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URBAN TRAFFIC SIGNAL CONTROL FOR FUEL ECONOMY (ECONOMIE D'ESSEN--ETC(U)
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URBAN TRAFFIC SIGNAL CONTROL FOR FUEL ECONOMY

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OTTAWA

JANUARY 1980

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MECHANICAL ENGINEERING
REPORT
ME-247

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URBAN TRAFFIC SIGNAL CONTROL FOR FUEL ECONOMY

ECONOMIE D'ESSENCE GRACE A LA COMMANDE DES FEUX DE
CIRCULATION EN ZONE URBAINE

by/par

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- ** Metropolitan Toronto Traffic Control Centre
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SUMMARY

The Metropolitan Toronto Roads and Traffic Department and the Engine Laboratory of the Division of Mechanical Engineering at the National Research Council of Canada have completed a study to determine the influence of two computer-controlled traffic signal timing plans over a given route. The two plans are the existing plan based on SIGRID (Signal GRID Design program) and TRANSYT (TRAffic Network Study Tool).

The results show that under the TRANSYT timing plan, vehicles encountered fewer stops, saved time and used a slightly smaller amount of fuel than under the existing timing plan.

Vehicle fuel consumption was computed using a computer model of a vehicle which used velocity profiles obtained from an instrumented "floating" car. Single and multiple linear regression analyses were used to determine the relationship between the fuel consumption and the relatively easy-to-measure and statistically stable quantities such as trip time, number of stops and delay time.

It was found that fuel consumption could be expressed adequately as a linear combination of trip time, number of stops and delay time. Using only two independent variables showed a combination of delay time and stops to be equally as good as a combination of travel time and stops. When restricted to a single independent variable, any one of them could be used for predicting fuel consumption.

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RÉSUMÉ

Les travaux rapportés concernent une étude conjointe des Services de voirie de la Communauté urbaine de Toronto et du Laboratoire des moteurs de la Division de Génie mécanique, Conseil national de recherches du Canada, en vue de déterminer l'influence respective de deux plans de synchronisation des feux de signalisation contrôlés par ordinateur sur un parcours donné. Les deux plans sont intitulés SIGRID (Signal GRId Design program) et TRANSYT (TRAffic Network StudY Tool).

Les résultats obtenus dans le cadre du plan TRANSYT montrent que les véhicules automobiles effectuent un plus petit nombre d'arrêts, qu'ils mettent moins de temps à parcourir le trajet fixé et qu'ils consomment légèrement moins de carburant que pour le plan de synchronisation actuel.

La consommation de carburant a été déterminée à l'aide d'un modèle informatisé de véhicule se déplaçant selon des profils de vitesse obtenus avec une automobile équipée de divers instruments et suivant le flot normal de la circulation. Des analyses de régression linéaire à unique et multiples variables ont servi à établir la relation existant entre la consommation de carburant et des grandeurs relativement faciles à mesurer et statistiquement stables, soit la durée du trajet, le nombre d'arrêts et la durée des entraves à la circulation.

Il a été ainsi possible d'exprimer adéquatement la consommation sous la forme d'une combinaison linéaire des trois grandeurs susmentionnées. L'emploi de deux variables indépendantes uniquement a permis de démontrer que la combinaison de la durée des entraves à la circulation et du nombre d'arrêts donne d'aussi bons résultats que celle de la durée du trajet et du nombre d'arrêts, tandis que l'utilisation d'une seule variable indépendante autorise le recours à n'importe quelle combinaison pour prédire la consommation de carburant.

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URBAN TRAFFIC SIGNAL CONTROL FOR FUEL ECONOMY

1.0 INTRODUCTION

1.1 General

The Roads and Traffic Department of the Municipality of Metropolitan Toronto has been a world leader through the introduction and development of computerized control of traffic signals. There is an increasing public awareness of the environmental impact of the automobile in relation to noise and emission levels, and there exists a strong desire to achieve greater economy in fuel consumption in light of rising energy costs. In consequence, the provision of an efficient traffic signal control system has become extremely important in urban areas. Through the development of more sophisticated control techniques, significant progress has been made in improving the operation of urban traffic signal systems. Computer control of these signals has given the traffic engineer the opportunity to effectively co-ordinate traffic movements over a large area with a resulting decrease in unnecessary stops and delays. This results in corresponding improvements in vehicular travel times and overall safety of operation.

A joint research venture was undertaken with the Engine Laboratory of the National Research Council whereby the actual effect of urban traffic signal timings on vehicular fuel consumption could be investigated.

Over 50% of the petroleum products consumed in North America every year are used for the purpose of transportation. Since over 80% of this fuel is consumed by road users, it is apparent that any improvements in the efficiency of its use can result in substantial economic and environmental benefits. It has not been conclusively proven however, that a traffic signal control strategy based on minimizing vehicular travel times is the most economic in terms of fuel usage. In fact, some recent studies in Europe have indicated that significant fuel savings may be possible by employing a different signal control philosophy. Research done in Glasgow (Ref. 1) found that minimizing the number of stops resulted in a decrease in fuel consumption of 5.8% while average journey time increased 0.3%. Conversely, studies by General Motors Corporation in the U.S. (Refs 2 to 9) showed that the fuel consumption per unit distance could be reduced by decreasing the average trip time. It was found that fuel consumption per unit distance could best be accounted for in terms of average trip time per unit distance. If K_1 and K_2 are calibration constants, where K_1 is the fuel used to overcome rolling resistance, and K_2 is the idle fuel flowrate, it was demonstrated that the following linear equation is a simple but effective method of predicting fuel consumption:

$$\phi = K_1 + K_2 t \quad (1)$$

where ϕ = fuel consumption per unit distance
 t = trip time per unit distance

For urban trips slower than 60 km/h it was found that the single parameter of average trip time per unit distance explained more of the variation in fuel consumed per unit distance than any other parameter considered. Equation (1) shows that for a certain fixed trip length, fuel consumption could be reduced by decreasing the average trip time. This equation was developed from actual fuel flow measurements, and the average values given for K_1 and K_2 were 85.2 ml/km and 0.7844 ml/sec, respectively, for one series of tests (Ref. 9).

The Toronto study described below presents data showing the influence of two computer controlled signal timing schemes on fuel consumption. Figure 1 is a map of the 2.79 km (1.73 mile) test route on Lawrence Avenue East in a light industrial/commercial area of Metropolitan Toronto. This route was selected since it had recently been widened to a 7-lane cross-section with a continuous two-way left-turn median lane. All intersections are suburban high-type with exclusive turn lanes, good visibility, pavement structure, markings and turning radii. Therefore, the test section is essentially

free-flow during both the offpeak and rush hour periods of the day. Traffic congestion is minimal along the entire stretch and there is a low frequency of stops other than those caused by the traffic signals. Thus, any delays which occur along this section of roadway are almost entirely signal-related, and show any differences between the two timing schemes. Vehicular volumes are very directional during the two peak periods and almost equally balanced during the offpeak hours of the day. This offers a wide range of prevailing traffic conditions, from heavy well-platoon flows during the high volume peak periods, to light unstructured flows during the mid-day hours. Cycle lengths are identical throughout the network to permit co-ordination among all signals, but the actual timings vary from intersection to intersection depending on the side-street volume/capacity ratios.

It is anticipated that the results derived from this test network will be applicable to any traffic signal controlled situation in an urban environment. Since the emphasis was placed on delay, stops and travel time with respect to the signals alone, the results do not reflect the impact of uncontrollable parameters such as midblock parking and stopping activities, excessive queueing, pedestrian crosswalks, and heavy turning movements.

1.2 Traffic Signal Timing Plans

The underlying assumption used in the application of the two plans was that the prevailing signal splits and cycle lengths were at or near the optimum for the seven signalized intersections. The splits at the critical signals were designed with reference to the volume/capacity ratios on all the approaches. The cycle lengths were determined by considering the volume/capacity relationship in conjunction with constraints set by pedestrian requirements, clearance interval design, and queue storage problems. In the case of minor intersections in the remainder of the network, the cycle is governed by the critical signals, and the splits are governed by cross street pedestrian walk times.

Since the cycles and splits were fixed for both control strategies, the only remaining variable to be optimized was the "offset" or start of the main street green interval at each signal, relative to a master clock.

1.2.1 The Existing Plan

The existing signal timings for the Metropolitan Toronto signal system are basically the result of applying the "SIGRID" off-line optimization program. The SIGRID (Signal GRId Design) program (Ref. 10) was originally developed by the Traffic Research Corporation for the Metropolitan Toronto Roads and Traffic Department as a computational tool for signal network offset design. Given the system cycle length, signal splits, and "ideal" or "desirable" offset differences for the various individual links in a signal network, the program systematically searches for the set of offset values which are closest to their corresponding ideal values and yet satisfy the network constraints.

The offset optimization procedure in SIGRID is based on the concept that the total delay to vehicles travelling along a network link during an average cycle can be represented by a quadratic function in the form of:

$$Y = AX^2 + C \quad (2)$$

where

- Y = link delay
- X = deviation of chosen offset difference from ideal offset difference
- A = curvature indicating the steepness of the delay curve
- C = minimum link delay corresponding to ideal offset difference

The curvature of the quadratic curve is given by the product of the link volume and an arbitrary parameter used to quantify the relative importance of co-ordination for the link, commonly known as a "link importance factor".

Offset values are calculated by minimizing the aggregate system delay function which is a summation of all the individual link delay functions. It should be noted, however, that neither the

system delay nor the individual link delay functions represent the actual true delay values. They are only measures of discrepancies between the ideal offset and the program-generated offsets.

In the program algorithm, a set of random offsets are chosen as the starting point, and corrections are applied systematically to the initial offsets until the system delay function reaches a minimum value. Then the procedure or "game" is repeated for different sets of random offsets until an overall minimum value of the system delay function is found. The resulting offsets of each game are evaluated by calculating the average vehicle waiting time at each downstream signal and also the overall system average waiting time, assuming a square wave arrival pattern and using the given signal splits and ideal offsets.

After the minimization of the system delay function has been completed, the lowest value of the system average waiting times from all the games is selected as the "optimum" value, and the calculated offsets corresponding to this optimum value are then designated as the optimum offsets for the system under consideration.

The existing plan for the test network was derived initially from the SIGRID program together with continuous "manual tuning" and upgrading efforts over the years. Since Lawrence Avenue East is a carrier of significantly higher volumes of traffic than most of the roads which it intersects, a "preferential street treatment" can be applied. This technique essentially involves favouring the directions of travel with heavier traffic volumes during the peak periods. A "balanced" arrangement is provided during the mid-day offpeak hours when no particular directionality is evident in the east-west movements.

1.2.2 The TRANSYT Program

TRANSYT (TRAffic Network StudY Tool) was developed by D.I. Robertson (Ref. 11) as a co-operative effort between the British Road Research Laboratory and Plessey Automation, and contains the following major components:

1. a split computation routine based on the Webster Method,
2. a traffic flow model for generating flow patterns on all netlinks,
3. a hill-climbing process for optimizing offsets. As an option, this process may also re-adjust the given or previously calculated signal splits for optimum system performance.

To find the optimum signal settings for the network, a system performance index expressed in terms of system delay and stops is used in the program as an engineering evaluation tool. To calculate this performance index, a traffic flow model is used to compute the required pattern information on each link. In the flow computation routine, the cycle is divided into a number of equal units of time, and the flow rate entering a link during each interval is assumed to be a given fraction of the flow leaving the upstream links. To obtain the arrival rates at the downstream signal, the flow entering the link is exponentially smoothed by the use of Robertson's platoon dispersion model (Ref. 12). The departure rate leaving the link is assumed to be equal to the saturation flow when a queue exists at the signal approach, or equal to the arrival rate if no queue is present.

In the optimization logic of TRANSYT, a hill-climbing iteration process is used to obtain a set of optimum signal settings which will minimize the performance index. The first step in this process is the calculation of a performance index for an initial set of signal timings. The next stage is to alter the offset at one of the signals by a pre-determined increment of cycle intervals and then re-calculate the network performance index. This is repeated until a local minimum value of the index is reached. The same procedure is then applied to each of the other signals in the network. The entire offset optimization procedure for the network is in turn repeated for a given variety of cycle interval increments to obtain the final optimum settings.

TRANSYT also has the capability of optimizing the given or calculated splits at each signal by re-allocating the green time among the various intersection approaches, if by virtue of the re-allocated green split, a reduction in the network performance index could be achieved. However, this option was not exercised since it was necessary to optimize only the offsets within the seven signal network.

For this study TRANSYT/5 was used since it had been previously tested in Metropolitan Toronto during the IOUTS study (Ref. 13) and was fully operational on the Univac 1107/418 system at the Traffic Control Centre.

2.0 INSTRUMENTATION

Data were obtained by an instrumented vehicle defined as a "floating" car, which recorded on magnetic tape the vehicular velocity as measured by a Nucleus Corporation fifth wheel using both analog and digital signals. The digital signal consisted of 70 pulses per wheel revolution. One channel of the Bruel and Kjaer, Type 7003, recorder was used for voice identification of the runs and another was used for a "blip" signal which was used as a high speed read signal for the computer.

3.0 TEST PROCEDURE

The fifth wheel was attached to its bracket and its output checked at the beginning of a test series. The tape recorder was turned on at the start of a test series and allowed to run continuously. Each speed and delay "run" was identified by voice with time of day, date, run number and direction. The "blip" switch was turned on at the beginning of the run and shut off at the end of the run. Approximately 3-5 minutes of tape were left blank between runs to act as a separator. Each signalized intersection was identified by voice to aid in analysis. Several times during each run the recorded signals were monitored to ensure that all systems were functioning properly.

During the test runs the car driver operated the blip switch and the microphone at the same time. It was found on analysis that the blip signal was forgotten or late at the beginning and end of some runs. Approximately 20% of the runs were rejected because of this problem. Some difficulty was experienced with loosening of the bracket attaching the fifth wheel to the car. Other than a bulb failure in the fifth wheel pulse sending unit, the test equipment performed as expected. Calibration of the fifth wheel was done on a Nucleus Corporation calibrator before the test series.

3.1 Manual Collection of Speed and Delay Data

Simultaneous to the instrumented car tests, speed and delay data were collected by the observer during each pass through the network. As in a normal floating car survey, the drivers were instructed to "float" among the vehicular platoons, in essence behaving like an average motorist. As a link boundary was crossed, the observer noted the cumulative link journey time and the link stopped time from the appropriate stopwatches. In this study, the far-side curb lines were considered the link boundaries or reference points.

In addition, he/she also noted the reason for the stopped time and any general comments regarding anomaly events. A "signal stop" was only recorded if the traffic was freely flowing to the signal and the delay was caused entirely by the signal itself. A delay was noted if the vehicle speed was less than 8 km/h (5 mph) while approaching a signal, subject to the judgement of the survey crew. Where signal stops were greater than one signal cycle in duration, an additional stop was recorded for each signal cycle delayed.

An actual field sheet used for the study is presented in Figure 2 and the floating car survey schedule is outlined in Table 1. Table 2 indicates the signal control periods or "optimization time periods" during which the peak and offpeak runs were completed. The number of data samples gathered during the tests are presented in Table 3. It should be noted that all offpeak runs were

carried out during the morning mid-day period. Only one of the two offpeak periods had to be investigated since an adequate sample size was obtained, and because of past volume trends the morning period was considered representative of "balanced" conditions.

4.0 REDUCTION OF FIELD DATA

To decode the recorded signals, the digital velocity signal and the analog "blip" signal were coupled to the Compact System Controller (CSC) which is part of the PDP 11/34 computer data acquisition sub-system. The computer's frequency counter tallied the number of pulses per second and the computer converted these to km/h at one second intervals by dividing by the wheel's calibration factor of 9.20945. Any speed less than 2 km/h was set to 0 km/h to avoid the problem of trying to count 0 pulses at a stopped condition. These data were stored, linearized, and then plotted. Figure 3 is a schematic of the data flow.

Each "speed and delay" run was processed individually. Typical linearized velocity profiles with points at one second intervals are shown on Figures 4 to 9. The velocity profile data were then entered in the NRC Computation Centre IBM 370 computer system for use in the Vehicle Simulator Program. These velocity profiles will be useful in future studies of acceleration and deceleration rates and in actual traffic simulation studies. They will also give the traffic engineers involved an accurate pictorial representation of actual conditions on the street.

5.0 FUEL CONSUMPTION CALCULATIONS

The "floating" car determined the typical driving pattern or velocity profile which is virtually independent of the vehicle type. The Vehicle Simulator (VS) program (Ref. 14) calculates fuel consumption using this velocity profile and the characteristics of a specific vehicle. All calculations were done using the original VS vehicle, a 2177 kg (4800 lb) car with automatic transmission and a 6554 cc (400 in³) spark ignition engine. It was assumed for the spark ignition case that trends shown in fuel consumption will be reasonably similar regardless of the engine size used in the simulation.

A vehicle model was used to calculate fuel consumption from actual velocity profiles rather than measuring fuel flow in a real vehicle. This was done to reduce the number of on-street runs required by eliminating the effects of individual drivers, state of tune and type of vehicle, tire inflation and environmental factors. Also, different engine-drive train characteristics could be used in the program without having to re-measure the actual flow of fuel. The above factors must be accounted for in order to make accurate fuel consumption measurements, but they are unrelated to the effect of various traffic signal timings on the actual vehicular velocity profiles.

Simpler models for fuel consumption were obtained using the fuel consumptions calculated above and relating them to observed trip times, stops and delay times. These quantities are easier to measure than the velocity profiles. Single and multiple regression analyses provided the necessary coefficients to express fuel consumption as linear functions of trip time, stops and delay or any subset of these three.

6.0 ANALYSIS

Mean values of time, fuel consumption, stops and delay (all per unit distance) for the three different periods of day and traffic direction were computed for each of the two signal light timing plans. For the fuel consumption, student "t" tests showed that in almost all cases there was a statistically significant difference between corresponding results obtained under the existing and TRANSYT timing plans.

Regression results were derived from the International Mathematical and Statistical Libraries, Inc. (IMSL) subroutines "RLONE" for single regressions and "BECOVN" in combination with "RLMUL"

for multiple regressions. These subroutines are an accepted standard for statistical analysis and each of them is available on the NRC TSS 370 computer.

In conjunction with this analysis, the Traffic Control Centre staff carried out a detailed summarization of the manually-collected speed and delay information. This was done by means of the "SPEEDA" program which calculates link averages for speeds, travel times, stops, and delays, and then summarizes the data over the whole route by direction of travel and time of day. The program also calculates a performance index, which gives a relative measure of effectiveness, and enables comparisons to be drawn between the two signal timing plans. In addition, single linear regression analysis was done using the "REGR" program which is available on the Traffic Control Centre's Univac 1107/418 computer system. The results compared favourably with those obtained from the IMSL programs which lends credence to both the manual and automatic data collection techniques as well as the resulting computer analysis.

7.0 RESULTS

The mean values of travel time, calculated fuel consumption, stops and delay, expressed in units of sec/km, ml/km, stops/km and sec/km respectively, are shown in Table 4 in order to compare the existing and TRANSYT plans. The significance levels determined from the student "t" distribution are also included in Table 4 for travel time and fuel consumption. Figure 10 is a histogram of the data from Table 4. Interpretation of significance levels gives an indication of whether the means are from the same parent population or from different ones. For example, a significance level of 0.01 indicates that there is only a 1% chance that the two means considered are from the same population, or alternatively, there is a significant difference between the sample means. On the other extreme, a significance level of 0.8 indicates that there is an 80% chance that the means are from the same population, or in fact there is no significant difference between the two means.

The favoured flow or high volume directions are westbound in the morning rush hour and eastbound in the evening. It can be seen that TRANSYT generally has a larger beneficial effect in a direction opposite to that of the majority of roadway users. For example, during the evening rush hour, the "floating" car travelling westbound was 31.6% faster under the control of the TRANSYT plan. By comparison, the eastbound flow during the evening rush hour performed better under the existing timings by a margin of 7.6% in terms of overall travel time. These results should not be interpreted as an indication that TRANSYT favours only the lighter direction of travel. The reasons for the greater benefits being realized by the non-favoured flow direction were due to the preferential street treatment under the existing plan. When the signal offsets favour only the heavy direction, then the opposing movements frequently experience a significantly higher number of stops and delays. The TRANSYT plan attempts to achieve more of an equitable arrangement, whereby the heavy direction is still favoured on the strength of its higher volume, but not at the total expense of the lighter flow. In fact, during the A.M. and offpeak periods, TRANSYT was able to improve on the existing timings even for the heavy direction of travel.

In general, the beneficial effects of TRANSYT in the non-favoured flow direction were so pronounced, that despite the lower traffic density in this direction, the overall, weighed effect of TRANSYT on travel times, fuel consumption, number of stops, and delay always resulted in an improvement compared to the existing schedule. The cumulative beneficial effects of TRANSYT over the existing plan are reductions of 12.4% in time, 2.2% in fuel, 40.4% in delay and 34.5% fewer stops. Table 5 summarizes traffic volumes and weighted means.

From Table 6 we see that between 73% to 93% of the variation in fuel consumption is explained when all three independent variables delay, stops and time are used together. When this case is compared with either of the best two-variable cases — stops and delay or time and stops, it can be seen that little is added to the total variation explained by the inclusion of a third variable.

Both of the above two-variable cases are equally good in their percentages of variation explained. There is an advantage from a practical point of view in selecting the time and stops results since travel time is easier to measure than delay time.

In the single variable case, a good percentage of variations (55% to 90%, (Table 6)) in fuel consumption can be accounted for by any one of the three variables — time, stops and delay. Delay alone explained the highest variation in three cases, stops in two cases and time in one case. This is somewhat different from the findings of General Motors (Refs 2 to 9) where time alone explained more than 70% of the variation in the fuel consumption.

Table 7 to 9 are multiple regression listings of intercept, coefficients and percent of variation explained for stops and time together and delay and stops together. The prediction equation of the fitted plane is of the form:

$$y = b_0 + b_1 x_1 + b_2 x_2 \quad (3)$$

Where: A) for Tables 7 and 8, combined and separate directions

- y = fuel consumption, ml/km
- b_1 = regression coefficient of x_1 , ml/stop
- x_1 = stops/km
- b_2 = regression coefficient of x_2 , ml/sec
- x_2 = travel time, sec/km

B) for Table 9, combined directions

- y, b_1, x_1, b_2 — same as above
- x_2 = delay time, sec/km

Tables 10 to 16 are regression listings of slope, Y intercept and percent of variation explained for fuel versus delay, fuel versus stops, fuel versus time, and time versus stops respectively. The slope figures can be used to give:

- 1) the cost of a unit of delay in terms of fuel,
- 2) the cost of a stop in terms of fuel,
- 3) the rate of fuel usage, and
- 4) the time increment per stop.

The prediction equation of the regression line for the data in Tables 10 to 16 is of the form:

$$y = mx + b \quad (4)$$

Where: A) for Tables 10 and 11, combined and separate directions

- y = fuel consumption, ml/km
- m = slope, ml/sec
- b = y axis intercept, ml/km

x = delay time, sec/km

B) for Tables 12 and 13, combined and separate directions

y = fuel consumption, ml/km

m = slope, ml/stop

b = y axis intercept, ml/km

x = stops/km

C) for Tables 14 and 15, combined and separate directions

y = fuel consumption, ml/km

m = slope, ml/sec

b = y axis intercept, ml/km

x = travel time, sec/km

D) for Table 16, separate directions

y = time, sec/km

m = slope, sec/stop

b = y axis intercept, sec/km

x = stops/km

Note that in Table 15, of Fuel versus Time, there is a low percentage of explanations for the variations in both plans in the eastbound offpeak period, and in TRANSYT in the eastbound morning period.

Figures 11 to 14 are typical scatter diagrams of fuel consumption versus travel time, showing the regression line through the points, and the equation of the line which is of the form of Equation 4, above. Also listed is the percentage variation explained by the fit. These examples were chosen to show several good fits and one of the poorer ones having clustered data points.

Regression analysis of the total number of all the existing and TRANSYT data points was also considered and the results are shown in Table 17. From the table it is seen that 82% of the variation in fuel consumption is explained when the three variables are used together. Comparing the three variable case with either of the best two variable cases — stops and delay or time and stops, it is found that all have 82% of variation explained. This confirms the separate plan analysis, above, that little or nothing is gained by the inclusion of the third variable.

For the single variable case, Table 17 shows 75% to 79% of the variation is explained when all the existing and TRANSYT data are combined. Again, fuel consumption could be accounted for by any one of the three variables. Stops explained the highest variation with time next and delay last.

8.0 CONCLUSIONS

- (1) Improvements with TRANSYT in travel time, fuel and stops were found in both directions for the three time periods with the exceptions of the eastbound evening rush hour and fuel consumption in the westbound morning and offpeak periods. TRANSYT decreased delay in all but the westbound morning rush hour.

- (2) Overall, the TRANSYT plan reduced travel time by 12.4%, delay by 40.4%, had 34.5% fewer stops and saved 2.2% in fuel when compared to the existing schedule.
- (3) Between 73% and 93% of the variation in fuel consumption could be explained by multiple linear regression analysis on the separate existing and TRANSYT data using time, stops and delay as independent variables. Eighty-two percent of the variation in fuel consumption could be explained, using these three variables, when all the data were combined.
- (4) Use of only two independent variables in such an analysis causes very little information to be lost. Between 71% and 93% of the variation in fuel consumption could be explained for the separate plans by considering either a combination of delay time and stops or travel time and stops. Eighty-two percent of the variation could be explained for each of the above combinations when all the data were combined. Travel time and stops are the easiest to measure.
- (5) When using a single independent variable in the regression analysis to estimate fuel consumption, any one of delay, stops or time may be used. However, only between 55% and 90% of the variation in fuel consumption can be explained in this way for the separate plans. Between 75% and 79% was explained when all the data were combined.

9.0 RECOMMENDATIONS

- (1) The characteristics of a small car should be run in the simulation program for comparison with the large vehicle used for this study, to verify that the trends in fuel consumption as presented in this report are applicable to any spark ignition engined vehicle.
- (2) Modifications should be made to the "stop penalty" used in the TRANSYT program to reflect the significance of a stop with respect to fuel consumption. Further analysis of the test data is necessary before a specific value can be derived.
- (3) TRANSYT/7 should be run for the Lawrence Avenue East network to ascertain if any significant changes in the output arise due to improvements in the program over TRANSYT/5.
- (4) Since only the offsets were modified in this experiment, signal split and cycle length changes should be field-tested to determine the impact of all signal timing parameters on fuel efficiency.
- (5) An improved definition of an actual vehicular "stop" is required to assist in the analysis of both the automatic and manually-collected field data. It is apparent that some threshold value greater than 0 km/h is essential to obtain accurate test results.
- (6) For future tests, one crew member should have the sole responsibility for voice keying and blip signal operation. Also, the fifth wheel attachment bracket should be redesigned.

10.0 ACKNOWLEDGEMENTS

The authors wish to thank Mr. Joseph K. Lam, Senior Traffic Engineer, and the staff of the Metropolitan Toronto Traffic Control Centre for the collection and partial analysis of the floating car data. In addition, they would like to acknowledge the assistance of Mr. Don M. Rudnitski of the Engine Laboratory at NRC. This work was partially supported by grants from the Transportation Research and Development Centre of Transport Canada.

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TABLE 1

FLOATING CAR SURVEY SCHEDULE

Control Plan	Test Period 1979
Existing	Feb. 27 to Mar. 2 Mar. 5 and Mar. 8
TRANSYT	Mar. 8 and Mar. 9 Mar. 12 and Mar. 13

TABLE 2

SIGNAL CONTROL PERIODS (OPTIMIZATION TIME PERIODS — O.T.P.)

O.T.P.	Time of Day	Reference Name
1	7:00 a.m. — 9:00 a.m.	Morning
2	10:00 a.m. — 12:00 noon	Offpeak
3	1:00 p.m. — 3:00 p.m.	Offpeak
4	4:00 p.m. — 6:00 p.m.	Evening

TABLE 3

FLOATING CAR SURVEY SAMPLES

Control Plan	O.T.P.	Eastbound	Westbound
Existing	1	19	17
	2	20	20
	3	0	0
	4	<u>19</u>	<u>19</u>
	Total	58	56
TRANSYT	1	18	18
	2	24	22
	3	0	0
	4	<u>18</u>	<u>20</u>
	Total	60	60

TABLE 4
MEAN VALUES OF TIME, FUEL, STOPS AND DELAY

	Direction	Control Plan	Number of Data Points	Time sec/km	"t" Test Significance Level	Fuel ml/km	"t" Test Significance Level	Stops stops/km	Delay sec/km
Morning	E	E	18	120.3	< 0.01	245.0	< 0.01	1.58	36.9
		T	16	90.3		216.6		0.81	12.2
	W	E	13	90.3	0.8	204.0	0.56	0.55	14.4
		T	17	88.5		209.6		0.53	15.2
Offpeak	E	E	17	94.6	< 0.01	210.6	< 0.01	0.80	17.9
		T	17	74.0		196.2		0.34	4.9
	W	E	17	81.8	0.02	197.3	0.90	0.49	10.5
		T	16	73.9		198.3		0.36	8.0
Evening	E	E	13	94.2	0.4	196.4	0.04	0.50	21.8
		T	11	101.4		217.2		0.62	20.4
	W	E	18	118.8	< 0.01	244.1	< 0.01	1.54	38.4
		T	11	81.3		210.2		0.59	12.3

TABLE 5
TRAFFIC VOLUME AND WEIGHTED MEANS

Time and Vehicles/Hr	Control Plan	Weighted Over Day				Control Plan	Weighted Over Day			
		Time sec/km	Fuel ml/km	Stops stops/km	Delay sec/km		Time sec/km	Fuel ml/km	Stops stops/km	Delay sec/km
Morning East 669 West 1503	E	99.5	216.6	0.87	21.3	E	98.7	213.6	0.84	22.5
	T	89.1	211.8	0.62	14.3					
Offpeak East 728 West 950	E	87.4	203.1	0.62	13.7	T	86.5	209.0	0.55	13.4
	T	73.9	197.4	0.35	6.7					
Evening East 1452 West 1175	E	105.2	217.7	0.96	29.2	T	86.5	209.0	0.55	13.4
	T	92.4	214.1	0.61	16.8					

TABLE 6

REGRESSION RESULTS

	Number of Data Points	MORNING		OFFPEAK		EVENING	
		EXISTING	TRANSYT	EXISTING	TRANSYT	EXISTING	TRANSYT
% of Variation Explained by		31	33	34	33	31	22
Time, Stops and Delay All 3 Together		85.7	72.5	75.2	76.5	92.7	91.5
Time and Stops Both Together		84.2	72.5	71.2	71.0	92.7	89.0
Time and Delay Both Together		85.5	63.5	69.7	72.3	87.0	89.9
Stops and Delay Both Together		84.5	68.2	75.1	76.2	90.8	91.5
Time — sec/km Only		83.9	62.6	62.9	55.5	86.9	76.6
Stops — stops/km Only		77.5	64.4	68.0	68.9	88.2	77.6
Delay — sec/km Only		82.1	54.8	69.2	72.1	74.1	89.8

TABLE 7
INTERCEPT, COEFFICIENTS AND % OF VARIATION EXPLAINED FOR STOPS AND TIME (BOTH TOGETHER)
VERSUS FUEL REGRESSION BOTH DIRECTIONS TOGETHER

	EXISTING				TRANSYT			
	Y Intercept ml/km	X ₁ Coeff. ml/stop	X ₂ Coeff. ml/sec	% Variation Explained	Y Intercept ml/km	X ₁ Coeff. ml/stop	X ₂ Coeff. ml/sec	% Variation Explained
MORNING	101.9	7.2	1.1	84.2	136.9	22.5	0.7	72.5
OFFPEAK	137.4	28.0	0.6	71.2	152.3	33.1	0.5	71.0
EVENING	118.4	25.9	0.7	92.7	151.3	26.9	0.5	89.0

TABLE 8
INTERCEPT, COEFFICIENTS AND % OF VARIATION EXPLAINED FOR STOPS AND TIME (BOTH TOGETHER)
VERSUS FUEL REGRESSION EAST AND WEST DIRECTIONS

	Direction	EXISTING				TRANSYT			
		Y Intercept ml/km	X ₁ Coeff. ml/stop	X ₂ Coeff. ml/sec	% Variation Explained	Y Intercept ml/km	X ₁ Coeff. ml/stop	X ₂ Coeff. ml/sec	% Variation Explained
MORNING	East	96.4	25.8	0.9	76.3	197.1	29.1	-0.05	67.0
	West	90.4	- 1.6	1.2	71.8	90.1	6.2	1.3	81.7
OFFPEAK	East	220.9	50.3	-0.5	58.7	188.9	- 0.02	25.4	53.7
	West	66.3	19.9	1.5	84.5	118.0	33.6	0.9	85.9
EVENING	East	62.4	-20.1	1.5	90.4	115.9	4.0	1.0	96.9
	West	119.1	13.2	0.9	74.8	137.0	25.9	0.7	79.4

TABLE 9
INTERCEPT, COEFFICIENTS AND % OF VARIATION EXPLAINED FOR DELAY AND STOPS (BOTH TOGETHER)
VERSUS FUEL REGRESSION BOTH DIRECTIONS TOGETHER

	EXISTING				TRANSYT			
	Y Intercept ml/km	X ₁ Coeff. ml/stop	X ₂ Coeff. ml/sec	% Variation Explained	Y Intercept ml/km	X ₁ Coeff. ml/stop	X ₂ Coeff. ml/sec	% Variation Explained
MORNING	182.6	15.7	1.0	84.5	188.3	25.8	0.5	68.2
OFFPEAK	173.4	22.3	1.1	75.1	182.0	19.9	1.3	76.2
EVENING	168.8	34.8	0.5	90.8	189.0	13.2	1.0	91.5

TABLE 10

SLOPE, INTERCEPT AND % OF VARIATION EXPLAINED FOR FUEL
VERSUS DELAY REGRESSION BOTH DIRECTIONS TOGETHER

	EXISTING			TRANSYT		
	Slope ml/sec	Y Intercept ml/km	% Variation Explained	Slope ml/sec	Y Intercept ml/km	% Variation Explained
MORNING	1.5	186.1	82.1	1.2	196.1	54.8
OFFPEAK	2.0	175.6	69.2	2.1	183.6	72.1
EVENING	1.6	172.3	74.1	1.3	191.9	89.8

TABLE 11

SLOPE, INTERCEPT AND % OF VARIATION EXPLAINED FOR FUEL
VERSUS DELAY REGRESSION EAST AND WEST DIRECTIONS

	Direction	EXISTING			TRANSYT		
		Slope ml/sec	Y Intercept ml/km	% Variation Explained	Slope ml/sec	Y Intercept ml/km	% Variation Explained
MORNING	East	1.4	193.0	85.6	1.1	203.7	42.5
	West	1.3	185.7	60.3	1.4	189.1	67.0
OFFPEAK	East	1.7	180.6	56.5	1.2	190.2	45.6
	West	2.5	171.5	69.0	2.7	176.8	87.9
EVENING	East	1.2	171.1	76.3	1.3	190.7	93.6
	West	1.1	201.4	70.4	1.9	187.3	88.6

TABLE 12

SLOPE, INTERCEPT AND % OF VARIATION EXPLAINED FOR FUEL
VERSUS STOPS REGRESSION BOTH DIRECTIONS TOGETHER

	EXISTING			TRANSYT		
	Slope ml/stop	Y Intercept ml/km	% Variation Explained	Slope ml/stop	Y Intercept ml/km	% Variation Explained
MORNING	39.4	182.6	77.5	37.8	187.9	64.4
OFFPEAK	42.6	176.6	68.0	42.7	182.4	68.9
EVENING	46.1	173.4	88.2	45.8	186.0	77.6

TABLE 13

SLOPE, INTERCEPT AND % OF VARIATION EXPLAINED FOR FUEL
VERSUS STOPS REGRESSION EAST AND WEST DIRECTIONS

	Direction	EXISTING			TRANSYT		
		Slope ml/stop	Y Intercept ml/km	% Variation Explained	Slope ml/stop	Y Intercept ml/km	% Variation Explained
MORNING	East	60.1	150.3	63.8	28.4	193.6	66.9
	West	33.3	185.6	65.8	47.9	184.3	68.4
OFFPEAK	East	37.0	180.9	56.4	25.1	187.8	53.7
	West	47.0	174.5	64.2	53.4	179.1	80.5
EVENING	East	49.3	171.9	78.8	49.7	186.3	82.3
	West	42.1	179.5	47.3	37.6	188.1	73.6

TABLE 14

SLOPE, INTERCEPT AND % OF VARIATION EXPLAINED FOR FUEL
VERSUS TIME REGRESSION BOTH DIRECTIONS TOGETHER

	EXISTING			TRANSYT		
	Slope ml/sec	Y Intercept ml/km	% Variation Explained	Slope ml/sec	Y Intercept ml/km	% Variation Explained
MORNING	1.3	86.8	83.9	1.3	100.9	62.6
OFFPEAK	1.3	88.4	62.9	1.4	92.7	55.5
EVENING	1.4	68.7	86.9	0.9	132.2	76.6

TABLE 15

SLOPE, INTERCEPT AND % OF VARIATION EXPLAINED FOR FUEL
VERSUS TIME REGRESSION EAST AND WEST DIRECTIONS

	Direction	EXISTING			TRANSYT		
		Slope ml/sec	Y Intercept ml/km	% Variation Explained	Slope ml/sec	Y Intercept ml/km	% Variation Explained
MORNING	East	1.3	86.4	71.9	0.6	158.9	21.3
	West	1.2	94.5	71.8	1.5	79.6	81.5
OFFPEAK	East	1.0	115.5	33.9	0.6	148.5	29.3
	West	2.0	30.3	78.9	2.0	52.3	75.5
EVENING	East	1.1	91.3	89.5	1.0	111.3	96.9
	West	1.1	118.0	72.2	1.6	81.5	63.7

TABLE 16

SLOPE, INTERCEPT AND % OF VARIATION EXPLAINED FOR TIME
VERSUS STOPS REGRESSION EAST AND WEST DIRECTIONS

	Direction	EXISTING			TRANSYT		
		Slope sec/stop	Y Intercept sec/km	% Variation Explained	Slope sec/stop	Y Intercept sec/km	% Variation Explained
MORNING	East	38.2	60.1	62.4	14.8	78.3	34.8
	West	27.6	75.1	92.3	31.7	71.7	79.5
OFFPEAK	East	24.9	74.7	76.2	21.4	66.8	55.8
	West	18.3	73.0	51.2	21.4	66.2	67.2
EVENING	East	45.4	71.7	93.1	46.9	72.3	82.6
	West	32.8	68.4	44.8	16.4	71.7	55.1

TABLE 17
SLOPE, INTERCEPT, COEFFICIENTS AND % OF VARIATION EXPLAINED FOR
ALL EXISTING AND TRANSYT DATA TOGETHER (184 DATA POINTS)

General Equation and Variables	Slope m	b_0 Y Axis Intercept ml/km	Coefficients			% of Variation Explained
			b_1 ml/stop	b_2 ml/sec	b_3 ml/sec of delay	
$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3$						
Time, Stops and Delay All 3 Together	—	162.5	23.0295	0.2920	0.3326	82.4
$y = b_0 + b_1 x_1 + b_2 x_2$						
Time and Stops Both Together	—	148.4	24.7296	0.4947	—	82.0
$y = b_0 + b_2 x_2 + b_3 x_3$						
Time and Delay Both Together	—	141.9	—	0.6410	0.6352	77.2
$y = b_0 + b_1 x_1 + b_3 x_3$						
Stops and Delay Both Together	—	182.8	25.6499	—	0.6035	81.9
$y = mx + b_0$						
Time Only	1.1 ml/sec	109.9	—	—	—	75.6
Stops Only	40.3 ml/stop	182.6	—	—	—	78.7
Delay Only	1.4 ml/sec of delay	187.4	—	—	—	74.5

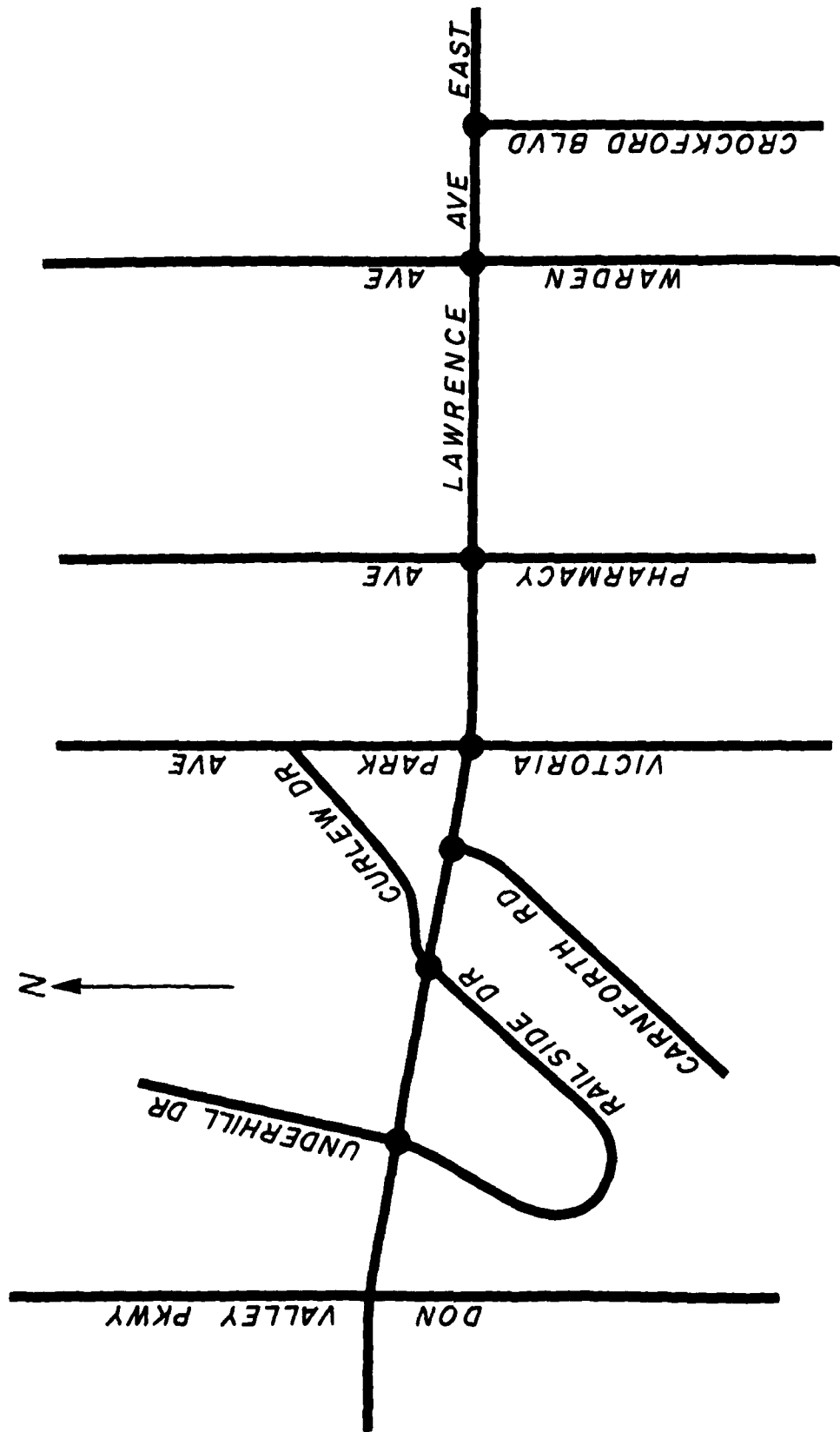


FIG. 1: TEST ROUTE - LAWRENCE AVE EAST

M.R.T.D. ARTERIAL EVALUATION

Use for SPEEDA program

FOR: Lawrence Avenue Westbound

Type	Day No.	Mo./Dy/Yr	O.T.P.	Blank	From Hr. Min.	To Hr. Min.	Town	No. of Cards	Route I.D.
[5]		/ /			:	:		[07]	[002]

[illegible]

**FIG. 2: FIELD SHEET FOR
MANUALLY COLLECTED SPEED
AND DELAY DATA**

SYMBOLS FOR CAUSE OF STOP

- T.S. - Traffic Signal**
L.T. - Left Turning
R.T. - Right Turning
S.T. - Stop Sign

- O.T. - Other
P.C. - Parked cars
X. - Accident
P.X.O. - Pedestrian Crossover

- B.P.L.** - Bus passenger loading
- E.V.** - Emergency vehicle
- C.** - Construction
- G.C.** - General Congestion
- Ped.** - Pedestrian

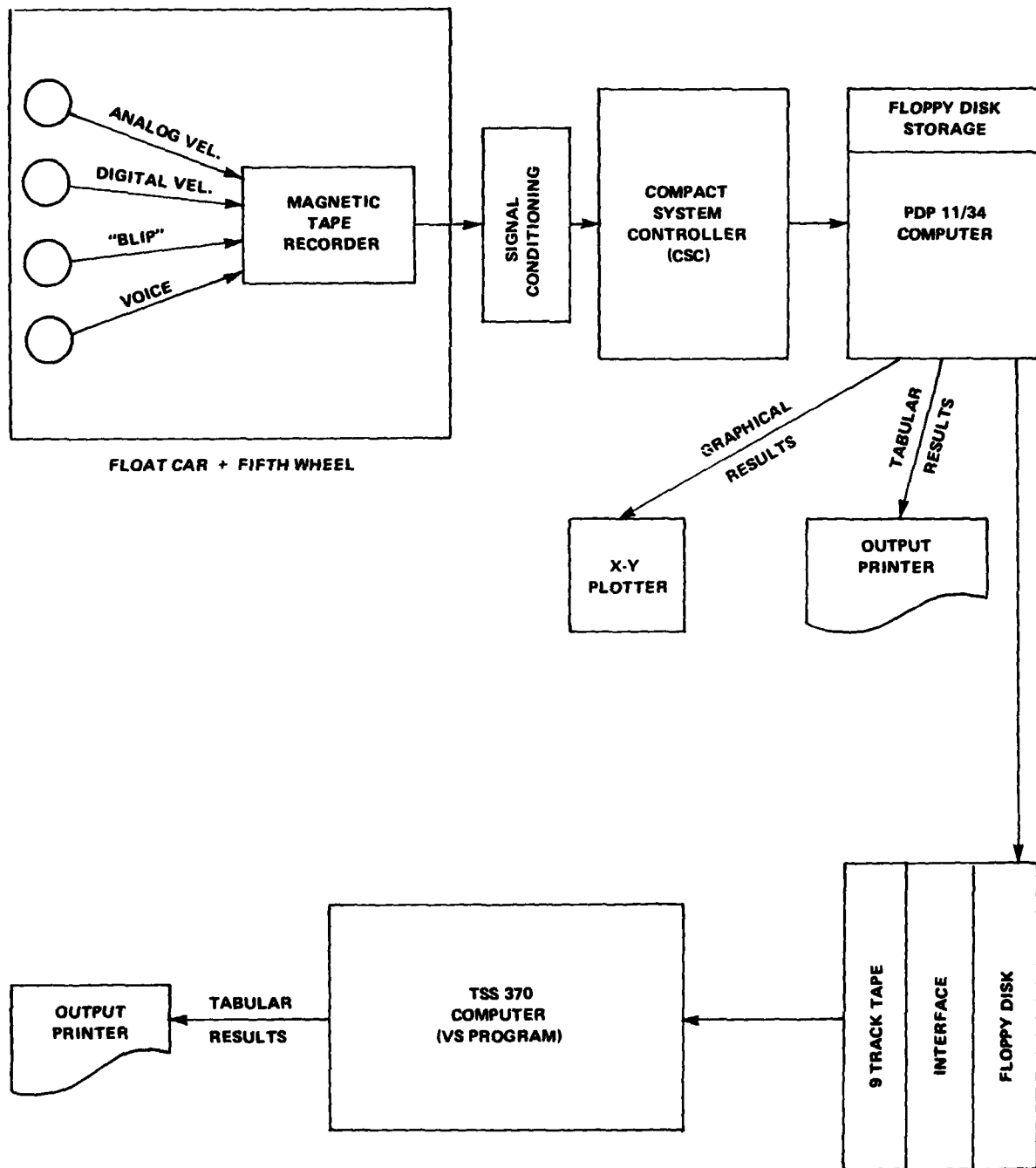


FIG. 3: DATA FLOW SCHEMATIC

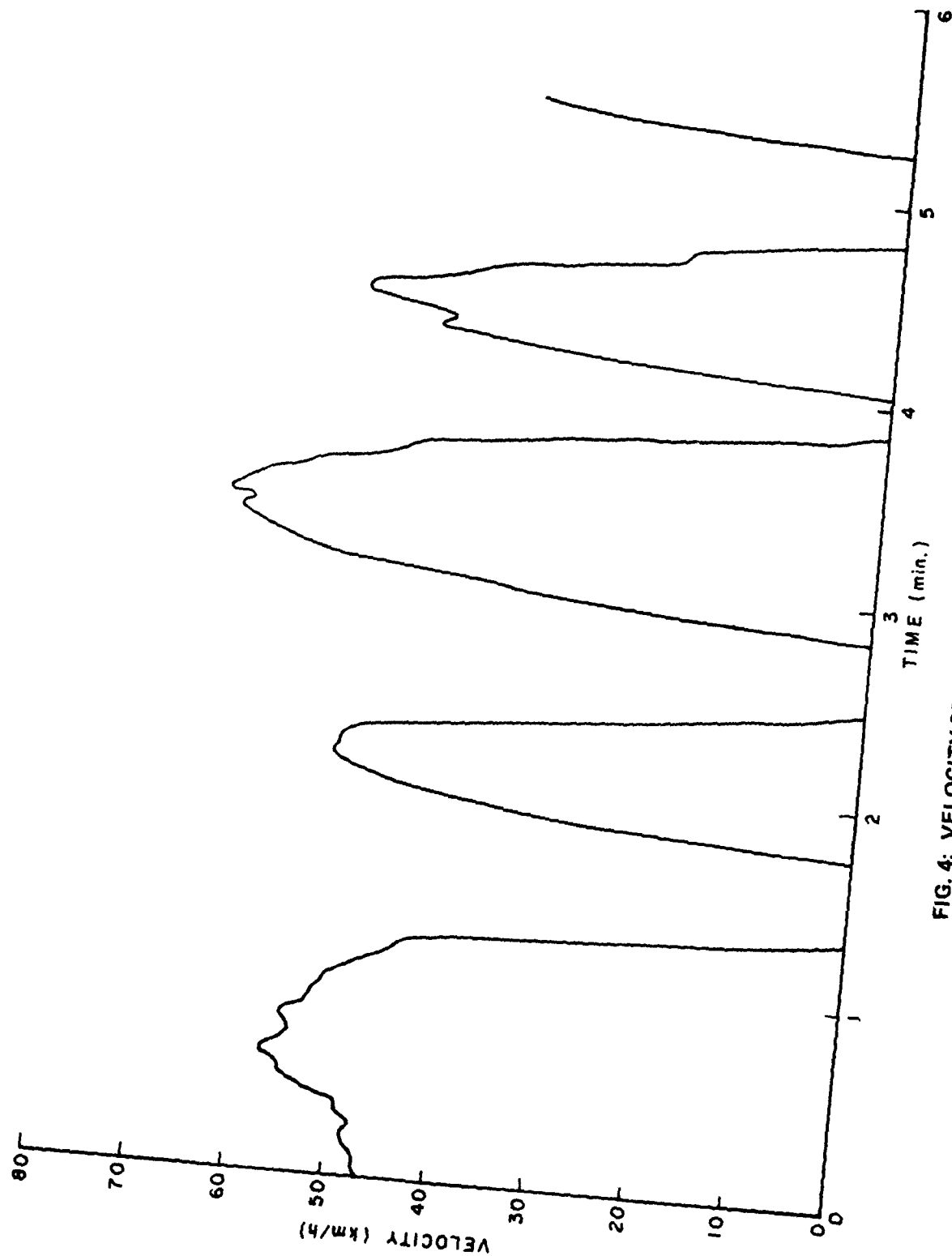


FIG. 4: VELOCITY PROFILE OF LAWRENCE AVE W/B
RUN 20, 16:17, MAR. 02.79

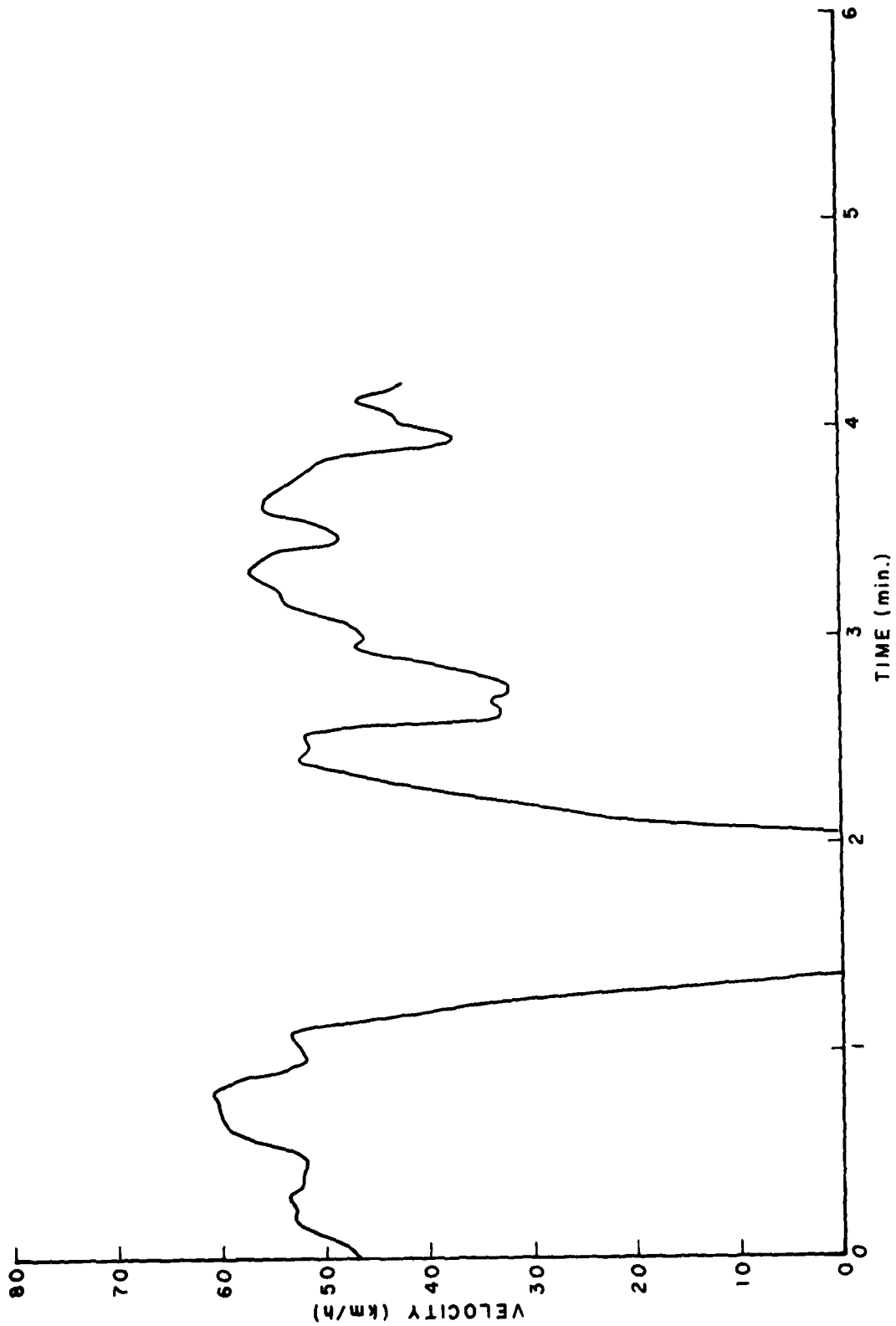


FIG. 5: VELOCITY PROFILE OF LAWRENCE AVE E/B
RUN 21, 16:26, MAR. 02.79

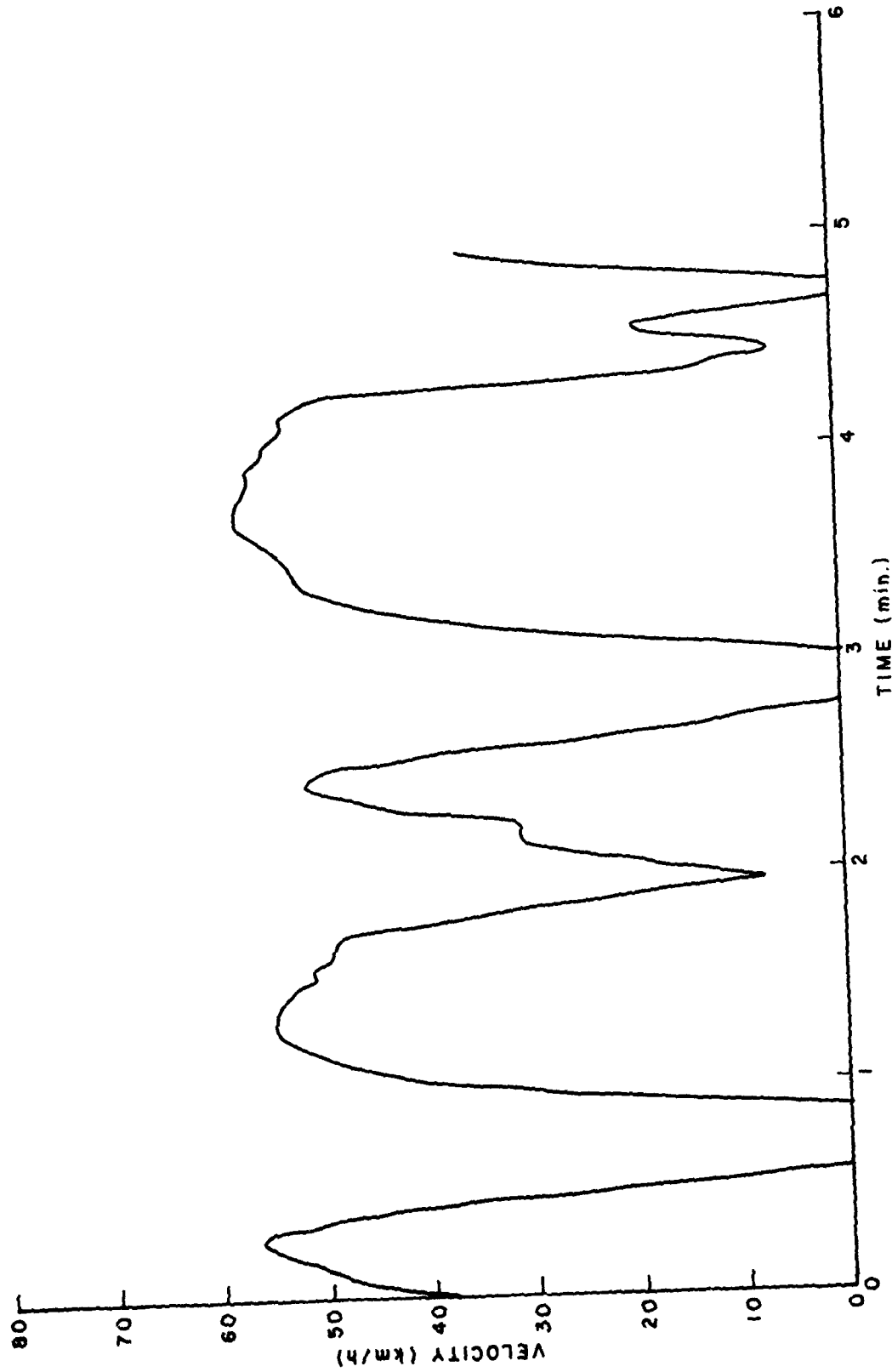


FIG. 6: VELOCITY PROFILE OF LAWRENCE AVE E/B
RUN 1, 7:15, MAR. 5.79

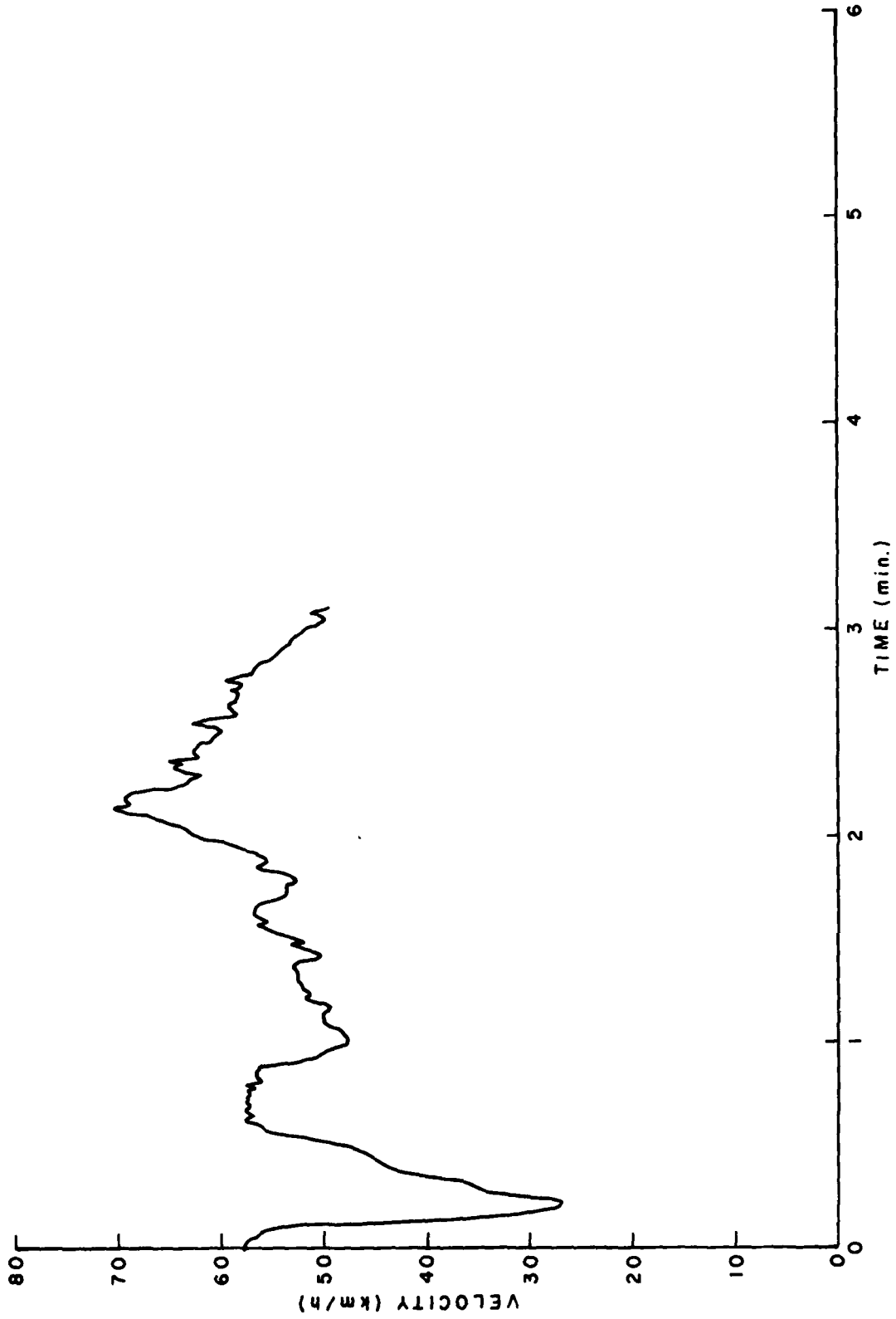


FIG. 7: VELOCITY PROFILE OF LAWRENCE AVE W/B
RUN 2, 7:28, MAR. 5.79

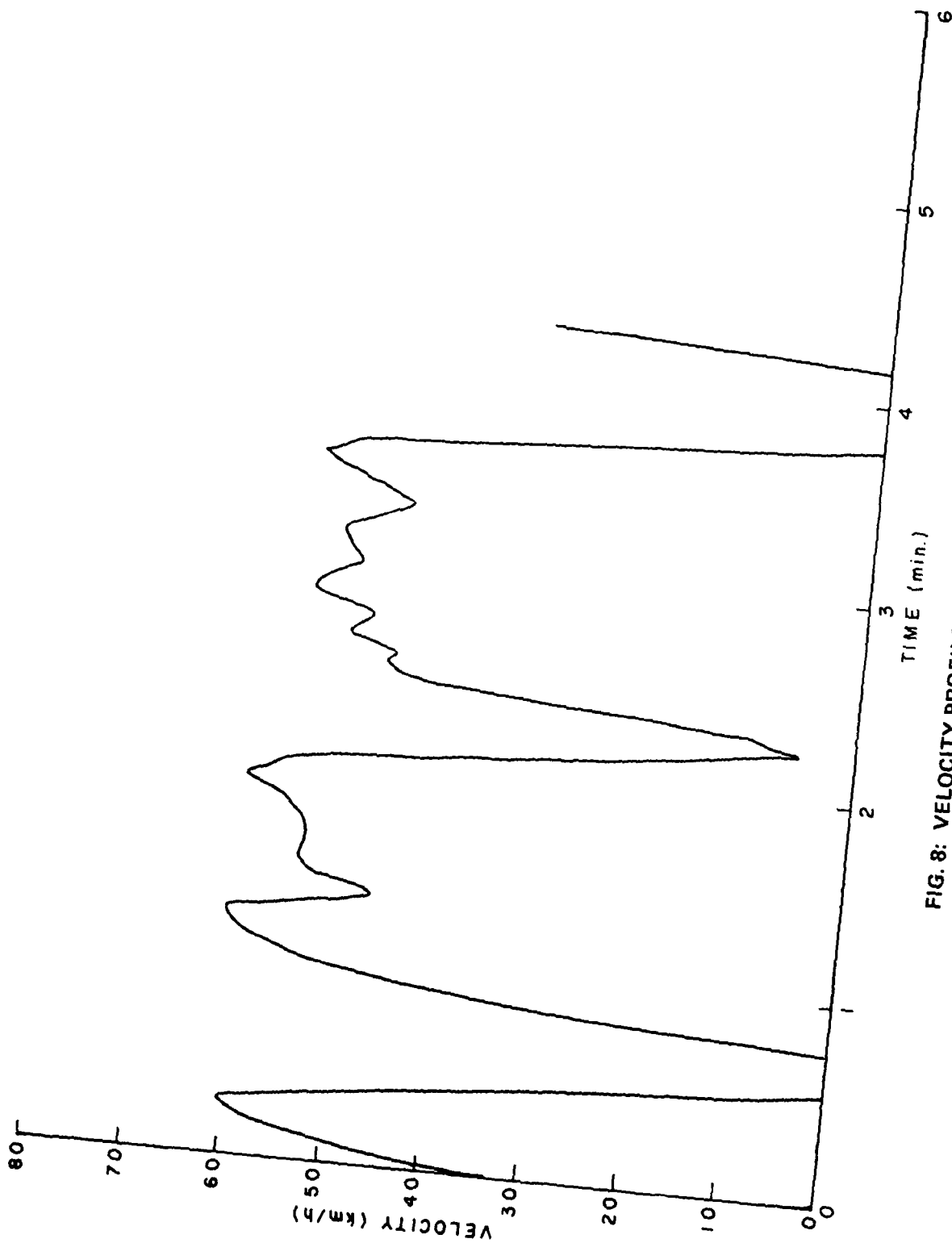


FIG. 8: VELOCITY PROFILE OF LAWRENCE AVE E/B
RUN 13, 10:34, MAR. 5.79

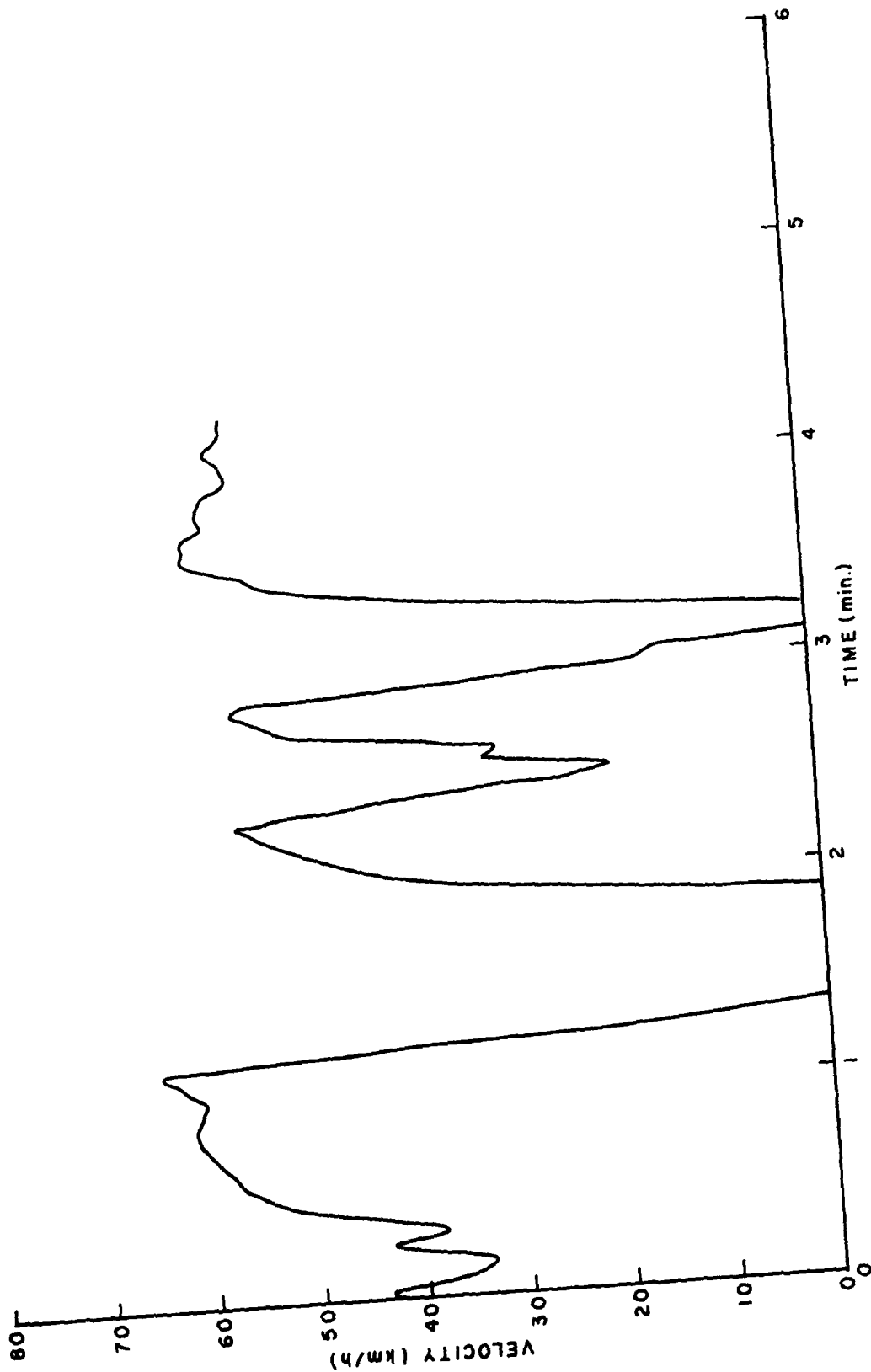


FIG. 9: VELOCITY PROFILE OF LAWRENCE AVE W/B
RUN 14, 10:42, MAR. 5.79

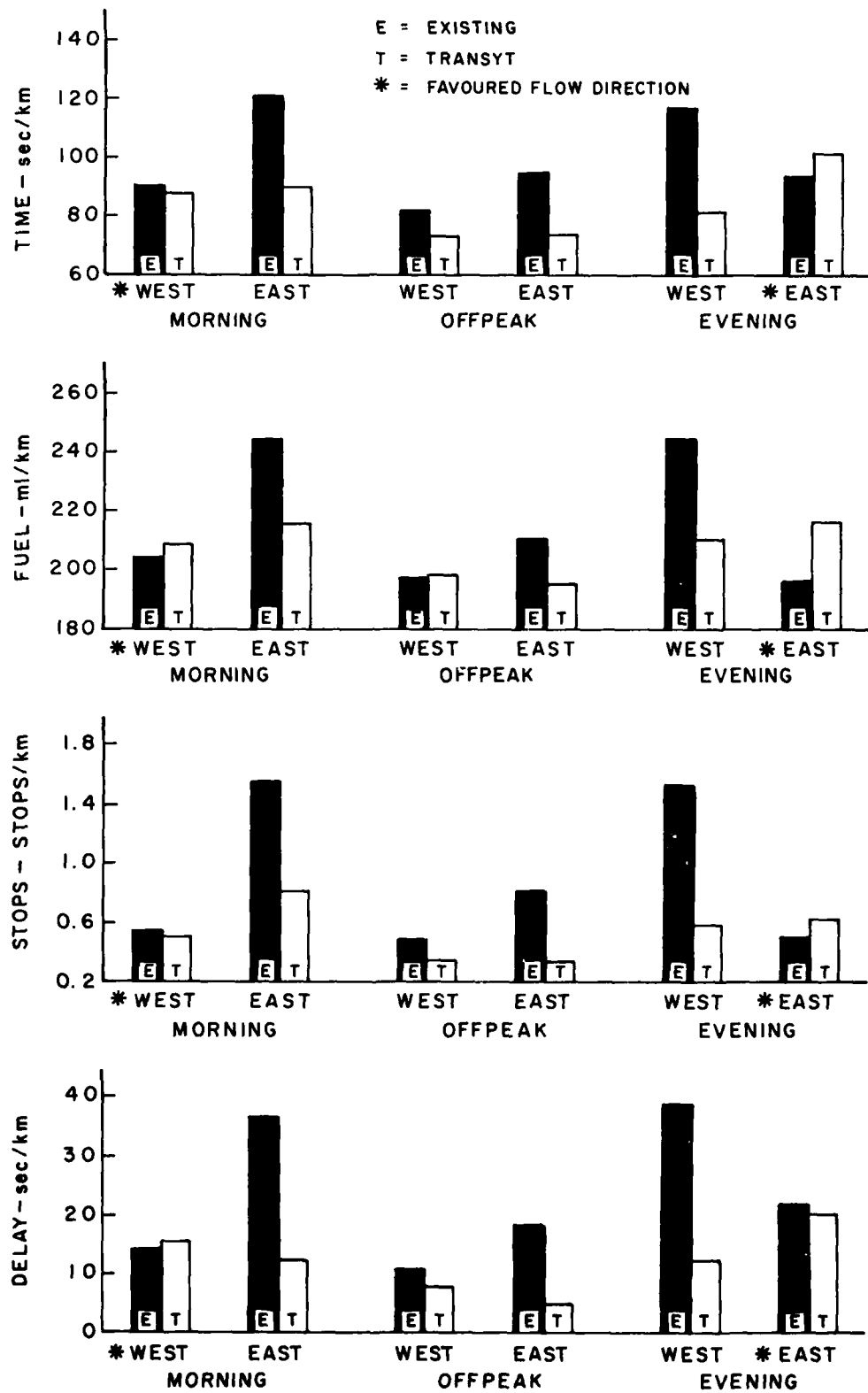


FIG. 10: MEAN VALUES OF TIME, FUEL, STOPS AND DELAY

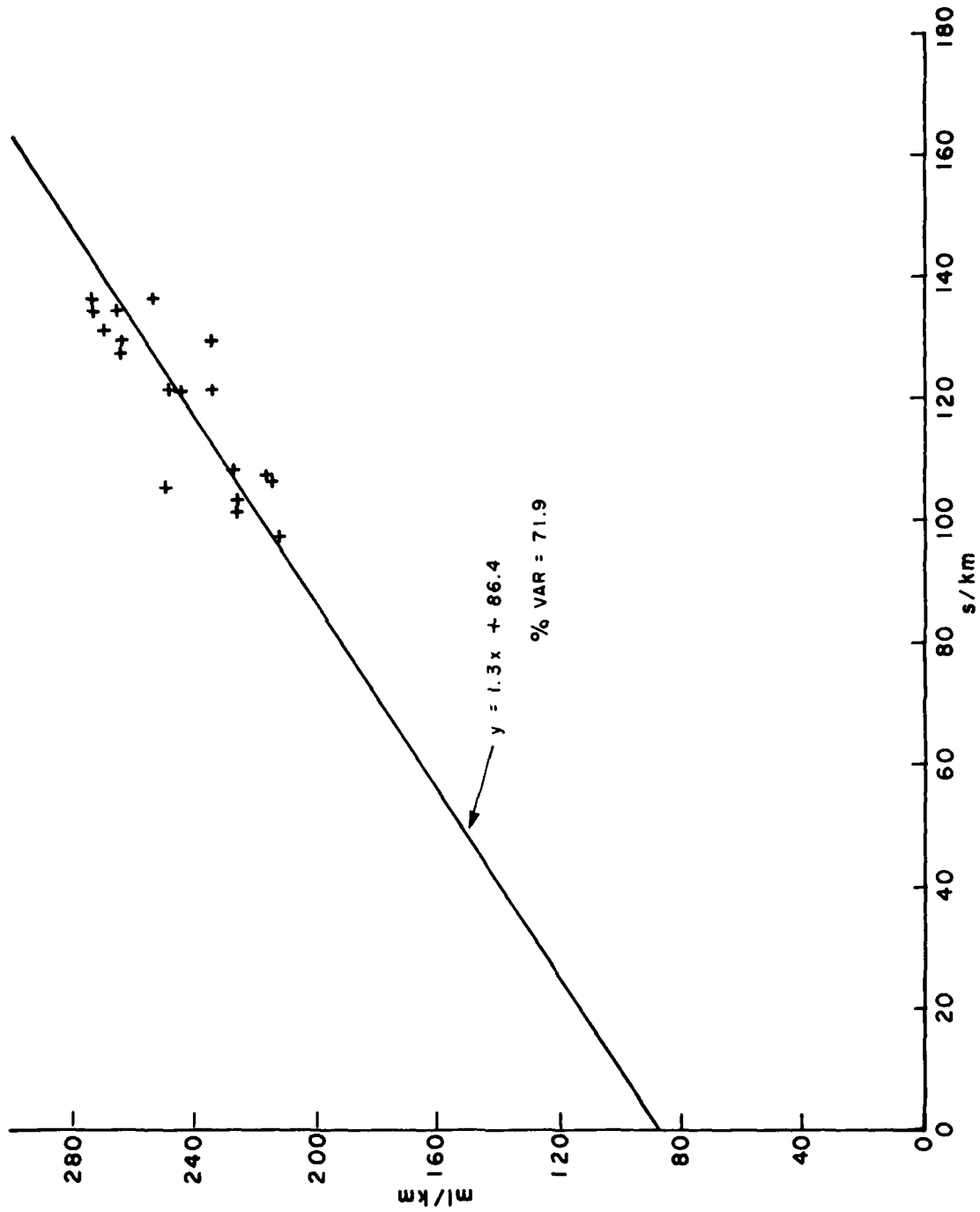


FIG. 11: EXISTING PLAN MORNING E/B DATA POINTS AND REGRESSION LINE

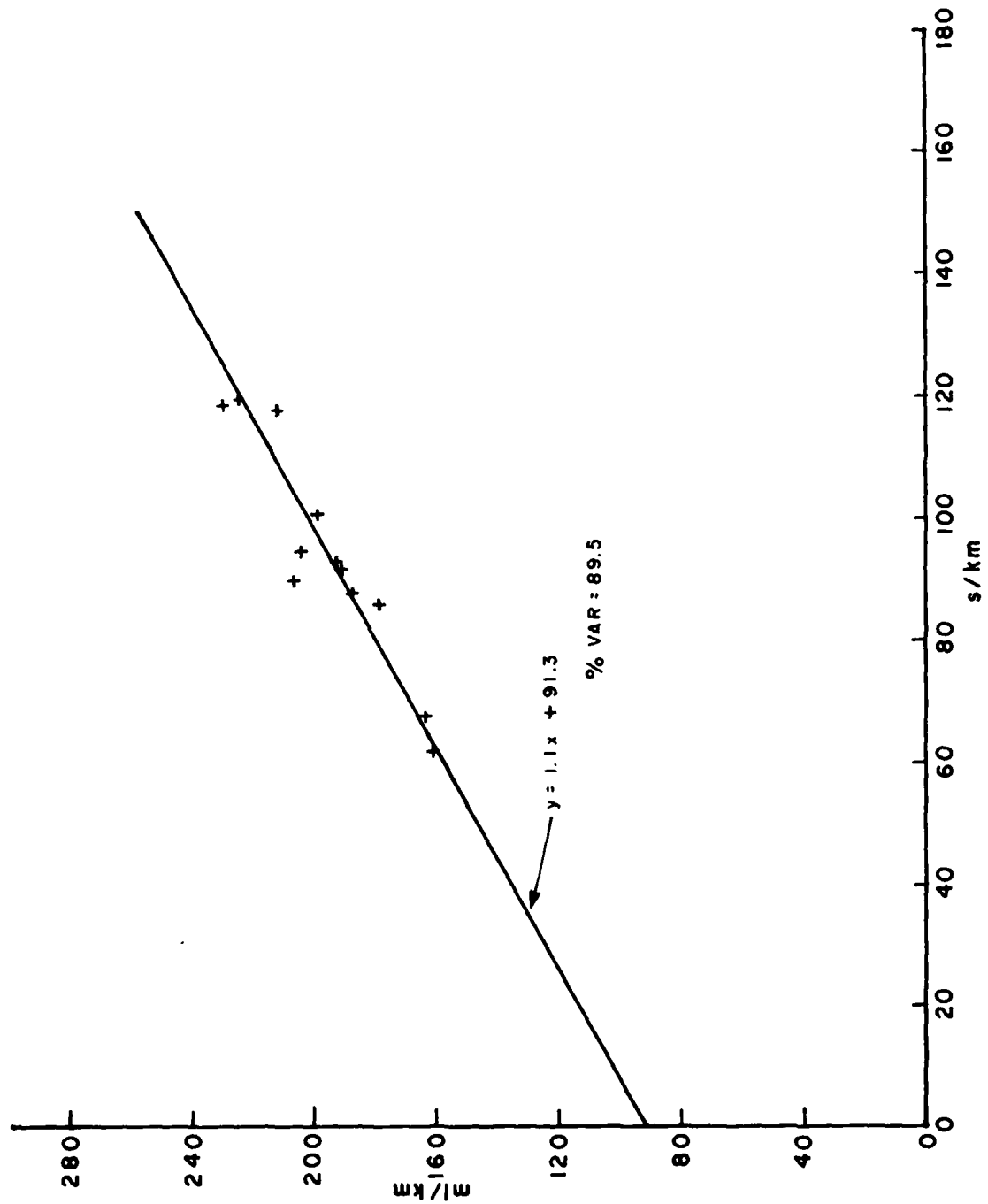


FIG. 12: EXISTING PLAN EVENING E/B DATA POINTS AND REGRESSION LINE

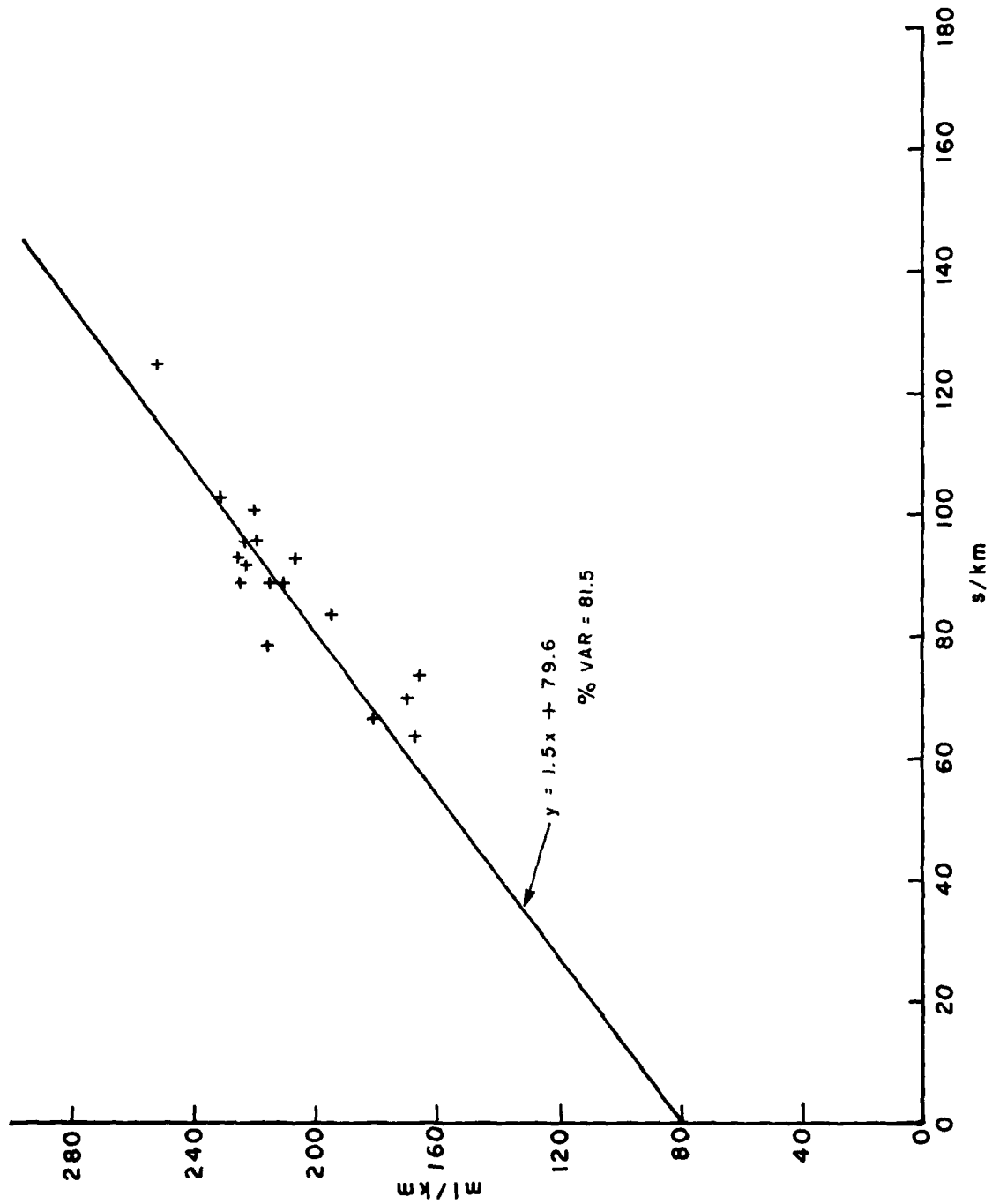


FIG. 13: TRANSYT PLAN MORNING W/B DATA POINTS AND REGRESSION LINE

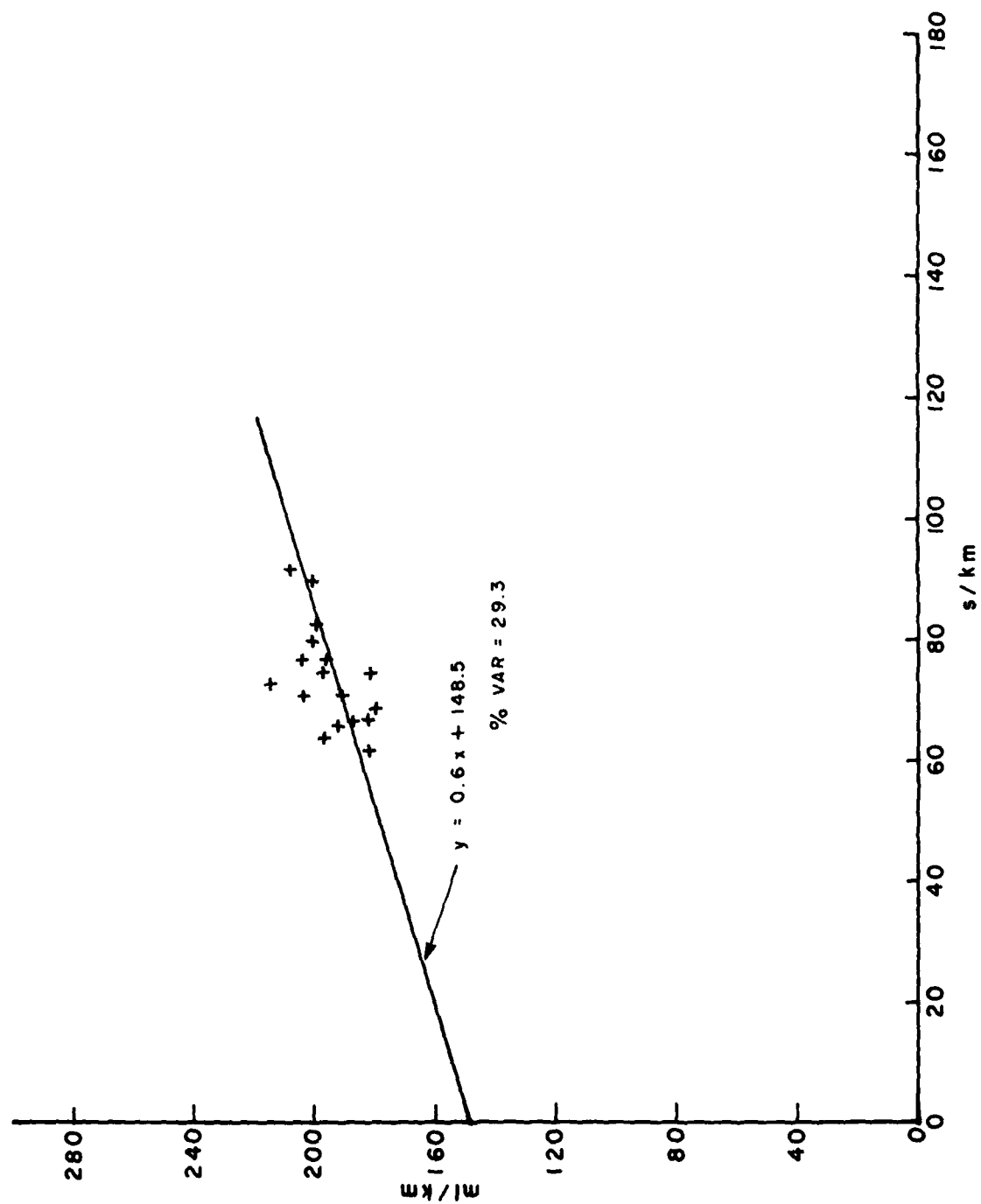


FIG. 14: TRANSYT PLAN OFFPEAK E/B DATA POINTS AND REGRESSION LINE

NRC, DME ME-247

National Research Council Canada, Division of Mechanical Engineering.

URBAN TRAFFIC SIGNAL CONTROL FOR FUEL ECONOMY

Messenger, G.S., Richardson, D.B., Graefe, P.W.U., Mufti, I.H., January 1980, 45 pp. (incl. tables and figures).

The Metropolitan Toronto Roads and Traffic Department and the Engine Laboratory of the Division of Mechanical Engineering at the National Research Council of Canada have completed a study to determine the influence of two computer-controlled traffic signal timing plans over a given route.

The results show that under the TRANSYT timing plan, vehicles encountered fewer stops, saved time and used a slightly smaller amount of fuel than under the existing timing plan (based on SIGRID).

A linear regression analysis showed that fuel consumption could be expressed adequately as a linear combination of either delay time and stops or travel time and stops.

UNCLASSIFIED

1. Traffic control.
- I. Messenger, G.S.
- II. Richardson, D.B.
- III. Graefe, P.W.U.
- IV. Mufti, I.H.
- V. NRC, DME ME-247

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1. Traffic control.
- I. Messenger, G.S.
- II. Richardson, D.B.
- III. Graefe, P.W.U.
- IV. Mufti, I.H.
- V. NRC, DME ME-247

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