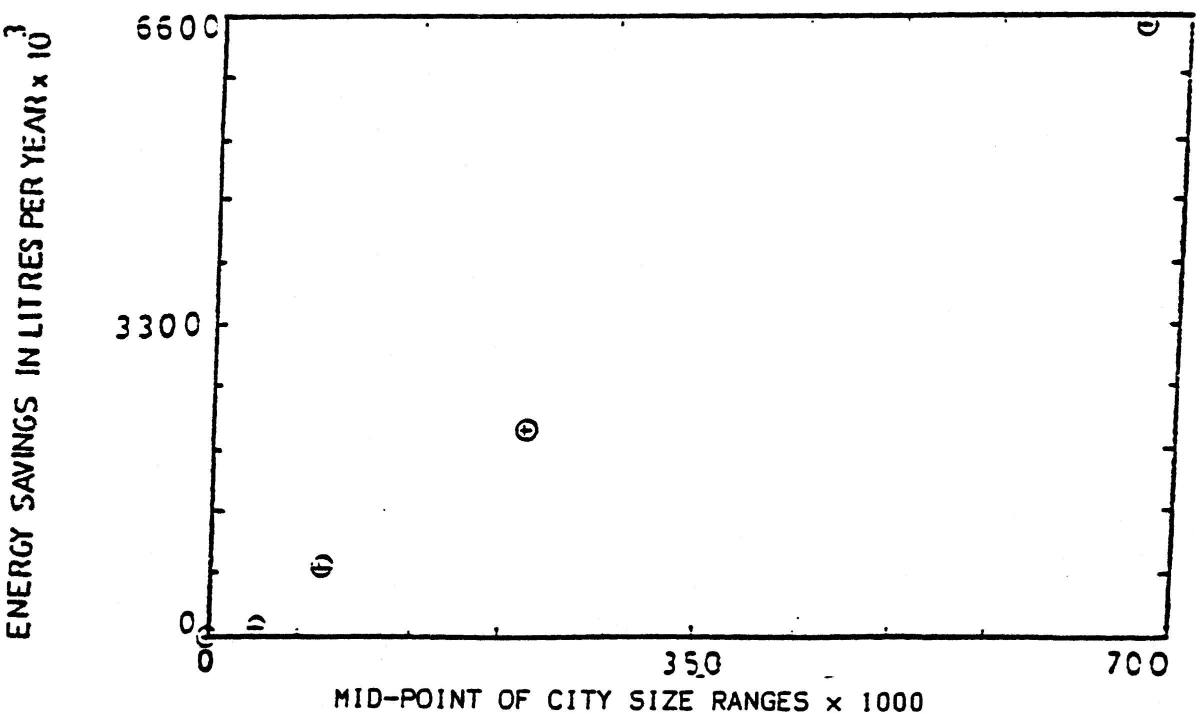

FIGURE A6 Observed energy savings against mid-points of city size ranges due to implementation of improved signal timings.

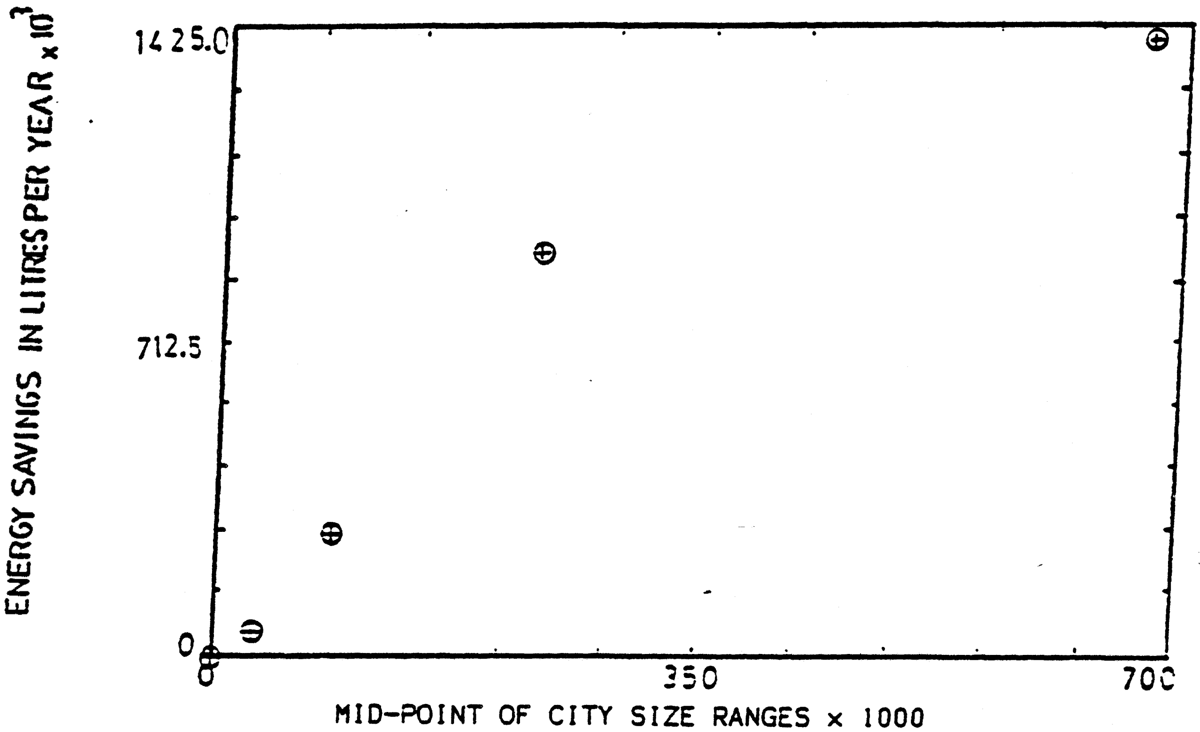

FIGURE A7 Observed energy savings against mid-points of city size ranges due to implementation of interconnected signals.

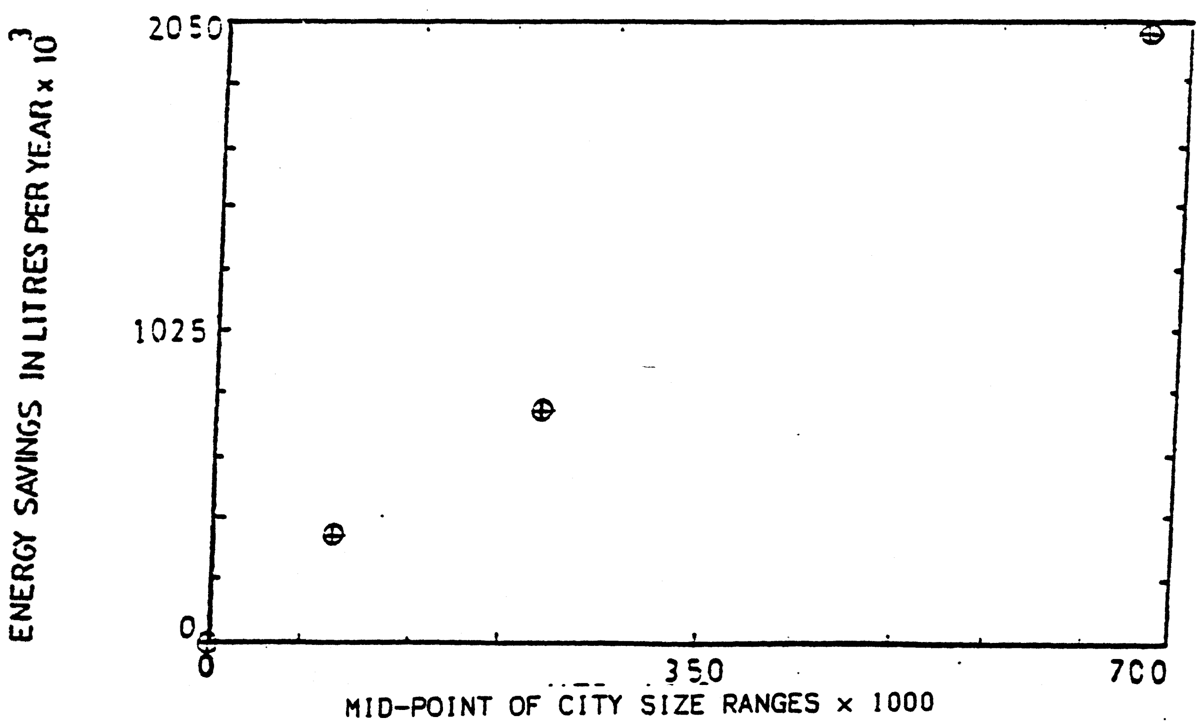

FIGURE A8 Observed energy savings against mid-points of city size ranges due to implementation of computerized signal control.

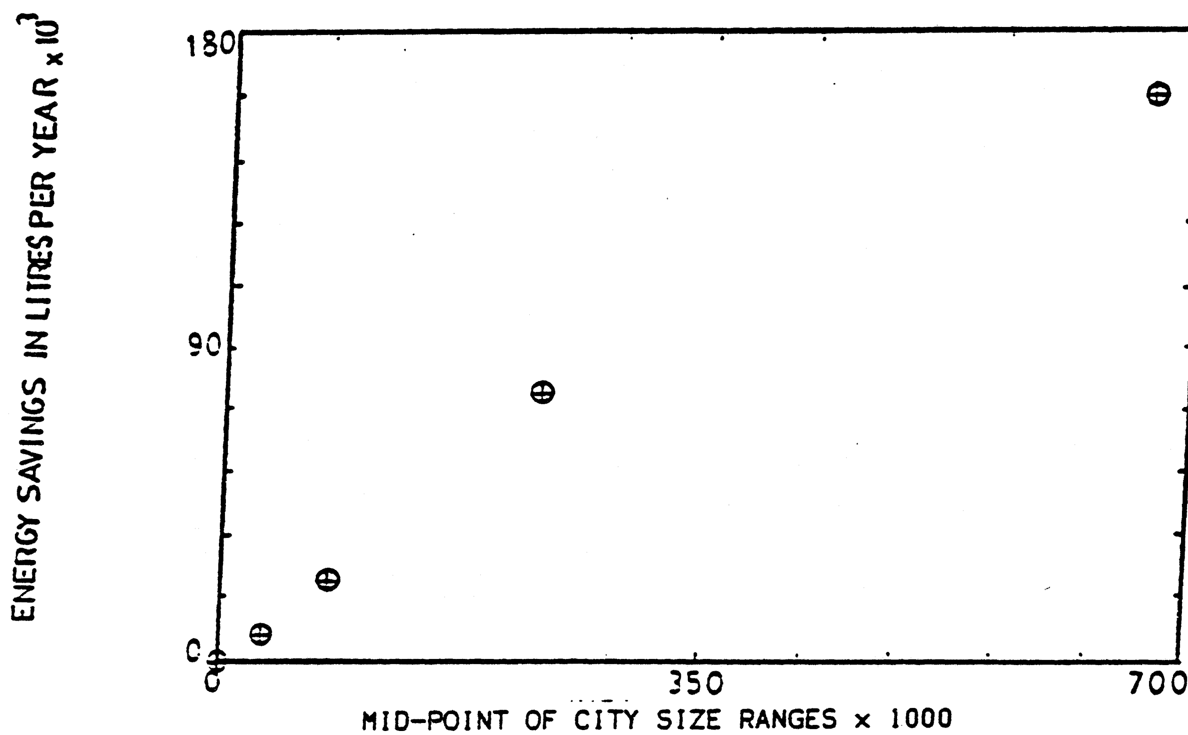

FIGURE A9 Observed energy savings against mid-point of city size ranges due to implementation of increased parking enforcement.

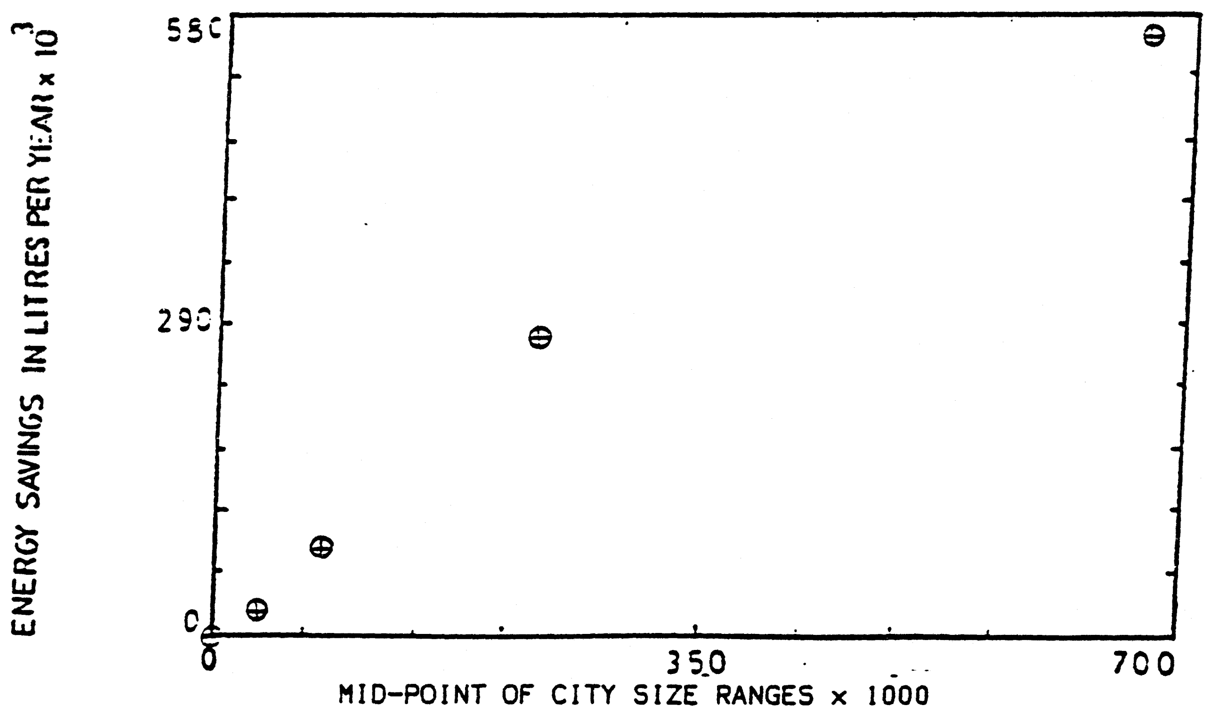

FIGURE A10 Observed energy savings against mid-point of city size ranges due to implementation of parking prohibition.

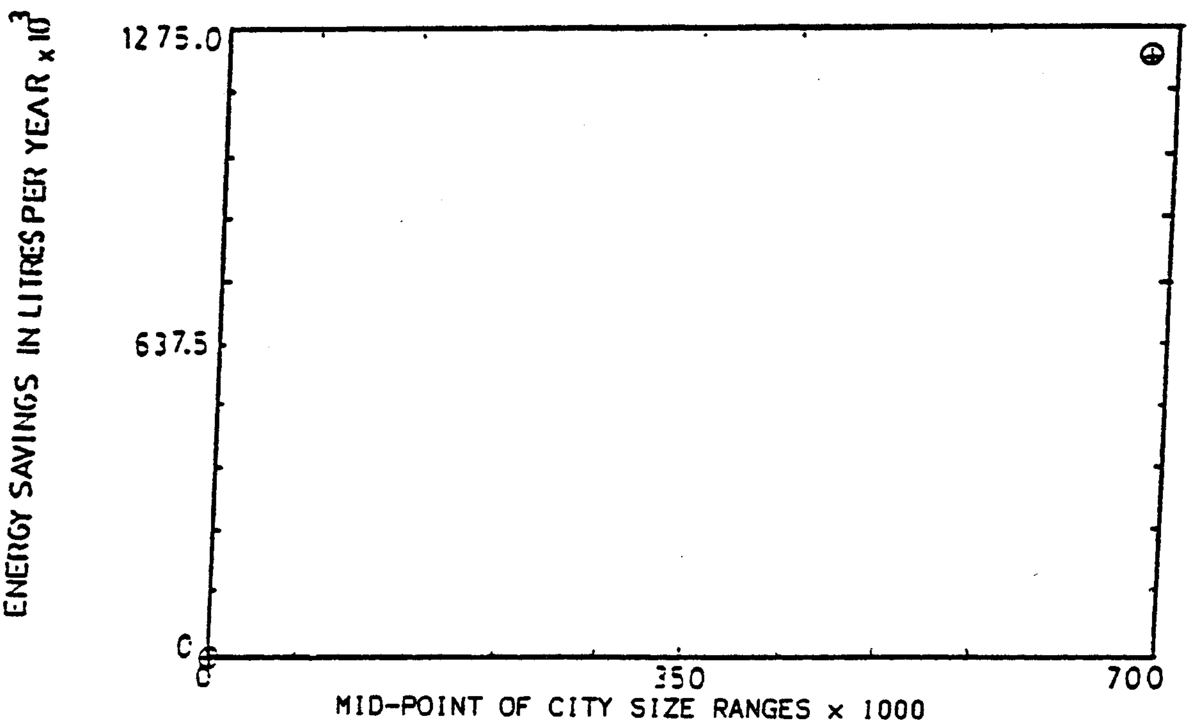

FIGURE A11 Observed energy savings against mid-points of city size ranges due to implementation of freeway surveillance.

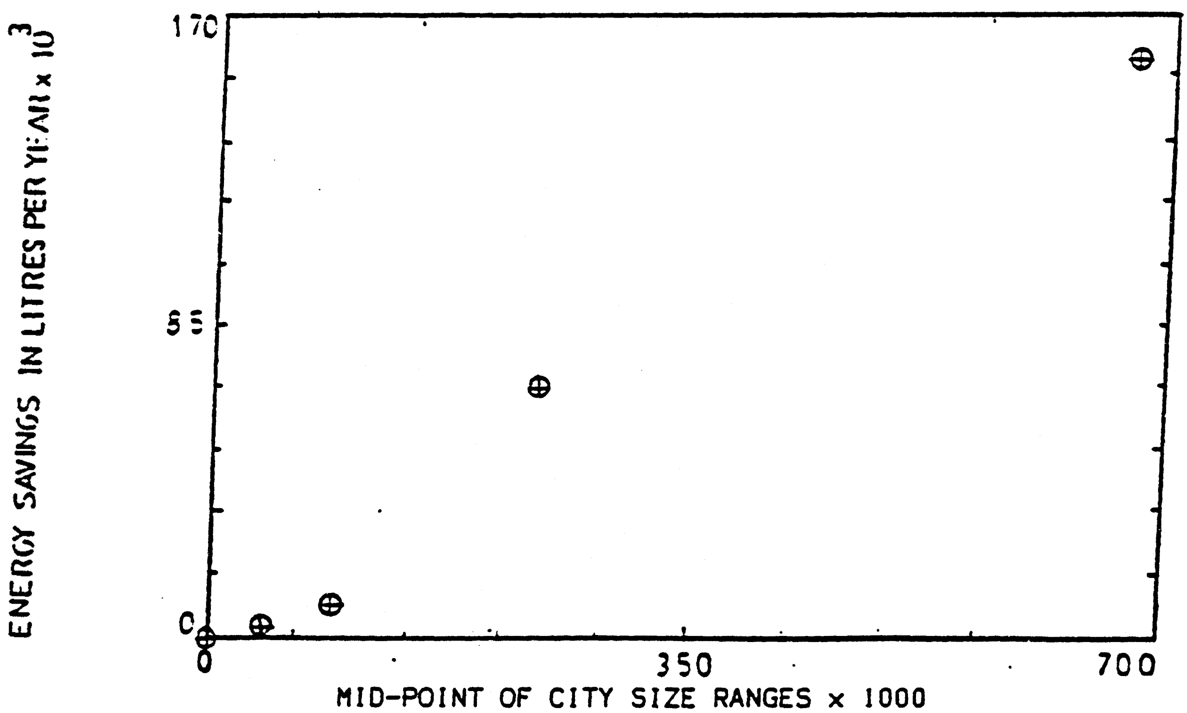

FIGURE A12 Observed energy savings against mid-point of city size ranges due to implementation of bus scheduling.

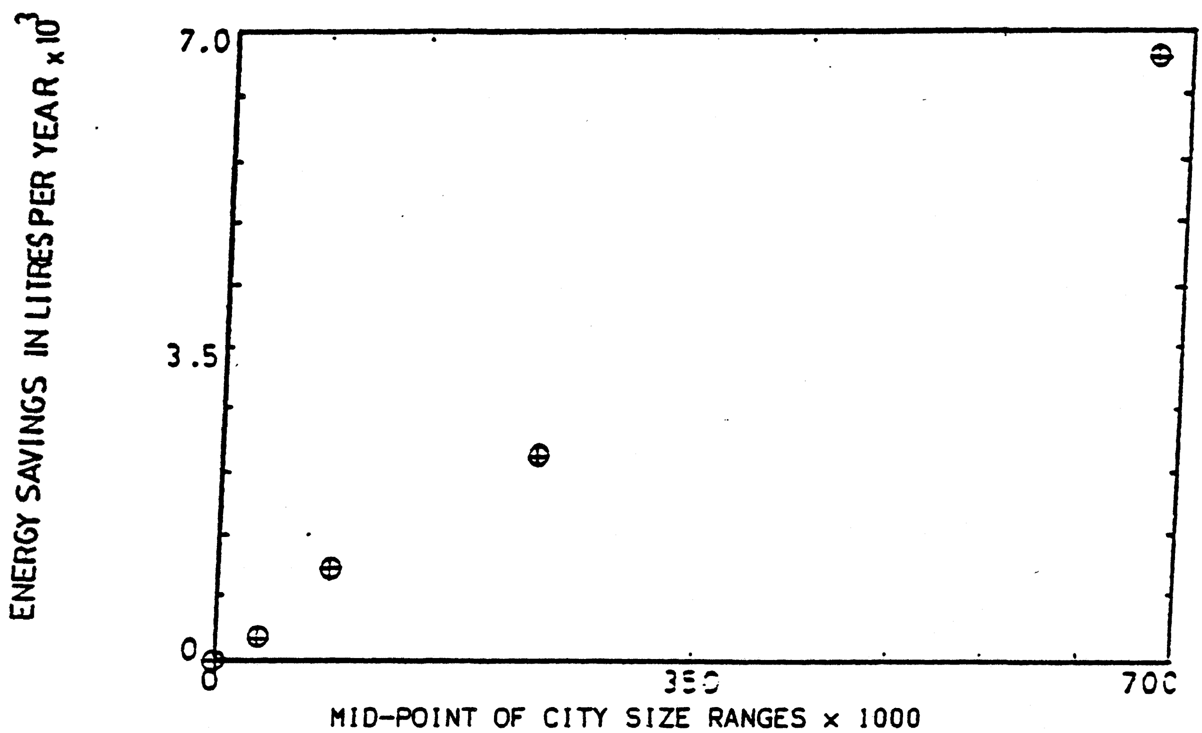

FIGURE A13 Observed energy savings against mid-point of city size ranges due to implementation of transit priority.

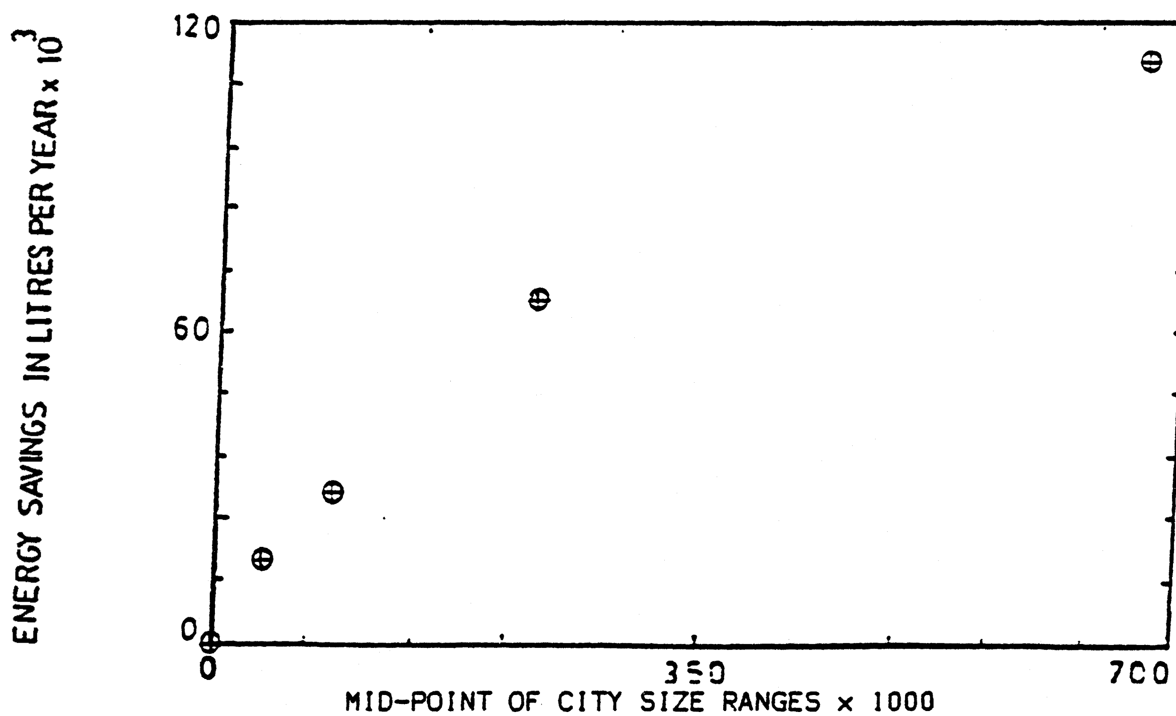

FIGURE A14 Observed energy savings against mid-points of city size ranges due to implementation of optimization of transit routes.

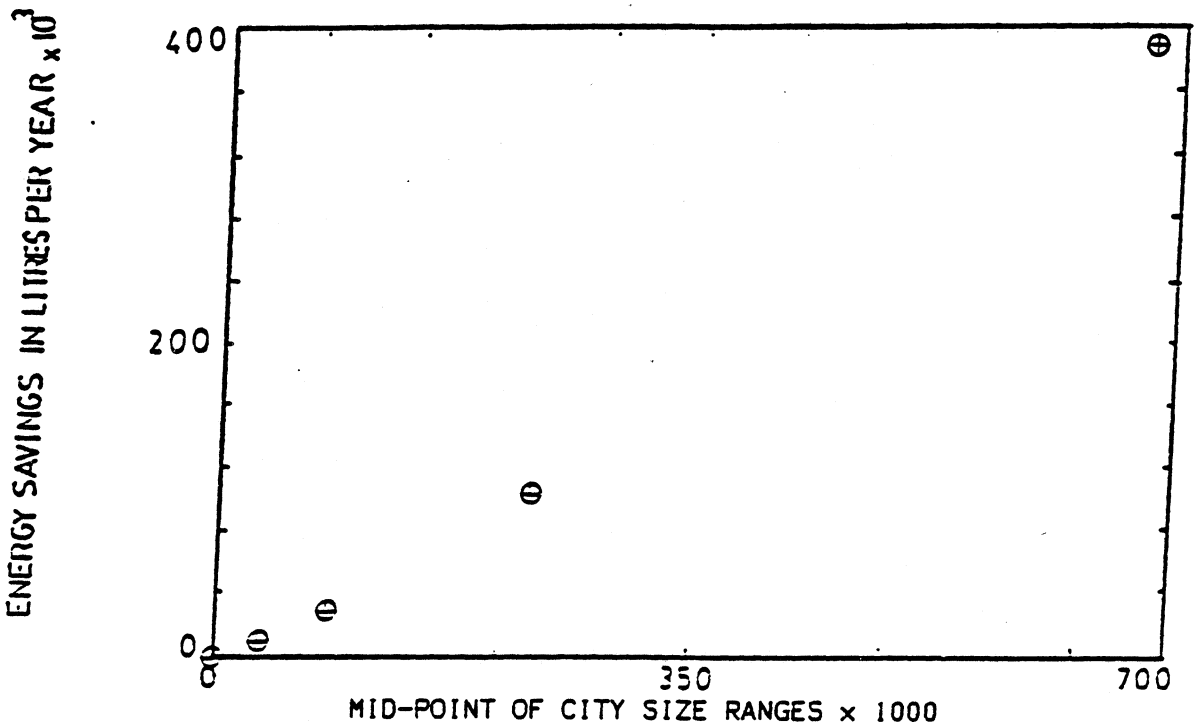

FIGURE A15 Observed energy savings against mid-points of city size ranges due to implementation of automatic vehicle monitoring.

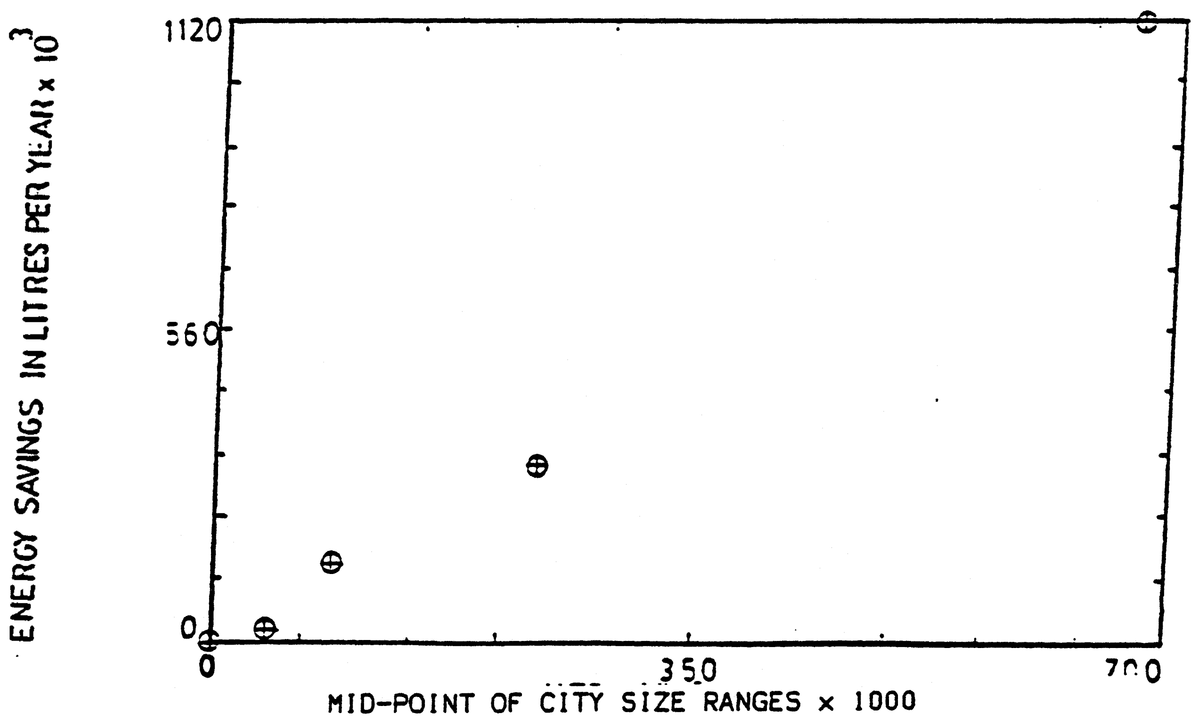

FIGURE A16 Observed energy savings against mid-points of city size ranges due to implementation of car/vanpooling preferred parking scheme.

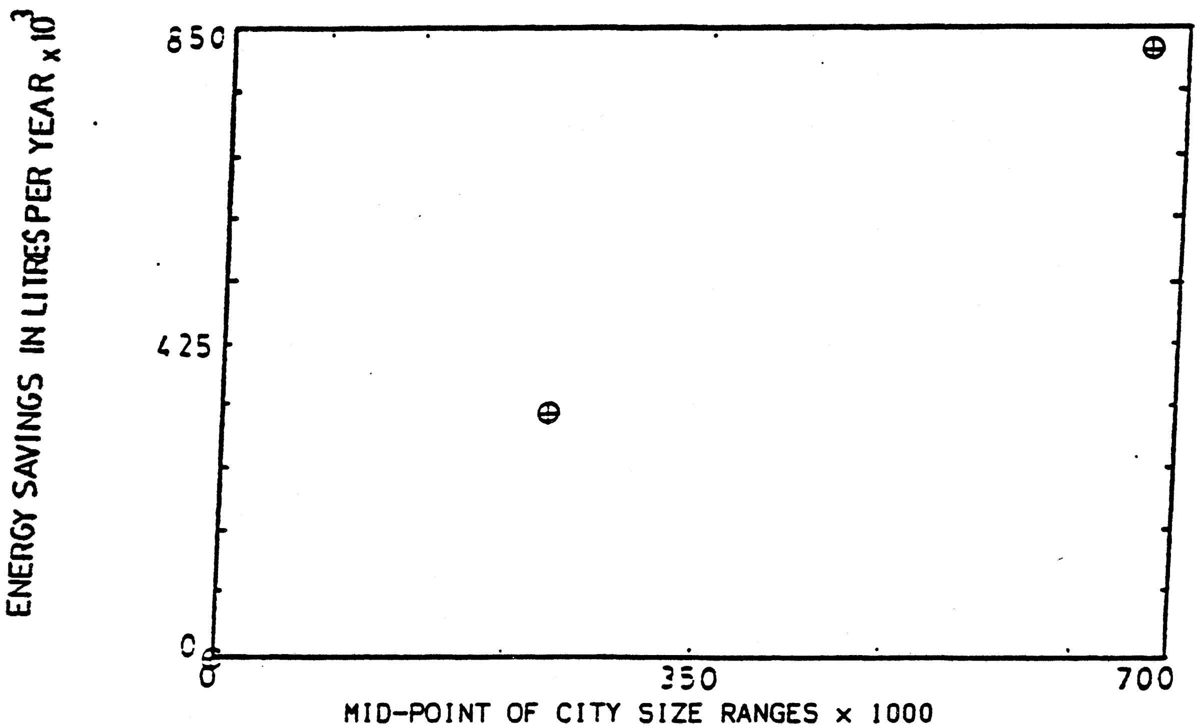

FIGURE A17 Observed energy savings against mid-point of city size ranges due to implementation of fringe parking lots.

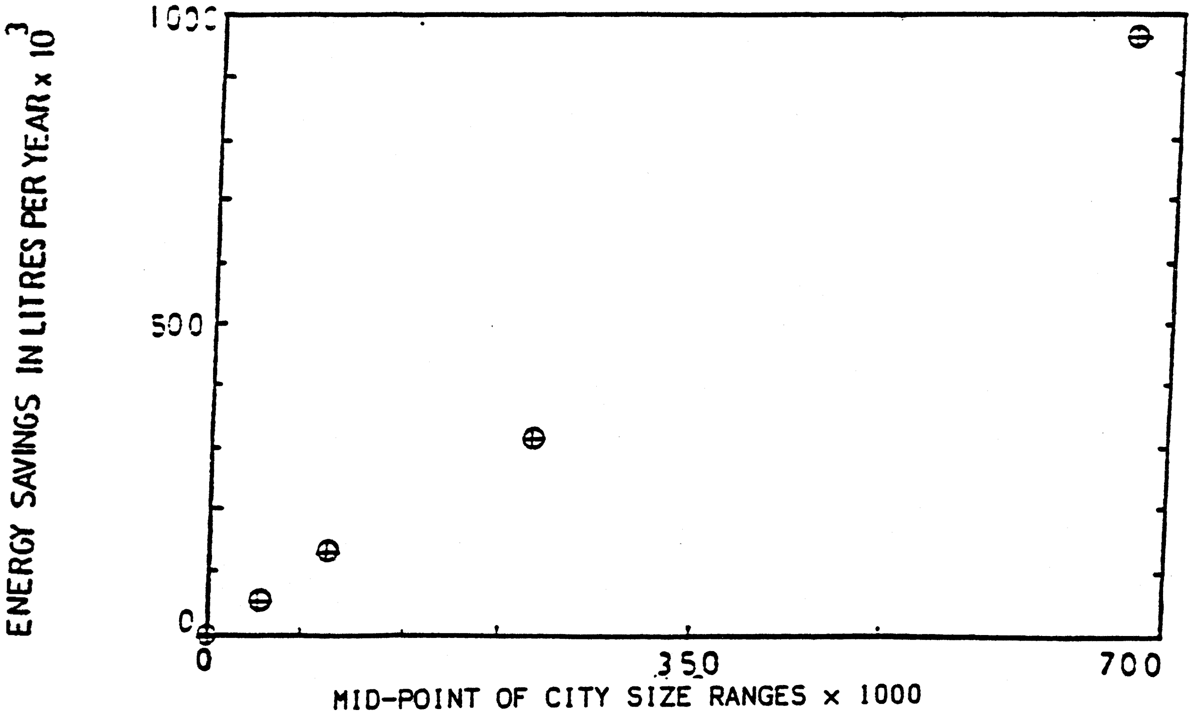

FIGURE A18 Observed energy savings against mid-points of city size ranges due to implementation of shared ride taxis.

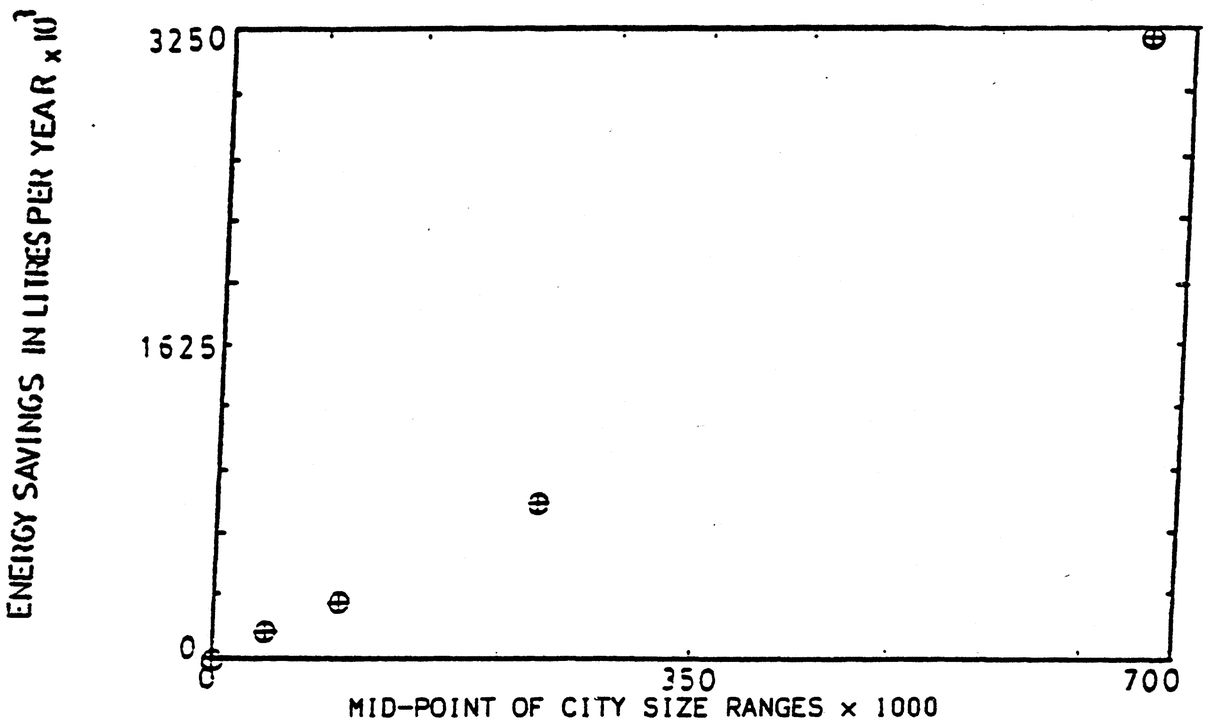

FIGURE A19 Observed energy savings against mid-point of city size ranges due to implementation of driver training.

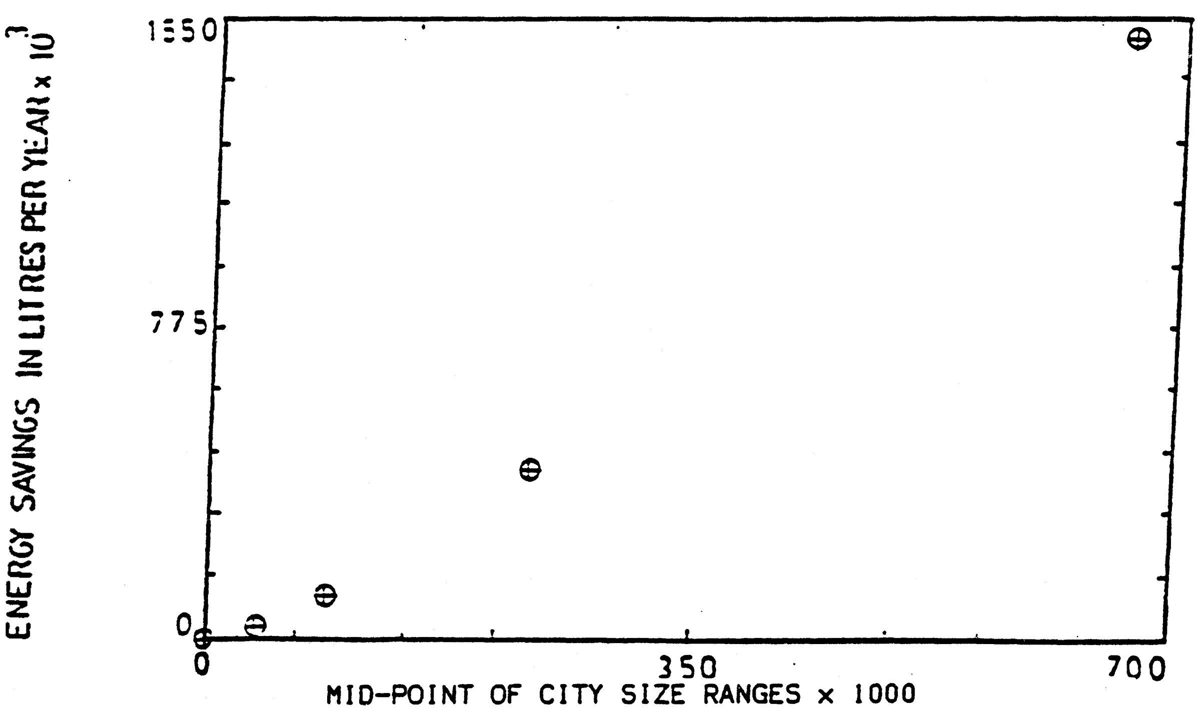

FIGURE A20 Observed energy savings against mid-points of city size ranges due to implementation of improved vehicle dispatching.

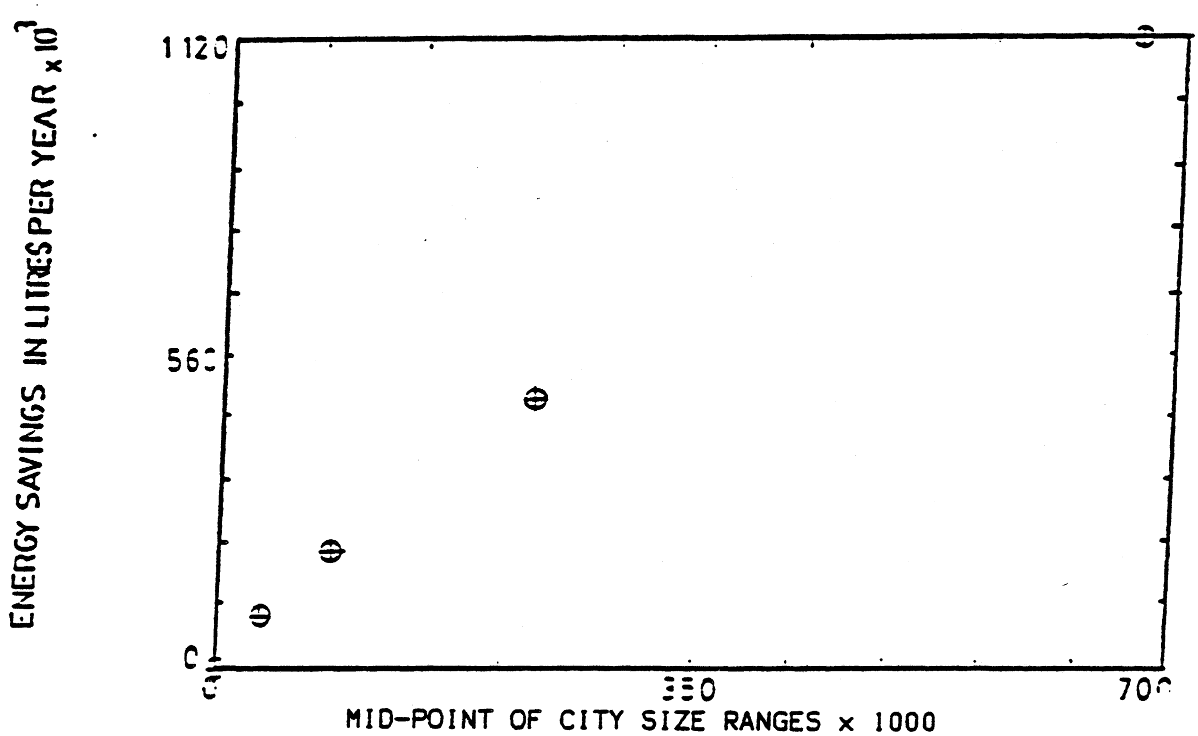

FIGURE A21 Observed energy savings against mid-point of city size ranges due to implementation of truck route networks.

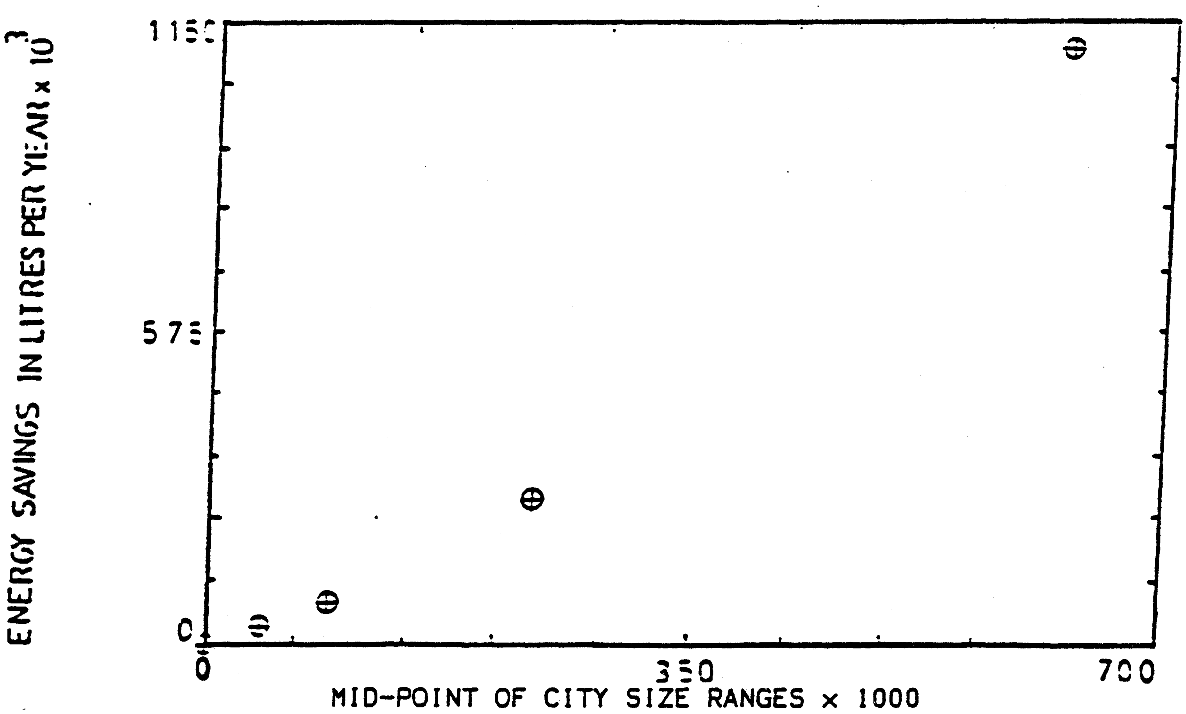

FIGURE A22 Observed energy savings against mid-point of city size ranges due to implementation of variable work hours.

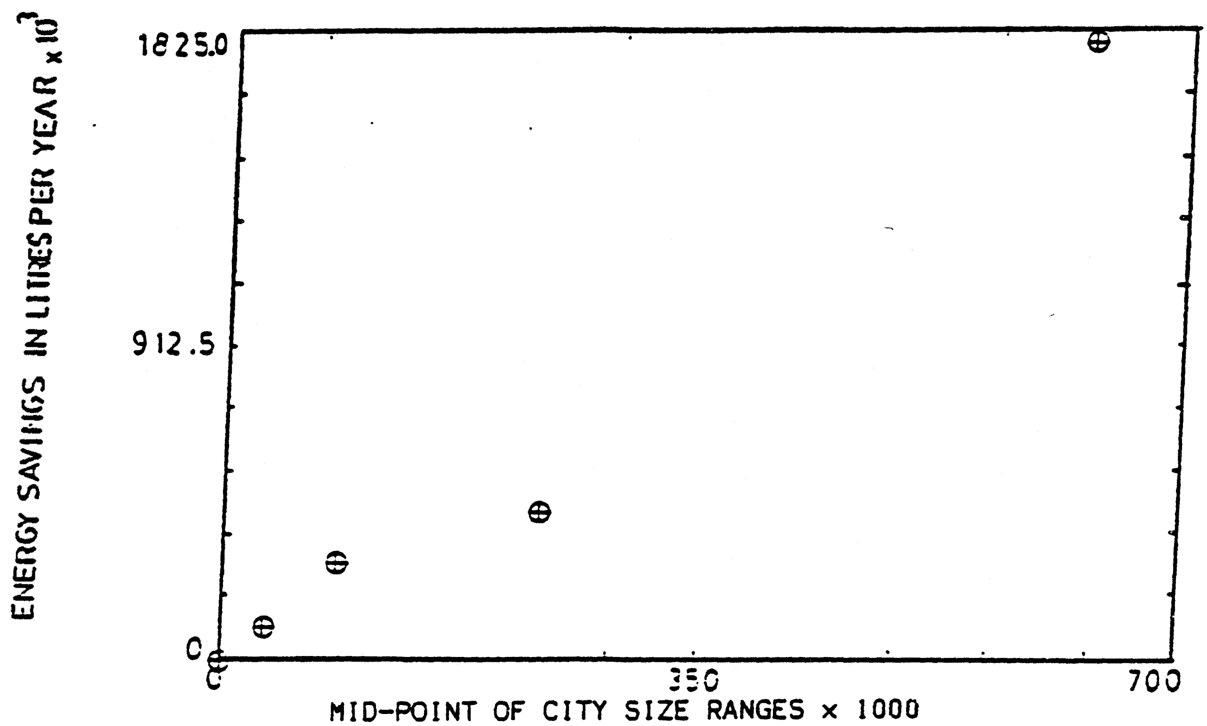

FIGURE A23 Observed energy savings against mid-points of city size ranges due to implementation of a compressed work week.

5. TRANSPORTATION ENERGY ANALYSIS MANUAL (TEAM) [10]

This section of the appendix contains an excerpted summary of TEMM's from TEAM manual.

TEAM comprehensively describes the different strategies of transportation energy management program. These strategies are summarized in the following sections:

A. STREET SYSTEM OPERATION.

This strategy contains four groups of measures designed to increase the operational and energy efficiency of the existing facilities. These groups are explained as follows:

1. TRAFFIC FLOW IMPROVEMENTS.

The following measures smooth traffic flow by eliminating stops and delays (i.e. reducing congestion) that reduce vehicular energy consumption [14,15].

1. Signal timing and coordination can provide 4%-20% reduction in energy consumption.
2. Down signing (replacing stop sign with yield sign) gives 35.3 L/day/signal, and replacing 4-way stop sign with a signal gives 350.5L/day/signal).
3. Conversion to one-way streets saves from 5%-25% of consumed fuel.
4. Turning lanes and turn restrictions provide 75% and 25% reduction in delay time and number of stops respectively.
5. Bus bays contribute to fuel saving by 4%.

6. Reserved lanes give 8%-10% reduction in fuel consumption.
7. Improved signing decrease energy consumption.
8. Additional capacity at points of system constraint can provide 0%-1% reduction in fuel consumption (widening of intersection approaches).
9. On-street parking restrictions

2. PREFERENTIAL TREATMENT FOR HIGH-OCCUPANCY VEHICLES.

High-Occupancy Vehicles (HOV) are vehicles that carry more than one person [9,13]. This mode is the most common form of HOV, vanpools and carpools can be considered as HOVs form also. Another good attempt to give priority to multiple-occupant vehicle movement is preferential treatment for HOVs. It can be provided through the use of HOV lanes, traffic-signal controls, and preferential parking. All of these techniques are directed to reduce travel time and improve the service level of HOVs. For transit particularly, such improvements enhance the people-moving productivity and energy efficiency of the street system.

3. BICYCLE FACILITIES.

The bicycle is considered to be the most energy-effective urban transportation mode [12,15]. Vehicles will be removed from the roadways and the energy consumption will be reduced when bicycle ridership can be encouraged for purposes other than recreation. Measures that encourage bicycle usage include:

1. Provision of bikeway systems (separated or shared)
2. Downtown and transit stops should be provided with bicycle

storage facilities.

3. Bikeway maps should be distributed widely.
4. Intersection regulations should be revised and redesigned.
5. Adminstrative support actions should be adopted such as regulation services, safety programs, and promotional events.

4. PEDESTRIAN FACILITIES.

Walking as a travel mode in it self has a limited energy saving potential because it can only replace more energy-intensive modes for short trips. However, transit and pedestrian facilities together can play a significant role in shifting the travel patterns to more energy efficient modes.

B. TRANSIT SERVICE.

The main objective of transit system improvements is to attract newriders and to increase the energy effeciency of transit operations. These improvements are described by the following strategies:

1. INCREASING RIDERSHIP.

This strategy reduces the number of vehicles sharing the road, and increase the capacity of the travel corridor. This shift in travel mode has a significant impact in reducing consumed energy, and can be accommodated by using a combination of appropriate measures such as those following:

1. Reducing travel time through transit service restructrion in

terms of minimizing the need to transfer by providing limited stop service.

2. Reducing travel time by improving transit vehicle flow ("Transit only" streets).
3. Provision of alternative fare packages such as monthly passes.
4. Reducing passenger waiting time by introducing a computerized transit information system.
5. Increasing ridership through improved transit marketing.
6. Increasing transit orientation into land-use planning.

2. RAISING EFFICIENCY.

The introduction of fleet operations techniques to increase the energy efficiency of transit operations can result in significant cost savings, and these techniques include:

1. Using the best type and size of vehicle for the job.
2. Improving the operation and maintenance of vehicles which includes energy-effecient driving habits, and maintenance checks.
3. Energy improvement due to good use in storage and maintainance facilities.
4. Using alternative fuels such as propane for small buses and electric power for trolley buses.

C. RIDESHARING.

Increasing vehicle occupancy is considered to be one of the cheapest and most effective methods of saving energy. Public transit is the major mode for High-Occupancy Vehicle that can supplement transit service. Carpooling/vanpooling offer flexible and low-cost methods for increasing vehicle occupancy and decreasing energy consumption.

With a minimum of staff, time and cost, municipalities can play great roles in adopting ridesharing programs. Municipalities interested in taking advantage of benefits resulting from this method can undertake the following:

1. Assign a municipal ridesharing coordinator.
2. Conduct a local ridesharing market survey.
3. Implementation of ridesharing for municipal employees.
4. Stimulation and support of ridesharing program by other major employers.
5. Develop third-party vanpooling programs.
6. Promote and support area-wide carpooling.
7. Provide paratransit services in fringe areas such as subscription bus services, contract vans, or shared-ride taxi services.
8. Provide incentives like park -and- ride lots, reserved lanes, priority access, subsidized parking.

D. TRAVEL DEMAND MANAGEMENT.

The major ways to reduce energy consumption include reduction of number and length of trips, and leveling out peaks in the remaining travel demand. Various actions can be taken to manage travel demand by adopting different measures [20]. These measures are extremely cost-effective (requiring little capital investment)but, by their nature have a long term pay back.

1. LAND USE PLANNING.

The basic goal of energy conscious land use planning is the energy efficiency that will result when land use activity is concentrated [20]. Several municipalities used some measures by implementing the following plans.

1. Increasing residential density by infilling and building compact housing.
2. Improving the balance of people and jobs in communities through mixed use zoning.
3. Encouragement of multi-use building developements.
4. Concentrate new developement along transit cooridors.
5. Street system design to facilitate transit service and bus route access for pedestrian.

2. ALTERNATIVE WORK SCHEDULES.

Alternative work schedules spread peak transportation demand over longer time periods. Energy savings are achieved by reducing stops and delays and also by smoothing the traffic flow, thereby enhancing the efficiency of street and transit systems. The major techniques for changing work schedules are:

1. Staggered work hours (i.e. specific work periods offset by 15-30 minutes assigned by groups of the total work force.
2. Flexible work hours (i.e. by allowing the workers to choose their own work periods in which the peak arrival and departure times can be spread out).
3. Compressed work week (i.e. by working longer hours each day people can shorten their work week to four days only).

3. PARKING MANAGEMENT.

By modifying the availability and price of parking, the vehicular travel demand can be significantly reduced. Parking management measures are represented by the foilowing:

1. Increase the parking fare to encourage transit usage, especially for work trips.
2. By reducing the availability of parking space, transit usage will be increased.
3. Providing preferential parking to HOVs, and using supply and cost measures as a factor in generating a shift in the mode of travel.

4. AUTO-RESTRICTED ZONES.

Auto-restricted zones involve the restriction of general-purpose automobile travel in a traffic area of the city, such as a CBD. Based on the objective and purpose, the auto restriction may be in place 24 hours, or for peak periods, or for off-peak periods. The aim is to restrict travel in the zone and to discourage auto travel, in general. The objective of these measures is to penetrate the zone or to utilize non-vehicluar modes, such as pedestrian travel, for specific segments of their trips.

In general, the TEAM gives energy saving guidelines for traffic engineers. Objectives, goals, measures, techniques, and methods of calculations are presented, as well as the interactions between these measues and the applicability of any measure.

APPENDIX B

REGRESSION ANALYSIS

APPENDIX B-REGRESSION ANALYSIS

This appendix contains a complete listing of the CURFIT technique as well as some definitions and explanations of the regression analysis that was used in this study.

THE CURFIT TECHNIQUE

This subroutine was developed by Dr. A. A. Smith, of the Department of Civil Engineering and Engineering Mechanics, McMaster University [11]. This subroutine is selected for the purpose of regression analysis. This program was chosen because it is simple, very fast and suitable for application to small data sets. This subroutine basically reads data directly from files and attempts to regress these data. This regression usually performed by fitting the best line or curve through the data to minimize the error of Y on X using the Least Square Method. The CURFIT subroutine listing reproduced from reference [11] is shown on the following two pages.

```
      SUBROUTINE CURFIT(NREAD,NO,TYPE,A,B,R2,STERR)
*****************************************************************************
* The routine reads data from a file and attempts to fit a best line or
* curve through the data to minimize the error of Y on X. (i.e. least
* squares analysis).
* The equation may be of the following forms:
*
*   Linear:         Y = A  +  B^X
*   Exponential:    Y = A*exp(B*X)       A > 0.0  and all X     .GT.0
*   Logarithmic:    Y = A + B*ln(X)                   all Y     .GT.0
*   Power:          Y = A*X^B            A > 0.0  and all X, Y  .GT.0
*
*   NREAD  = Channel number assigned to Input data file (i.e. by OPEN
*            statement) containing records of X and Y in Format (2F10.3)
*   NO     = Number of data pairs to be read.
*   TYPE   = CHARACTER*3 string containing the type of equation to which
*            the data is to be fitted, i.e.
*            'LIN',  'EXP',  'LOG'  or  'PWR'
*   A      = Computed Y intercept.
*   B      = Computed slope of Y on X.
*   R2     = Computed square of coefficient of correlation
*   STERR  = Computed value of standard error of estimate of ordinate Y
*
* Note that the routine also provides the sums, squares and cross-
* products of variables, (or the natural log transforms where approp-
* riate) in the labelled COMMON block:
*      COMMON /SUMS/ SX,SY,SXX,SYY,SXY
*
* N.B.  The Input data file linked to 'NREAD' is NOT rewound by routine
* CURFIT prior to processing.  This allows the user to skip any number
* records in the calling program thus restricting the input data to a
* subset of the file.
*****************************************************************************
      CHARACTER*3 TYPE
      COMMON /SUMS/ SX,SY,SXX,SYY,SXY
      ITYPE=0
      IF (TYPE.EQ.'LIN') ITYPE=1
      IF (TYPE.EQ.'EXP') ITYPE=2
      IF (TYPE.EQ.'LOG') ITYPE=3
      IF (TYPE.EQ.'PWR') ITYPE=4
      IF (ITYPE.EQ.0) THEN
        WRITE(*,*)' In CURFIT ',TYPE,' not recognized'
        STOP
      ENDIF
* Zero summation variables
      SX=0.0
      SY=0.0
      SXX=0.0
      SYY=0.0
      SXY=0.0
```

```
* Read and process data
     DO 10 J=1,NO
       READ(NREAD,*) X,Y
       GOTO (34,32,33,32) ITYPE
 32    CONTINUE
       IF (Y.LE.0.0) THEN
         WRITE(*,*)' In CURFIT with Type ',TYPE,Y,' not allowed'
         STOP
       ELSE
         Y=ALOG(Y)
       ENDIF
       IF (ITYPE.EQ.2) GOTO 34
 33    CONTINUE
       IF (X.LE.0.0) THEN
         WRITE(*,*)' In CURFIT with Type ',TYPE,X,' not allowed'
         STOP
       ELSE
         X=ALOG(X)
       ENDIF
 34    CONTINUE
* Now accumulate sums
       SX=SX+X
       SY=SY+Y
       SXX=SXX+X*X
       SYY=SYY+Y*Y
       SXY=SXY+X*Y
 10  CONTINUE
* Now compute equation of line
     AN=REAL(NO)
     C1=AN*SXY - SX*SY
     B=C1/(AN*SXX - SX*SX)
     A=(SY - B*SX)/AN
* Get R-squared
     R2=B*C1/(AN*SYY - SY*SY)
     SDYONX=SQRT((SYY - SY*SY/AN)/(AN-1.0))
     STERR=SDYONX*SQRT(1.0-R2)
     IF (ITYPE.EQ.2.OR.ITYPE.EQ.4) A=EXP(A)
     RETURN
     END
```

REGRESSION ANALYSIS

Introduction

Often people want to predict the value of Y for any given values of one or more variables Xj. Sometimes a physical law connects these variables so that Y may be expressed as a function of the X's. If X and Y values are plotted as points in X-Y plane, they lie scattered about the curve that represents the ideal formula that governs these points [18]. Based on the geometrical shape of scattered data and fitting that curve through this scatter, it is possible to describe these scattered data by eye or by estimating the equation of that curve. This is called regression of Y on X. Therefore, simple regression analysis shows how the variables of any scattered data are related to each other [19].

The general method used in estimating a regression curve from sample data is the Least-Square method. The sample regression curve of Y on X of a given degree is the curve among all those of that degree that minimizes the sum of squares of vertical Y deviations of the observed points from the curve (the best curve fit) [16]. "It is the time to ask more precisely, what is a good fit ? the answer is surely is a fit that makes the total error small. One typical error is defined as a vertical distance from the observed Y to the fitted line or curve. This value considered positive when Yi is above the line and negative when Yi below the line" [17].

Coefficient of correlation

Definition: Correlation coefficients indicate the degree to which variation (or change) in one variable is related to variation (or change) in another.

A correlation coefficient not only summarizes the strength of association between a pair of variables, but also provides an easy means for comparing the strength of relationship between two pairs of variables. The correlation coefficient always lies between -1 and +1, and only if all points lie on the regression line, the $r=\pm1$. The correlation coefficient sign is taken as (+ve) or (-ve) to agree with the sign of the slope of the regression line. For example, -ve correlation indicates that high values of Y associated with low values of X. If r=0, the regression does not explain any thing about the variation of y and the regression line is horizontal.

The Standard Error

Definition : The Standard Error is simply defined as the standard deviation of actual Y values from the predicted Y' values.

If an infinite number of equal-sized samples are drawn from a given population, the mean of each sample would be an estimate of the true population mean. But not all of these sample means would be identical. The pattern of these means would actually constitute a normal distrbution and would have a standard deviation of its own. The standard deviation of this distrbution is called the Standard Error of the mean [19]. Thus you can you use the Standard Error to estimate the potential degree of discrepancy between the sample mean and the usually unknown population mean. If the researcher wishes to evaluate the accuracy of the prediction equation or, or equivalently, to determine the amount of prediction error associated with the predictions, it will be necessary to examine one or more of the statistics that reflect the average size of residuals. The squared value of correlation coefficient (R2) or its complement (1-R2) indicate proportions of variation explained and unexplained, respectively. For example, Standard Error = Square root of sum square of (obsereved values minus predicted values) divided by the sample size. If it is assumed that actual Y values are normally distributed about the regression line, the researcher will be able to estimate the proportion of cases that fall between ∓1 standard error of estimate units from predicted values, ∓2 standard error of estimate units from predicted values, and so on forth.