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THE UNIVERSITY OF ALBERTA

The Development and Validation of the Transit Route Analysis Model (TRAM)

by

Dean L. Cooper

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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To Dad and Mom

For instilling in me

the importance of education

Abstract

This thesis investigates the application of disaggregate choice behaviour modelling in a practical transit planning context. Individual transit user behaviour is modelled in detail to assess expected aggregate behaviour and to produce an objective measure of the perceived satisfaction urban travellers associate with the transit system.

A multinomial logit model is calibrated to represent the transit route choice behaviour of morning downtown commuters in Edmonton. The model, called the Transit Route Analysis Model (TRAM), is embodied in a computer program and produces (a) the expected number of transit users boarding at each stop in a transit network and (b) a composite measure of satisfaction with the transit network as perceived by transit users.

To validate the output of the model, an on-board survey consisting of brief passenger interviews was conducted. TRAM prediction of the most probable transit choice for each individual in the survey is compared with the observed choice of transit stop for each individual. TRAM prediction of the expected number of transit users boarding at each transit stop is compared with the observed number obtained from the data collection. Additionally, a simple model based on catchment areas is used as a basis of comparison for the observed and predicted numbers.

The research indicates that the TRAM model provides a good representation of the behaviour of morning downtown

commuters in Edmonton. However, it demonstrates that the relatively simple catchment area model can produce results which are quite similar to those of the TRAM model. It concludes that the TRAM model is potentially superior to the catchment area model since, in more complex applications, TRAM better accomodates trade-offs between the various attributes of a transit trip. The decision as to which model is appropriate in a given application depends on the level of detail required, the complexity of the problem, and the consequences of the resulting decision.

The thesis demonstrates the production of a composite measure of satisfaction labelled the Quality of Service Index (QSI). It concludes that the QSI provides a useful and valid method of measuring and understanding the perceptions of transit users regarding transit service.

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List of Abbreviations

AU - aggregation unit

CA - catchment area

CBD - central business district

CTH - Canadian Transit Handbook

CUTA - Canadian Urban Transit Association

EEDA - Edmonton Economic Development Authority

FHWA - Federal Highway Administration

IIA - independence of irrelevant alternatives

LRT - light rail transit

MDC - morning downtown commuter

MNL - multinomial logit

QSI - Quality of Service Index

QSR - Quality of Service Ratio

RMS - root mean squared

RTM - Regional Travel Model

TGR - trip generation rate

TRAM - Transit Route Analysis Model

UTPS - Urban Transporation Planning System

List of Notations

U_{in} - utility of alternative i to individual n

C_n - choice set of alternatives for individual n

$P_n(i)$ - probability that alternative i is chosen by individual n

V_{in} - deterministic component of U_{in}

ϵ_{in} - disturbance component of U_{in}

X_{in} - vector of attributes of the alternative i and characteristics of the individual n

ϕ - vector of weighting coefficients associated with X_{in}

ρ^2 - informal goodness of fit measure, rho-squared

$\bar{\rho}^2$ - informal goodness of fit measure, rho-bar-squared

R^2 - multiple correlation coefficient

E(i) - expected aggregate demand for alternative i

I. Introduction

This chapter explains the motivation which prompted this research and outlines the research objectives. The chapter also provides a brief description of the setting in which the research took place.

A. Motivation and Objectives

In recent years, research undertaken in Edmonton has contributed to the understanding of a relatively new transportation modelling technique known as disaggregate choice behaviour modelling. Specifically, Hunt (1988) used the multinomial logit formulation to model individual parking location choice in Edmonton, with a view to representing the automobile mode in a disaggregate model of mode choice.

At the same time, a need was identified to examine alternative approaches to evaluating a major transit network restructuring planned in response to extension of Edmonton's light rail transit (LRT) system. This need motivated the current research, and the application of disagreggate choice behaviour modelling to this and other route-level transit planning issues was a logical extension to previous research.

An example transit planning issue is the question of whether it is better to provide a network of transit services that establishes faster and more direct routes (with generally longer walking distances to transit stops) or to provide a network that reduces walking distances to stops by penetrating into neighborhoods (with generally slower and more circuitous routes). Furthermore, how would transit patrons be expected to distribute themselves to transit stops in each case?

Historically the analysis of such transit planning issues has centred on the optimization of system-related characteristics such as total travel time, total travel distance, total passenger-hours, or total passenger-kilometres. Network considerations, such as optimization of timed-transfer connections, may also affect the analysis. However, these approaches do not consider the actual perceptions and evaluations which transit users employ to assess the merits of a system and to determine their behaviour.

In the alternative approach of disaggregate choice behaviour modelling, individual transit user behaviour is modelled in detail to assess expected aggregate behaviour and to produce an objective measure of the perceived benefits or disbenefits urban travellers associate with the transit system.

The goal of the research is to investigate the application of disaggregate choice behaviour modelling in a practical transit planning context, observing its strengths and weaknesses in order to determine its validity. To accomplish this goal, the following objectives are identified:

1. To calibrate a multinomial logit model to represent the transit route choice behaviour of morning downtown commuters in Edmonton.
2. To embody the calibrated model in a computer program to facilitate the application of the model to transportation engineering practice and theory.
3. To validate the output of the model against observed behaviour in the field.

The model and computer program developed and validated in this research are given the name "Transit Route Analysis Model", abbreviated "TRAM".

B. Setting of the Research

Edmonton is the capital city of the province of Alberta, one of the western Canadian prairie provinces. The city's economy is dominated by the agriculture and petroleum industries as well as the sustenance of the provincial government administration. Edmonton is situated at 53 degrees north latitude; the mean daily high temperature is 22°C in summer and -11°C in winter (EEDA, 1987).

The metropolitan Edmonton region encompasses 750,000 people, including several suburban satellite communities. Edmonton is served by a well-developed road system consisting of 200 kilometres of freeways and expressways, 750 kilometres of arterial roads, and 2100 kilometres of collector and local roads (City of Edmonton, 1988a).

The Edmonton Transit system consists of 554 kilometres of transit routes, operating 1.6 million platform hours and carrying 42 million passengers annually (CUTA, 1987). The system functions on a timed-transfer basis; a flat fare is paid, and transfers are free in the ongoing direction. The system is owned and operated by the municipal government.

A feature of the transit system is an 11 kilometre light rail transit line joining the central business district (CBD) and the north-east sector of the city. Expansion of the ten-year-old LRT system is underway to the University of Alberta and the south sector of the city (City of Edmonton, 1988a).

II. Research Method

This chapter summarizes the method used in the development and validation of the Transit Route Analysis Model (TRAM). Concurrently, it describes the organization of the remaining chapters of the thesis, in which details of the method are provided as required.

Following this description of the research method in Chapter II, a review of current practice in transit planning is presented in Chapter III. The review indicates that most existing practices do not consider directly the perceptions of the transit user in directing the policies and administration of transit systems. This finding confirms the need for this research.

Chapter IV presents a brief synopsis of the theory of disaggregate choice behaviour modelling. The synopsis provides a level of detail sufficient to permit the understanding of the research and thesis.

A. Development of TRAM

The development of TRAM refers to the development of a procedure which is composed of two elements. The TRAM logit model is a representation of choice behaviour which is calibrated to observed transit user decisions. The TRAM computer program embodies the calibrated model and allows it to be used effectively in practice.

The calibration of the TRAM model is described in Chapter V. The calibration reflects the fact that the research is limited to the transit route choice behaviour of morning downtown commuters. Morning downtown commuters (MDCs) are defined as individuals undertaking trips by public transit, during the morning peak period, based at home, and destined for a workplace in the central business district. The morning peak period is defined as 07:00 to 09:00 on weekdays. The definition of work includes both full-time employment and post-secondary education.

The source of data for the model calibration is the Edmonton Morning Commuter Survey (Hunt, 1984). This database contains extensive detailed information on the morning-peak home-to-work trips of over 1700 individuals who work in Edmonton's CBD. The calibration approach is to observe the choices known to be made by MDCs among the alternatives available to them. On the basis of their home locations, a set of reasonable transit alternatives is identified for each member of a sample of MDCs drawn from the data source.

Each transit alternative is characterized by selected attributes such as travel time, service frequency and walking distance. On the basis of the selected attributes, the calibration routine determines the attribute weighting which maximizes the likelihood that the model predictions agree with the observed choices. A stepwise process is used to identify model attributes which are significant and those which are not. Goodness-of-fit measures are used to evaluate the overall significance of various potential models. The "best" model is adopted as the calibrated TRAM model.

The development of the TRAM program is described in Chapter VI. The calibrated TRAM model is embodied as the motor which drives the program. Written in the FORTRAN programming language, the program is structured around subroutines which can flexibly accommodate modifications.

To make the use of TRAM more practical, travellers are grouped into aggregation units which are similar in relevant model attributes. Various transit network scenarios can be input to TRAM and evaluated using its output. The two products of TRAM are (a) the expected number of transit users boarding at each stop in a transit network and (b) a composite measure of satisfaction with the transit network as perceived by transit users.

B. Validation of TRAM

In the validation of TRAM, an important distinction is drawn between the two products of the TRAM procedure. Predictions of the expected number of individuals boarding at transit stops are feasibly validated through observation of actual traveller behaviour. However, the validity of a composite measure of satisfaction is very difficult to determine with certainty since it attempts to gauge human perceptions of a complex environment. The validation of the composite measure of satisfaction is therefore indirect, by inference from the actual validation of the predictions of expected boardings.

The "environment" of a transit network exists at two levels. The macroscopic level is the aggregation of all the transit patrons boarding at each stop; the microscopic level is the set of choices among available alternatives, made by individual transit users, which contribute to the macroscopic totals. Since a particular state of the macroscopic level can represent many different configurations of the microscopic level, a complete validation of TRAM requires testing at both levels.

The procedures used to attain the data required for the testing of TRAM at both levels are described in Chapter VII. The data required for the validation of TRAM at the macroscopic level is simply the aggregate number of morning downtown commuters boarding over the morning peak period at each transit stop. Validation at the microscopic level requires three additional elements of disaggregate data to allow TRAM to attempt to replicate individual transit choice behaviour. First is the trip origin, which is assumed to be the home address for trips during the morning peak period and is used to determine transit walking distances. Second is the trip destination and third is the trip purpose; trips destined for other than the CBD and the workplace are excluded from the MDC market segment.

An on-board survey consisting of brief passenger interviews was chosen as the data collection mechanism. Three neighborhood-sized study areas were chosen as locations for data collection: Capilano, Beverly, and a portion of Clareview. Figure 1 illustrates the boundaries of the study areas and their locations in the city.

The microscopic level testing involved the TRAM prediction of the most probable transit choice for each of the individuals in the research survey. This prediction was compared with the observed choice of transit stop for each individual. Chapter VIII presents the details of the micro-level testing, including the procedure, results, and analysis.

The macroscopic level testing involved the TRAM prediction of the expected number of transit users boarding at each transit stop. This prediction was compared with the observed number obtained from the data collection. Additionally, a simple model based on catchment areas was used as a basis of comparison for the observed and predicted numbers. The details of the procedure for the macro-level testing are contained in Chapter IX.

The results of the macro-level testing are threefold. First, there is a comparison of the total number of transit trips observed for each study area and predicted using City of Edmonton trip generation rates. Second, there is a comparison of the observed and predicted proportioning of the transit trips among the routes serving each study area. Finally, there is a stop-by-stop comparison of the observed and predicted number of transit users boarding at stops in each study area. The details of the results of the macro-level testing are contained in Chapter X; the analysis

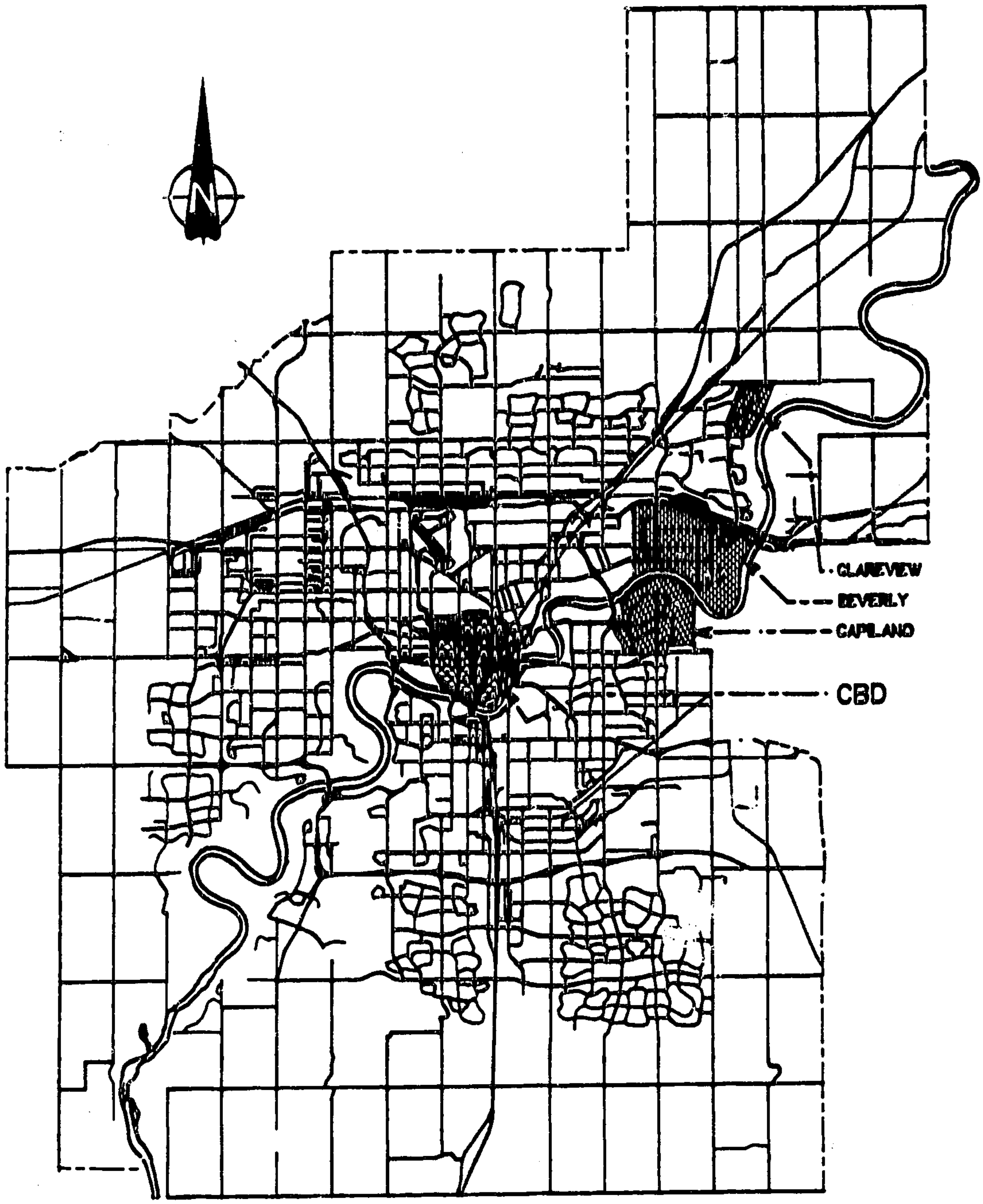

Figure 1 - TRAM validation study areas

of the results is in Chapter XI.

Finally, Chapter XII presents a discussion of observations drawn from all aspects of the validation of TRAM, and Chapter XIII presents the conclusions of the research.

III. Review of Current Practice

The most recent edition of the Canadian Transit Handbook [CTH] (CUTA, 1985) encapsulates the current state of transit planning in Canada and is a logical reference point in a description of current practice. The CTH describes the distinction between a marketing orientation and an operational orientation to public transit planning. The marketing orientation recognizes that "the [transit] system is a service organization which can only be effective if it meets the need of present and prospective patrons" (CUTA, 1985, p. 22-1). In contrast, the more common and traditional operational orientation holds that if the transit system is well-run (as measured by various system-related service performance indicators) it will be well-patronized and therefore successful.

Although it devotes a chapter to the marketing orientation to public transit planning, the CTH is written primarily from an operational perspective. For example, the Handbook states that "route design concerns itself with the assembly and dispersal of people so that they can be accumulated on a fixed route in quantities that will justify transit service and yet serve the many diverse trips that take place in an urban area" (CUTA, 1985, p. 10-1). In this statement, although the need to serve "many diverse trips" is acknowledged, transit users appear to be regarded mainly as a quantity which may or may not justify transit service.

The CTH describes the objective of transit network design as the maximization of ridership under certain economic and policy constraints. It notes that route planning involves difficult compromises between the need for good transit coverage (in order to minimize walking distances) and directness of transit service (to minimize travel times). However, no explanation is provided of how best to address this trade-off in an existing community.[1]

Another variety of trade-off described by the CTH involves the planning of transit route spacing: whether for a given transit demand it is better to supply many routes (closely spaced) with less frequent service or few routes (widely spaced) with more frequent service. The CTH suggests it is better to supply fewer routes with greater frequency, avoiding route overlaps and duplication of service in addition to yielding a greater (though undefined) "overall quality of service" (CUTA, 1985, p. 10-14).

With respect to the evaluation of transit performance in general, the CTH describes criteria such as minimum levels of service frequency, minimum hours of operation for various grades of service, and minimum amounts of transit coverage. The Handbook lists several "service performance indicators" relating to planning, operations, and administration. These include the average operating speed, the total number of passenger-hours or passenger-kilometres,

[1]The solution offered is to deal with the problem at the community design stage by providing extensive walkways to reduce the magnitude of the trade-off between walking distance and travel time.

and the load per vehicle at the maximum load point.

In terms of demand for transit service, the CTH describes demand models at the level of the transit route and of the system as a whole. For example, it describes the use of elasticity models to determine the effect of policy changes on daily ridership. Although it is noted that "the number of onboard passengers at the maximum load point is a basic information requirement for the provision of transit service" (CUTA, 1985, p. 5-2), there is no reference to prediction of transit demand on a stop-by-stop basis.

The City of Calgary uses a design guide based largely on the Canadian Transit Handbook. According to the design guide (City of Calgary, 1987), the fundamental goal of the Calgary transit system is to maximize ridership, and this is the basic measure of performance. In order to maximize ridership, several objectives (such as minimizing walking distance and minimizing travel time) have been adopted, all of which are to be achieved. Although it is acknowledged that the objectives are inter-related and often competing, no explanation is provided regarding the determination of the appropriate balance between them.

Calgary has numerous system-related standards (e.g. maximum walking distance of 450 metres, maximum peak-hour and off-peak load factors, maximum allowable headways) and performance measures (e.g. number of passengers per platform hour, other indicators related to financial performance, cost efficiency, and utilization of service, labour, and vehicles) which are monitored to evaluate the adequacy of the transit system. Additionally, complaints and inquiries are monitored to obtain "an indication of the public's perception of a route" (City of Calgary, 1987, p. 23).

However, in terms of Calgary's transit planning, the maximization of ridership is the most important goal. In this regard, the minimization of travel time is given the greatest weighting, and the public's perception of the trade-off between travel time and other competing factors is neglected.

The City of Edmonton employs the EMME/2 model (Babin, Florian, *et al.*, 1982) to evaluate the adequacy of its transit routes and to evaluate proposed changes in its network of transit service. EMME/2 belongs to the family of "systems analysis" methods described by Florian *et al.* (1976) in their survey of the state-of-the-art in transit route development and evaluation techniques.

The systems analysis technique, which is called "interactive analysis" in the Canadian Transit Handbook, relies on an assignment procedure which converts origin-destination information to predictions of flows on transit lines. In an iterative manner, the initial route network is manually modified and the assignment procedure is re-applied. Eventually, the various scenarios are compared on the basis of a chosen criterion, and the best alternative is selected. The technique is interactive in that the experience of the transit planner is used to design the scenarios which undergo comparison.

Florian *et al*. (1976) provide a thorough description of several other types of approaches to transit route development and evaluation. "Search and screen" methods begin with a network of all possible locations of transit routes plus a representation of the service available on each; the process selects a subset of the network and the transit service necessary to satisfy the given demand. The "analytic approach" represents the city and the transit network in abstract form and applies trigonometric and calculus techniques to determine the characteristics of the optimal network. Florian *et al*. describe further methods, but consider them impractical.

Wilson and Gonzalez (1982) review current practice in short-range transit planning, specifically service design, and propose changes to existing procedures which would increase the attention given to improving routes which are not obviously substandard. They deal with the identification of problems in existing service in terms of "service measures" (statistical summaries of route data, e.g. passengers per bus-hour) or "service standards" (critical levels for particular service measures, e.g. minimum 25 passengers per bus-hour). They also discuss the generation of alternatives, but do not address the assessment of the effectiveness of such alternatives, stating that "this analysis process is often largely judgemental, but it may include one or more models to predict impacts" (Wilson and Gonzalez, 1982, p. 2).

Yuratovic (1982) notes the lack of methods to determine the impact (with respect to system ridership) of either the introduction of new/extended transit routes or service changes on existing routes. He discusses an un-referenced review of current practice at forty North American transit systems, categorizing the existing methods into four groups: (a) professional judgement, (b) non-committal surveys (asking potential riders if they would use a proposed service), (c) cross-sectional data techniques (examining the relationship between transit use and various characteristics of the transit service and the population to be served), and (d) time-series data techniques (examining changes in ridership in response to service changes over time).

Yuratovic identifies two main problems common to many of the existing methods. Firstly, the accuracy of the methods is unknown since few tests have compared the results of predictions against actual riderships. Secondly, the informality of many of the techniques is not conducive to the replication of results or transferability of methods among jurisdictions.

Yuratovic proposes a model which is not fully described, but appears to be a regression equation which determines a transit trip generation rate on the basis of transit service frequency and average income. A transit route is segmented into logical parts (on the basis of timing points and major intersections), and a market area is determined for each segment. The number of generated transit trips is calculated and the trips are distributed, along with transfer trips (if any), in each direction along the route. Different models would be required for various types of transit routes (e.g. radial vs. crosstown, express vs. local).

The concept of a market area is applied at the transit stop level in the catchment area (CA) method, an approach used in this thesis. The market (or "catchment") area is combined with a pre-determined trip generation rate to obtain the transit demand on a stop-by-stop basis. The details of the method, including the determination of catchment areas and trip generation rates, are discussed in a later chapter.

Derbonne (1978) and the FHWA (1980) adopt the operational approach with operating standards and guidelines oriented primarily to the system operator with little direct consideration of the system user. In a public transportation textbook, Koski refers to "the detailed microplanning necessary in laying out transit routes" (Koski, 1979, p. 134) but does not provide a methodology for such microplanning beyond a cursory reference to computer modelling.

In summary, the review of current practice indicated that there are numerous system-related strategies to manage adjustments in a transit network, but that there is little regard for the way such adjustments are perceived by transit users. Most methods in use do not attempt to gauge the satisfaction which transit users derive from transit route planning measures, nor in what manner their patronage and boarding patterns will form as a result of a particular measure.

This thesis applies a relatively new approach which is capable of both gauging satisfaction and predicting boarding patterns: disaggregate choice behaviour modelling, specifically the use of the multinomial logit model.

IV. Synopsis of Disaggregate Choice Behaviour Theory

This research does not seek to expand the theory of disaggregate choice behaviour, rather to investigate its practical application to transit route choice behaviour and to observe its strengths and weaknesses. This chapter aims to provide the reader with a sufficient description of the theory to understand the procedures used within the thesis.

There are numerous references available to provide more detailed treatments of the many aspects of the theory. In particular, Domencich and McFadden (1975) is a benchmark work which provides a thorough development of the theory. The synopsis which follows is, unless otherwise specified, derived primarily from a recent text by Ben-Akiva and Lerman (1985).

Transit route choice behaviour is approached from an economic perspective in which the commuter is considered to be a consumer of transportation in general and transit in particular. There may be several different ways to get from an origin to a destination by transit. The transit consumer is presented with a discrete choice because only one transit alternative may be selected for a given trip.[2]

Each commuter has within his environment a virtually unlimited supply of transit alternatives.[3] However, within reasonable limits (constrained by resources such as time and

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[2]This is in contrast to a choice among continuous alternatives, of which one may choose a proportion of more than one alternative.
[3]The urban "environment" theoretically includes every transit route in the urban area.

money, and affected by the degree of awareness of the availability of alternatives) each individual has a limited choice set of alternatives. Alternatives can be characterized by an unlimited number of attributes, such as travel time, cost, comfort, and convenience. The combination of the various attributes of an alternative can be represented by an overall utility to the consumer.

Domencich and McFadden describe the concept of rational choice behaviour as asserting that "a decision maker can rank possible alternatives in order of preference, and will always choose from available alternatives the option which he considers most desirable" (Domencich and McFadden, 1975, p. 34). In other words, it is assumed that consumers make their choices such that the alternative with the maximum utility is selected. In mathematical terms, alternative *i* will be chosen by individual *n* if:

$$U_{in} > U_{jn}, \text{ for all } j \in C_n, \ j \neq i$$

where U_{in} is the utility of alternative *i* to individual *n*, and *i* & *j* are elements of the choice set of alternatives C_n.

However, rarely are models of human behaviour completely deterministic, and it is unrealistic to expect a model to predict choice behaviour with certainty. Ben-Akiva and Lerman (1985) cite Manski (1973) as identifying four sources of randomness which necessitate the assumption that utility is a random variable. First, not all attributes which affect choice behaviour can be observed by an outsider. Second, there exist variations in taste across a population which can not be determined with certainty for an individual. Third, there are errors inherent in the measurement of observable attributes. Finally, there is error due to the imperfect relationship between proxy variables and the related variables they attempt to represent.[4]

Under the assumption of random utility, the choice probability of an alternative is defined as the probability that the utility of that alternative is greater than the utilities of all other alternatives in the choice set. In mathematical terms:

$$P_n(i) = P(U_{in} > U_{jn}, \text{ for all } j \in C_n, j \neq i)$$

where $P_n(i)$ is the probability that alternative *i* is chosen by individual *n*, and the other symbols are as previously defined.

The utility of an alternative is assumed to consist of a deterministic component V_{in} and a disturbance component ϵ_{in}:

$$U_{in} = V_{in} + \epsilon_{in}.$$

The deterministic component (V_{in}) is the part of the utility which represents the observable attributes in a systematic way. It is assumed to be a weighted linear combination of terms X_{in} which may include attributes of the available alternatives *i* and characteristics of the individual *n*:

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[4]For example, "income" and "number of vehicles owned" are proxy variables which are not necessarily perfect representatives of an individual's economic status.

$$V_{in} = f(X_{in}) = \sum \phi X_{in}$$

where the vector of weighting coefficients ϕ must be calibrated to known transit choice behaviour.[5]

The disturbance component (ϵ_{in}) is the part of the utility which represents the inherent uncertainty and randomness. The assumption as to the form of the distribution of the disturbance component distinguishes among the various choice models such as logit and probit.

Ben-Akiva and Lerman (1985) fully describe the assumptions necessary for the formulation of the multinomial logit (MNL) model, which has the following form:

$$P_n(i) = \frac{\exp(V_{in})}{\sum_{j \in C_n} \exp(V_{jn})}$$

where the symbols are as previously defined. Note that the assumptions regarding the disturbance component allow it to be left out of the MNL formulation.

The multinomial logit model formulation is predicated on an assumption known as the independence of irrelevant alternatives, abbreviated "IIA". Ben-Akiva and Lerman (1985) describe this assumption as holding that the relative choice probabilities of any alternatives in a choice set are independent of the presence or absence of additional alternatives. The importance of the IIA assumption is described by Domencich and McFadden who state that it

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[5] V_{in} is also known as the measurable conditioning function, and is often loosely referred to as the utility function.

"requires that the alternatives [in a choice set] be perceived as completely distinct and independent" (Domencich and McFadden, 1975, p. 20).

Ben-Akiva and Lerman (1979) show that the natural logarithm of the denominator of the MNL formulation can be used as a "composite measure which describes the characteristics of a group of travel alternatives as they are perceived by a particular individual" (Ben-Akiva and Lerman, 1979, p. 654). They show that this composite utility is theoretically consistent with the random utility model structure used to represent individual choice behaviour.

For completeness, it should be noted that Ben-Akiva and Lerman (1979) discuss the application of the composite utility as an appropriate linkage among component models in a hierarchical (or "nested") choice model structure such as those in Sobel (1980), Teply (1982), and Ortuzar (1983). In this application, the composite utility is representative of the choice situation at a lower level of the choice hierarchy. For example, the full spectrum of automobile and transit alternatives could each be represented in a higher-level model of mode choice by their composite utility. (The hierarchical modelling structure also addresses an IIA problem by combining similar alternatives in their own "level" in a hierarchy.)

V. TRAM Model Calibration

This chapter describes the calibration of a multinomial logit model to describe the transit route choice behaviour of morning downtown commuters in Edmonton. Following a description of the calibration procedure, the results of several calibration "runs" are presented and analyzed. Finally, the calibrated model to be incorporated in the TRAM program is presented.

A. Procedure

Recall that the utility function used in the MNL model is assumed to be a linear combination of characteristics of the individual and the available alternatives (X_{in}), weighted by a vector of coefficients ϕ:

$$V_{in} = \sum \phi X_{in}$$

The calibration task is to determine the optimum values of the coefficients ϕ. The approach used to determine the optimum coefficients is the observation of revealed preferences. That is, one observes the actual choice made by an individual from the choice set of available alternatives.

The method used to estimate the optimum coefficients of the utility function is called the maximum likelihood method. For any given set of coefficients, the logit model can determine the choice probability for each alternative in every choice set. The likelihood of all the (known) chosen alternatives being predicted as such by the model is equal to the product of the choice probabilities of all the (known) chosen alternatives. The optimum set of coefficients by definition yields the maximum likelihood of occurrence of the (known) observed choices. For reasons of computational tractability, it is the logarithm of the likelihood which is the quantity maximized.

An ideal model would assign a probability of unity to all of the known choices. Therefore the likelihood of the occurrence of all those choices would also be unity and the log of the likelihood would be zero. For non-ideal models (found in reality), the likelihood is less than unity and the log-likelihood is negative. The maximum likelihood routine searches among all the possible values of the coefficients of the utility function and isolates the optimum set of coefficients.

From the Edmonton Morning Commuter Survey database (Hunt, 1984) was selected a sample of 121 transit users distributed randomly throughout the city. Among other things, the following information was known for each individual: home location, work location, actual chosen transit route/stop location, age, and income.

On the basis of their home locations, choice sets of alternatives were generated for each individual. The choice sets included the known chosen alternative, as well as any other available alternatives deemed reasonable.[6] In some cases, alternatives which added variability (in one or more attributes) were included in choice sets even though they

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[6]The determination of "reasonable" alternatives for choice sets is described in Chapter VIII.

would not necessarily be viewed as reasonable by a typical transit user. The resultant 121 choice sets were composed of a total of 332 transit alternatives.

The attributes of the choice set alternatives which were hypothesized to influence route choice and were determined for each individual are as follows:
(a) origin-end walking distance (ODIST), (b) total in-vehicle travel time (TRIDE), (c) transfer waiting time (TTRANS), (d) number of transfers required for the trip (NTRANS), (e) frequency of service (FREQ),
(f) destination-end walking distance (DDIST), and (g) a dummy attribute specific to the use of the LRT (NBLRT).

The origin-end walking distance is the shortest-path walking distance, in kilometres, from the home location to the boarding transit stop, as measured from a set of 1:5000 scale maps of Edmonton. The travel time, transfer time, frequency (all in minutes), and number of transfers were determined from regular transit schedules. The destination-end walking distance is the shortest-path walking distance, in kilometres, from the alighting transit stop to the work location, generated by a minimum path algorithm. The LRT-specific dummy attribute assumes a value of unity if the trip requires use of the LRT and zero otherwise; it was included to investigate the possibility that the use of the LRT as part of a transit alternative contributes a significant additional effect of its own.

The waiting time at the boarding transit stop is dependent on whether an individual arrives randomly or according to the scheduled transit arrival time. However, it was assumed that for a given individual this factor would be the same for each transit alternative, and therefore the waiting time was not included in the calibration. The frequency of service attribute "FREQ" may incorporate indirectly some influence of the waiting time, but more predominantly reflects the general prevalence of service of a particular transit alternative.

The maximum likelihood routine from a commercial statistical software package was used to determine the optimum utility function coefficients. The procedure was to select the attributes (of the alternatives) which would be expected to "explain" the observed choice behaviour revealed by the data. The software then determined the coefficients yielding the maximum log-likelihood for the specified attributes, and produced various statistics describing the significance of the resulting coefficients and model.

A stepwise approach was used to systematically determine the combination of attributes which "best" represents actual observed behaviour. The results of the series of steps are presented in tabular form in the next section of this chapter. The remainder of this section describes the content of the tabular results.

The body of each table of results consists of the estimated utility function coefficient for each attribute along with its corresponding t-statistic. The remaining statistics in each table are indicators of the significance of the estimated model as a whole. The "log-likelihood at zero" [L(0)] is the value of the log-likelihood when all utility function coefficients are initially set to zero.[7] The "log-likelihood at estimated coefficients" [L(B)] is the value of the log-likelihood using the estimated coefficients, i.e. the maximum likelihood. The magnitude of the difference between the two log-likelihood values corresponds to the degree that the chosen attributes have "explained" the observed choice behaviour.

It follows that a large value of the statistic "-2(L(0)-L(B))" is also indicative of the quality of the model. It has been shown by McFadden (1974) that this statistic is distributed as a chi-squared distribution. In practice it is limited to indicating only that the results of the model using the estimated coefficients are significantly different from the results of the model using all coefficients equal to zero. In all estimations completed for this study (and, indeed, for most models which include any reasonable explanatory variables) the statistic indicates that the models were significantly "different from zero".

Ben-Akiva and Lerman (1985) describe rho-squared (ρ^2) as an informal indicator of goodness of fit which measures

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[7]With all coefficients set to zero, the MNL model formulation collapses to a simple proportional model wherein the choice probability of any alternative is the inverse of the number of alternatives in the choice set.

the fraction of L(0) which is explained by the model and is analogous to the multiple correlation coefficient R^2. In mathematical terms,

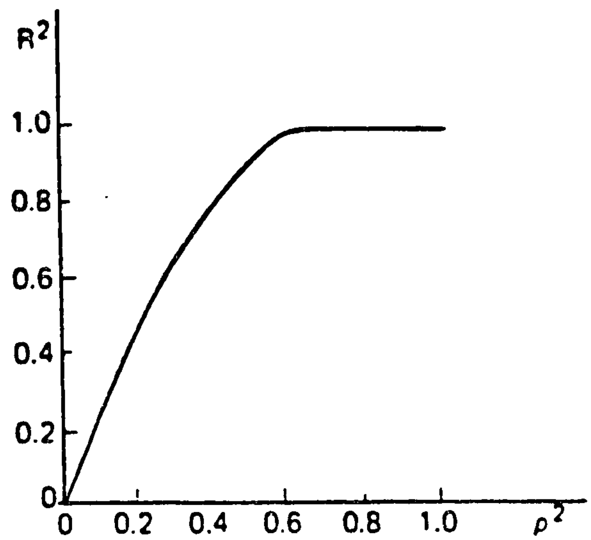
$$\rho^2 = 1 - \frac{L(B)}{L(0)}.$$

Domencich and McFadden (1975, p. 124) provide a "relatively stable empirical relationship between the indices [ρ^2 and R^2]", which is reproduced in Figure 2. As an example, the figure indicates that a typical ρ^2 of 0.345 is roughly equivalent to an R^2 of 0.7. However, we are cautioned that "there are no general guidelines for when a ρ^2 value is sufficiently high" (Ben-Akiva and Lerman, 1985, p. 167).

The rho-bar-squared statistic ($\bar{\rho}^2$) is very similar to ρ^2, but accounts for the influence of the number of attributes which compose the model:

$$\bar{\rho}^2 = 1 - \frac{L(B) - Z}{L(0)}$$

where Z is the number of model attributes. As with other statistical models, it is a property of the MNL formulation that a more complex model (i.e. including more attributes) appears better to represent reality because it encompasses more degrees of freedom. However, a simpler model requires less data, introduces less data error, and is conceptually more attractive. Thus, $\bar{\rho}^2$ is a superior indicator of the goodness of fit of the model. It has been shown by McFadden (1974) that even slight improvements in $\bar{\rho}^2$ (in the order of 0.01) indicate a significantly improved model overall.



(Source: Domencich and McFadden, 1975, p. 124)

Figure 2 - Relationship between R-squared & rho-squared

B. Calibration Runs

The first step in the calibration incorporated all seven of the attributes described previously: origin-end walking distance (ODIST), number of transfers (NTRANS), in-vehicle riding time (TRIDE), transfer waiting time (TTRANS), frequency of service (FREQ), destination-end walking distance (DDIST), and the LRT-specific dummy attribute (NBLRT). The results of the estimation are shown in Table 1. It can be seen that five of the attributes in Run 1 are significant, but that TTRANS and NBLRT are not.

The second step in the calibration re-estimated the coefficients excluding the insignificant attributes from Run 1. The results of Run 2 are shown in Table 2. Most of the coefficients and t-statistics are virtually unchanged. The $\bar{\rho}^2$ measure has improved from 0.321 to 0.327, indicating that the second model is superior to the first.

Despite the fact that the attribute TTRANS was insignificant in Run 1, it is conceptually attractive that some measure of the transfer time (which contributes to the total time required for the transit trip) be included in the model. Thus, the third step combined transfer time with travel time to form a new attribute "TTOTAL", which is the total transit trip time. The results are presented in Table 3. It can be seen that all five attributes are significant and the $\bar{\rho}^2$ statistic is unchanged.

Further steps attempted to improve the model by including hypothesized interactions of age and income with

ATTRIBUTE	COEFFICIENT	T-STATISTIC
ODIST	- 6.14	6.14
NTRANS	- 2.05	3.38
TRIDE	- 0.166	4.16
TTRANS	- 0.0798	0.48 *
FREQ	- 0.166	3.74
DDIST	- 2.48	2.42
NBLRT	+ 0.0529	0.04 *

* = Insignificant attribute; minimum t-statistic of 1.96 required for significance at 95% confidence

<u>SUMMARY STATISTICS:</u>

L(0) = LOG LIKELIHOOD AT ZERO = -146.924

L(B) = LOG LIKELIHOOD AT ESTIMATED COEFFICIENTS = -96.278

-2[L(0)-L(B)] = 101.292

RHO SQUARED = 0.345

RHO BAR SQUARED = 0.321

Table 1 - Coefficient summary for calibration Run 1

ATTRIBUTE	COEFFICIENT	T-STATISTIC
ODIST	- 6.14	6.15
NTRANS	- 2.25	4.96
TRIDE	- 0.167	4.29
FREQ	- 0.117	3.78
DDIST	- 2.47	2.42

SUMMARY STATISTICS:

L(0) = LOG LIKELIHOOD AT ZERO = -146.924

L(B) = LOG LIKELIHOOD AT ESTIMATED COEFFICIENTS = -96.411

-2[L(0)-L(B)] = 101.026

RHO SQUARED = 0.344

RHO BAR SQUARED = 0.327

Table 2 - Coefficient summary for calibration Run 2

ATTRIBUTE	COEFFICIENT	T-STATISTIC
ODIST	- 6.09	6.18
NTRANS	- 1.84	4.35
TTOTAL	- 0.162	4.31
FREQ	- 0.115	3.71
DDIST	- 2.45	2.41

SUMMARY STATISTICS:

L(0) = LOG LIKELIHOOD AT ZERO = -146.924

L(B) = LOG LIKELIHOOD AT ESTIMATED COEFFICIENTS = -96.397

-2[L(0)-L(B)] = 101.054

RHO SQUARED = 0.344

RHO BAR SQUARED = 0.327

Table 3 - Coefficient summary for calibration Run 3

the attributes. For example, to reflect the greater value of time perceived by individuals with higher incomes, the model was estimated with "total time" replaced by "total time * income". It was also hypothesized that the perceived increase in the value of time might not be related linearly to income, and estimations were done for "total time * log(income)" and "total time * square-root(income)". Similarly, it was hypothesized that the perceived weighting of walking distance would be magnified with increasing age. Two estimations were done, multiplying ODIST and DDIST, respectively, by the age of the individual.

A list of the $\bar{\rho}^2$ statistics associated with these runs follows:

TTOTAL * INCOME 0.316

TTOTAL * LOG (INCOME) 0.301

TTOTAL * SQRT (INCOME) 0.312

ODIST * AGE 0.318

DDIST * AGE 0.320

C. Analysis

The fact that, in Run 1, NTRANS was significant and TTRANS was not suggests that only the requirement that a transfer be made, and not the time associated with the transfer *per se*, is perceived as significantly "costly" by commuters.

It had been expected that the LRT-specific dummy variable NBLRT in Run 1 would have a significant positive coefficient. The fact that its coefficient is not significant might be a result of a lack variability in the data; there were few choice sets in the sample which involved the decision of whether or not to use the LRT. For example, in north-east Edmonton the bus-feeder system essentially compels the transit user to choose to ride on the LRT and there are few non-LRT transit alternatives which lead to the Central Business District. Conversely, in west Edmonton the use of the LRT on a transit trip to the Central Business District is not appropriate. The structure of the logit model formulation is such that, without adequate variability of data, a significant coefficient can not be produced.

In Run 2, the attribute NTRANS seemed to absorb the significant explanatory portion of the excluded attribute TTRANS. The improvement in the overall model performance is because of the decrease in the number of attributes and the fact that the omitted attributes were insignificant. However, because of the conceptual attractiveness of the TTOTAL attribute and the equivalence of the models of Run 2 and Run 3 in terms of significance, the model of Run 3 is deemed the best model of the three.

With regard to the additional attempts to improve the model, it is evident that none of the models is as good as that of Run 3 (for which $\bar{\rho}^2 = 0.327$) even though in all cases the hypothesized attributes were significant. Furthermore, each of these models would require input of age or income data when making model predictions, a disadvantage relative to the model of Run 3.

The signs and magnitudes of the Run 3 model coefficients are consistent with expectations. It is logical that utility decreases (i.e. "cost" increases) with increases in either origin-end or destination-end walking distance. It is likewise logical that the utility of a transit alternative decreases with increasing total transit travel time. Since FREQ represents service frequency in terms of minutes of headway, it would be expected that increased headway would decrease the utility of the transit alternative. Finally, it is also reasonable that a requirement to transfer would decrease utility.

In addition to its use within the MNL model, the calibrated utility function of Run 3 provides insight into the perceived weighting of the various attributes. The ratio of the coefficients of two attributes determines the quantity of one attribute which is equivalent to one unit of the other attribute. Table 4 presents a complete matrix of attribute equivalencies for the calibrated utility function.

Example equivalencies include:

(a) 1 kilometre of origin-end walking distance is perceived as equivalent to 2.5 kilometres of destination-end walking distance, and

(b) 1 transfer is perceived as equivalent to 0.3 kilometres of origin-end walking distance or 11.4 minutes of total travel time.

	ODIST (km)	TTOTAL (min)	FREQ (min)	NTRANS (#)	DDIST (km)
ODIST (km)	1	37.6	53.0	3.30	2.500
TTOTAL (min)	0.027	1	1.4	0.09	0.066
FREQ (min)	0.019	0.7	1	0.06	0.047
NTRANS (#)	0.300	11.4	16.0	1	0.750
DDIST (km)	0.402	15.1	21.3	1.33	1

NOTE: Read across row to determine equivalency of one unit of item in left column.

Table 4 - Matrix of attribute equivalencies

Information such as this can be used by the transit planner to determine strategies and policies for improving transit service. Examples of practical applications include considerations of transit network density in central and outlying areas, and considerations of the merits of no-transfer direct service versus feeder service which necessitates a transfer.

D. Calibrated TRAM Model

To summarize, it has been established that the "best" model is that of Run 3. The calibrated model is:

$$P_n(i) = \frac{\exp(V_{in})}{\sum_{j \in C_n} \exp(V_{jn})}$$

with the following utility function:

$$V_{in} = -6.09(\text{ODIST}) - 0.162(\text{TTOTAL}) - 0.115(\text{FREQ}) - 1.84(\text{NTRANS}) - 2.45(\text{DDIST})$$

where:

V_{in} is the utility of transit alternative *i* to individual *n*;

ODIST is the minimum walking distance from the residence of individual *n* to transit alternative *i* (in kilometres);

TTOTAL is the total transit trip time (riding and transferring) of transit alternative *i* (in minutes);

FREQ is the frequency of transit service for alternative *i*, expressed as minutes of headway;

NTRANS is the number of transfers required to be made for transit alternative *i*; and

DDIST is the minimum walking distance from the alighting stop of transit alternative i to the work location of individual n (in kilometres).

However, for the remainder of the thesis it is assumed that destination-end walking distance is randomly distributed and therefore on average can be assumed to be the same for all individuals who work downtown. DDIST is therefore excluded from the application of the TRAM model.

VI. TRAM Program

Previous chapters have addressed the theory behind the TRAM model and its calibration. This chapter describes the TRAM computer program, which embodies the calibrated TRAM model and allows it to be applied easily to practical situations.

A. Basic Principles

The function of the TRAM program is to (a) predict the number of transit users expected to choose each alternative in a transit network analysis area, and (b) determine a comparative composite utility associated with the transit network.

A transit alternative is defined as the representation of a transit route at a particular stop. Generally, each different route is a separate alternative, and more than one different alternative may be associated with a given stop. However, if several routes which are similar in terms of travel time, service frequency, and path service a particular stop, the combination of all of the similar routes are represented as one alternative.

With regard to the first function of TRAM, recall that the product of the TRAM model is the choice probability of each transit alternative available to a particular individual. Ben-Akiva and Lerman note that a link is required "between the disaggregate level models ... and the aggregate level forecasts of interest to planners and decision makers" (Ben-Akiva and Lerman, 1985, p. 131).

The expected aggregate demand E(i) for each transit alternative *i* could be determined by summing the choice probabilities of all individuals *n* in the analysis area[1] population *N*:

$$E(i) = \sum_{n \in N} P_n(i).$$

However, it would be a prohibitive task to determine the value of each attribute for each alternative for all individuals *n*. Instead, Ben-Akiva and Lerman (1985) describe a link whereby the analysis area population *N* is divided into groups *K* which are reasonably homogeneous with respect to the model attributes:

$$E(i) = \sum_{K \in N} k \times P_K(i)$$

The *k* members of each group *K* are represented by an "average individual" located at the geographic centroid of the group, and the choice probabilities of the group are determined on the basis of the average individual's representative attribute values. These groups are defined as <u>aggregation units</u> (AUs) in this thesis.

Because individuals in an AU are not entirely homogeneous, it is logical that the accuracy of the forecast decreases as the size of the AU increases. Ben-Akiva and Lerman (1985) note that establishing a balance between these two factors requires the careful judgement of the model user.

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[1]The term "analysis area" assumes that the model is applied to a limited geographic area, such as a neighborhood, as opposed to the entire urban area.

Aggregation units of approximately city-block scale were selected for three reasons. First, they seemed intuitively to be a practical and appropriate balance between the individual commuter and the entire neighborhood of commuters. Second, a convenient computer-based technique was available for data manipulation at that scale. Finally, city-block scale is the "lowest" level of detail for which socio-economic characteristics were available from census data.

With regard to the second function of TRAM, it was stated in Chapter IV that the natural logarithm of the denominator of the MNL formulation forms a measure of the composite utility of the transit network as perceived by transit users. This composite utility is defined for this research as the Quality of Service Index (QSI), and is a tool with which different scenarios of transit networks can be compared.

B. Program Structure

The TRAM model is the motor which drives the TRAM program. In fact, the utility function which is the basis of the TRAM model occupies a single line within the program code. Thus, the utility function can be conveniently changed to accomodate models calibrated to various conditions and purposes.

The TRAM model (and hence the program) requires input of the relevant attributes of each alternative for each AU.

TRAM program input consists of two groups of data: (a) a network scenario description and (b) an aggregation unit description. The network scenario description provides information on the routes composing the particular transit network scenario which is to be analyzed; the aggregation unit description provides information on the alternatives available to each AU in the analysis area.

The two groups of TRAM data are contained in separate input datafiles, each consisting of a descriptive title line and a series of program data lines. The data lines are categorized into line types to accommodate organization and data checking. A detailed description of the format and content of the data files is contained in Appendix A.

The TRAM program is written in the FORTRAN IV programming language. The structure of the TRAM program is represented as a flowchart in Figure 3. The rectangles generally correspond to subroutines; the flowchart depicts their interrelationships as controlled by the main TRAM program. At this initial stage, the program is designed to stand alone. However, it was developed to facilitate integration and interaction with larger system models. The use of subroutines in the program makes modifications and additions more convenient.

As shown in the flowchart, TRAM first reads the title lines from each input file and writes them to appropriate output files. Next, a subroutine reads the network scenario description information from the appropriate file. The

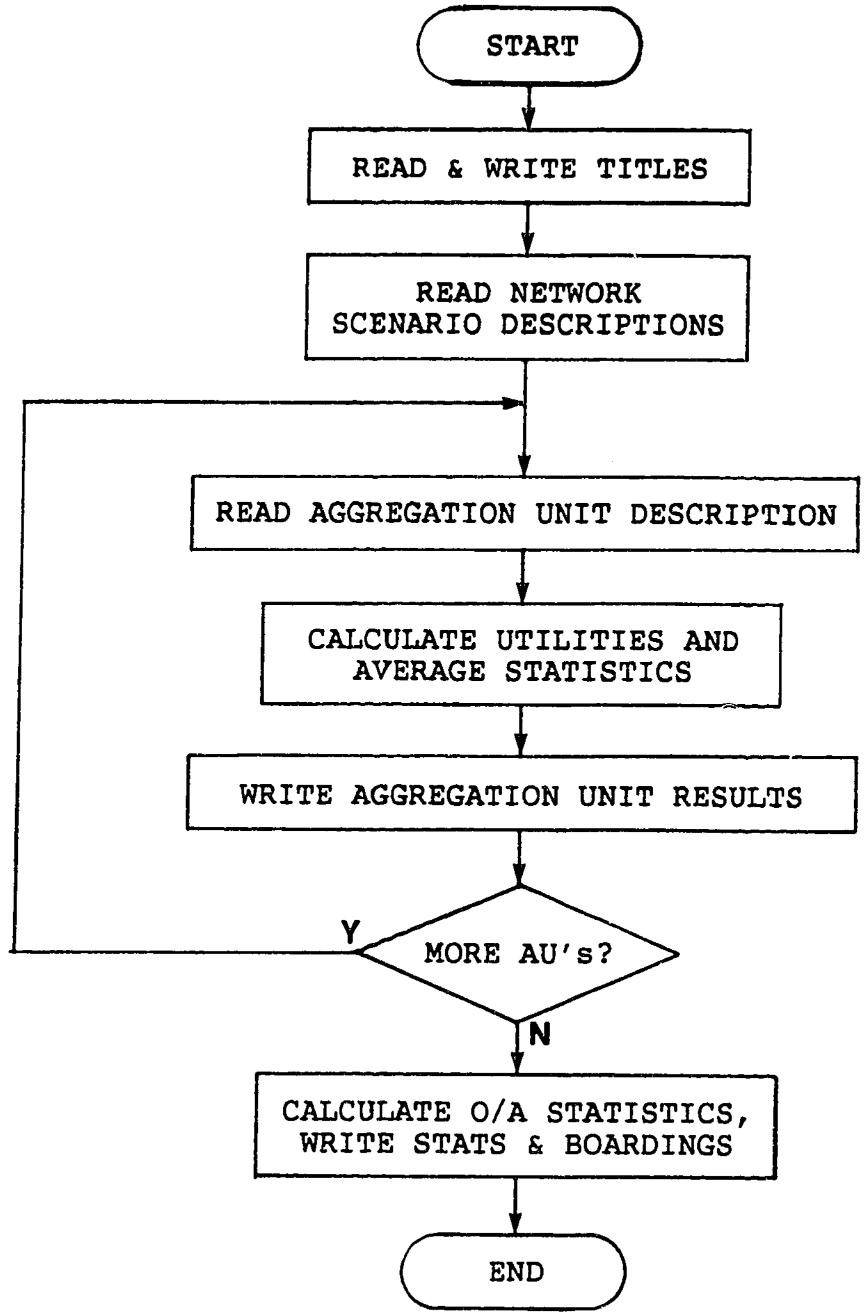


Figure 3 - TRAM program structure

network scenario description is essentially a list of the stops which constitute each route in the transit network scenario; included, for each stop, are the stop number, location, and scheduled transit arrival time.

Then, for each AU, subroutines are called to (a) read the AU description, (b) calculate the utility of each available transit alternative and calculate average statistics for the AU, and (c) write the generated results for the AU to an output file.

Aggregation unit descriptions contain (a) the population and transit trip generation rate of the AU, and (b) for each transit alternative available to the AU, the route and stop number of the alternative, the walking distance to the transit stop, the number of transfers required to reach the destination, and the frequency of the transit service. The utility of each alternative is calculated on the basis of the aggregation unit description data and the TRAM utility function. Transit users from each AU are assigned to transit alternatives in relation to the utilities of the alternatives. Weighted average walking distances, travel times and utilities for the AU are calculated. These results are then written in a table of AU averages.

Finally, when all AUs have been processed, a subroutine calculates and writes overall transit route analysis statistics and the total number of boardings at each stop. The statistics (consisting of overall weighted averages of transit travel time, walking distance and utility) are calculated from AU information which is accumulated over all the AUs. The number of boardings at each stop is written graphically and numerically in a format corresponding to the network description as initially input.

At several points in the program (not shown in the flowchart), special subroutines may produce warning or error messages indicating data input errors, unreasonable values of program variables, or exceeded program limits.

For illustrative purposes, the next two sections supplement the program structure description with a hypothetical example of program input and output.

C. Example Input

A hypothetical network scenario consisting of two routes in a four-block analysis area is shown in the diagram in Figure 4. Each city block in the area is considered to be a separate AU. The AUs are numbered and the population and transit trip generation rate of each are recorded. The transit routes are drawn on the diagram, including the transit stops. The routes and stops are numbered and the scheduled arrival time at each stop is recorded. The time of arrival at the downtown, the nominal service frequency, and the number of transfers required are noted. The average automobile travel time from the zone to the downtown is also included. Figure 5 shows the information on the diagram as transcribed for input to TRAM according to the line type

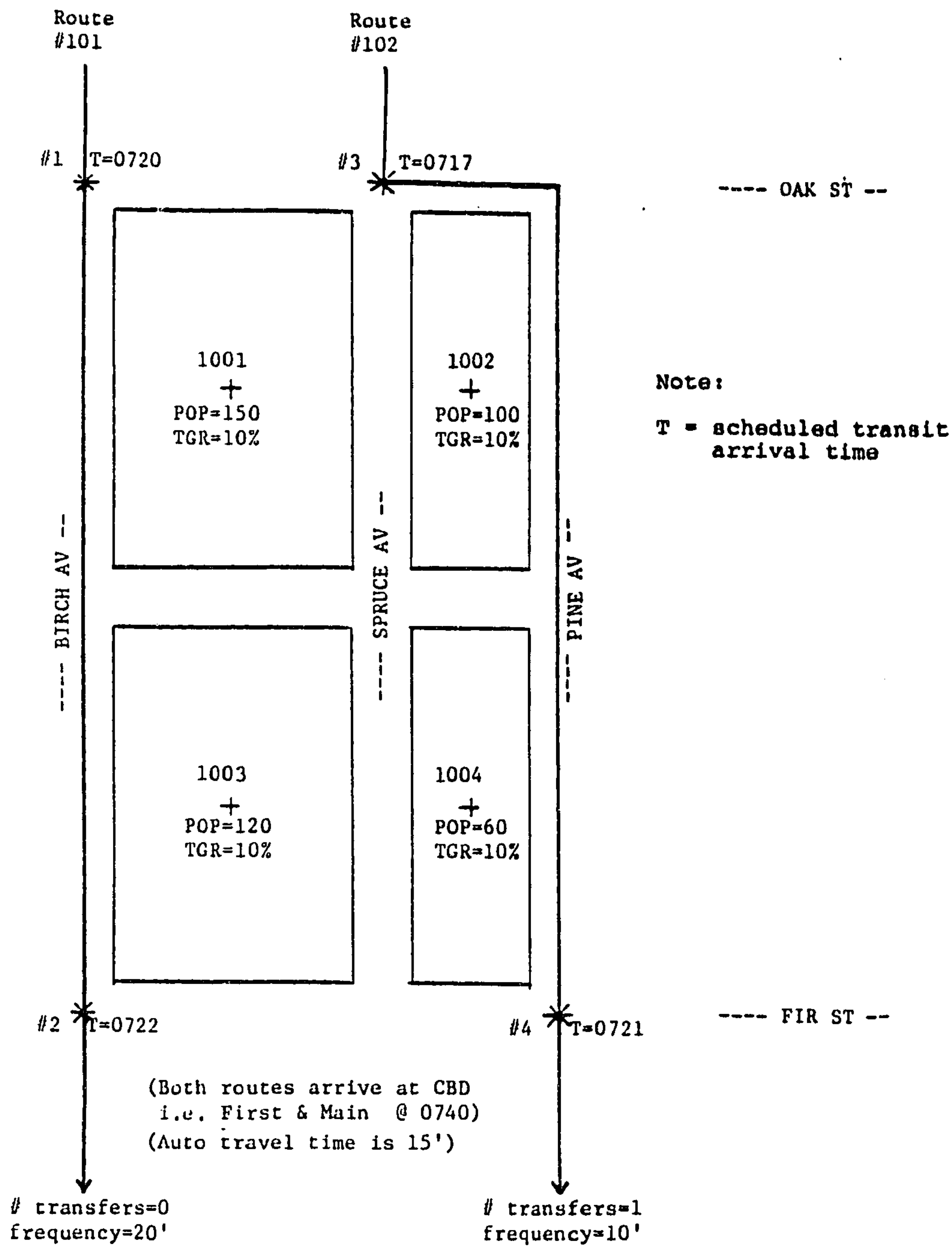


Figure 4 - Example transit network scenario

```
Routes 101 & 102
   11  101     3   20
   12    1 Birch   Av   Oak  St  720
   12    2 Birch   Av   Fir  St  722
   12  999 First   Av   Main St  740
   11  102     3   10
   12    3 Spruce  Av   Oak  St  717
   12    4 Pine    Av   Fir  St  721
   12  999 First   Av   Main St  740
```

(a) Network scenario description

```
Example run
   21   15
   22 1001  150   10   2
   23  101    1  250
   23  102    3  250   1   10
   22 1002  100   10   2
   23  101    1  400
   23  102    3  200   1   10
   22 1003  120   10   2
   23  101    2  250
   23  102    4  350   1   10
   22 1004   60   10   2
   23  101    2  400
   23  102    4  200   1   10
```

(b) Aggregation unit description

Figure 5 - Example TRAM program input

specifications.

The two transit routes are input as network scenario description data (Figure 5-a), the first line of which is the Title Line, following which each route is described by one Line Type 11 and three Lines Type 12. Line Type 11 provides the route number, the number of stops on the route, and the nominal frequency of service on the route. The route number is arbitrary and is used only for identification purposes in program output. The "number of stops on the route" includes each stop in the transit market area plus the final destination stop. The nominal frequency of service is the average scheduled frequency of service for the route for the time period under analysis. Each stop on the route is described by a Line Type 12 which provides the stop number, stop location, and scheduled stop arrival time.

The area description is input as aggregation unit description data (Figure 5-b), the first line of which is also a Title Line. Line Type 21 indicates that the average automobile travel time from the area to the CBD is 15 minutes; the program is capable of accepting further input if different automobile travel times apply to other areas. Each AU is then described by one Line Type 22 and two Lines Type 23.

Line Type 22 contains the number of the AU, its population and transit trip generation rate, and the number of available transit alternatives. In the example, each block was arbitrarily assigned a transit trip generation rate of 10 per cent. Each block was considered to have two available alternatives, one from each of the two routes.

Line Type 23 contains, for each transit alternative, the route and stop number of the alternative, the walking distance to the stop and, if applicable, the number of transfers required and the resulting effective service frequency. If no transfer is necessary, the nominal service frequency is assumed by the program; otherwise, a frequency must be specified since the service frequency of the transfer route may be inferior to that of the original route.

D. Example Output

The program output is also in two parts. Part I is an evaluation of the network scenario and provides indicators of transit service quality for each AU and for the overall area. Part II is a route-by-route tabulation of the predicted number of boardings at each transit stop.

As shown in Figure 6, Output Part I consists of a tabulation of performance indicators used to evaluate the transit network scenario. The main portion of the table contains one line of output for each AU, followed by two lines (separated by double spacing) of summary output.

The first column of output contains the label of each AU. The second column contains the Quality of Service Index (QSI), which increases with improved transit service quality; the maximum possible QSI is 35, chosen arbitrarily

```
*****************************************
*     TRAMD1  (05/85)   OUTPUT  PART I   *
*****************************************
```

RUN ID: Example run

USING: Routes 101 & 102

MARKET SEGMENT LABEL	QUALITY OF SVC INDEX (QSI)	QUALITY OF SVC RATIO (QSR)	AVERAGE WALKING DISTANCE (m)	AVERAGE TRAVEL TIME (min)	NUMBER OF TRANSIT USERS	NUMBER OF ALTS
1001	28.2	86.6	250.	20.7	15.	2
1002	27.7	85.2	298.	21.5	10.	2
1003	28.5	87.4	269.	18.2	12.	2
1004	28.2	86.7	282.	18.6	6.	2
O/A	28.2	86.5	271.	19.9	43.	---
AUTO	32.6	100.0	0.	15.0	---	---

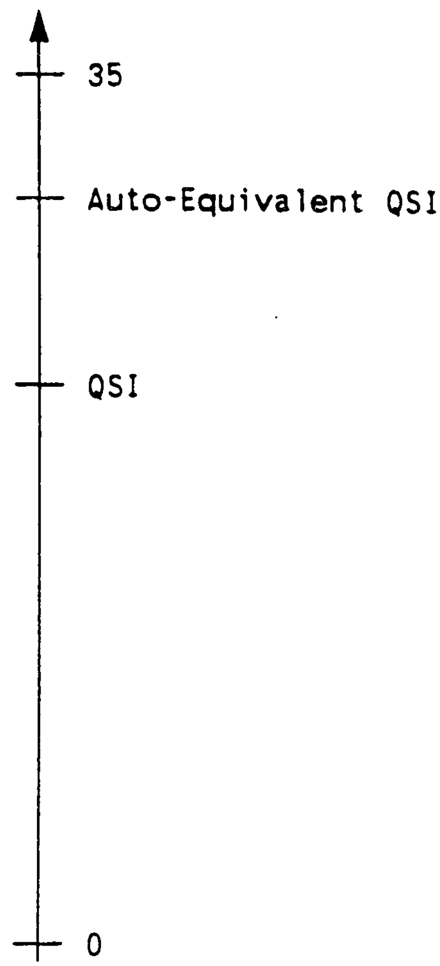
Figure 6 - Example TRAM output Part I

such that it is unlikely to be exceeded in any normal program application.

The third column is the Quality of Service Ratio (QSR), which is a measure of the degree to which the transit service for an AU approaches "automobile-equivalent transit service". Automobile-equivalent transit service is the hypothetical transit service which simulates the automobile mode, the attributes of which are: (a) origin-end walking distance (ODIST) is negligible, i.e. zero, (b) total travel time (TTOTAL) is the average automobile travel time, (c) frequency of service is unlimited (i.e. FREQ=0), and (d) number of transfers (NTRANS) is zero.

The definition of the QSR is depicted graphically in Figure 7. The auto-equivalent QSI usually approaches the maximum of 35; the actual transit Quality of Service Index is usually lower. The ratio of the latter to the former, expressed as a percentage, is defined as the QSR. The purpose of the QSR measure is to allow a comparison of transit service among different analysis areas, which cannot be accomplished using raw QSI values alone.

The fourth and fifth columns are the weighted average walking distance and weighted average travel time, respectively. Each transit alternative available to an AU has associated with it a walking distance and a travel time. The weighted averages are calculated based on the number of transit users choosing each alternative. They are indicators which can help explain the corresponding Quality of Service



$$QSR = \frac{QSI}{(\text{Auto-Equivalent QSI})} \times 100\%$$

Figure 7 - Definition of the Quality of Service Ratio (QSR)

Index, since QSI decreases with increases in either walking distance or travel time.

For example, if the QSI for an AU is relatively low, an examination of the average walking distance and average travel time may provide some insight. Perhaps the walking distance is relatively high, and consideration may be given to reducing the walking distance by adjusting the path of the transit route, thereby improving the QSI. If several adjacent AUs with large numbers of transit users are found to have relatively large walking distances, a transit route could be adjusted to reduce the walking distances. This would likely significantly improve the overall QSI.

The next column indicates the number of transit users generated by the AU, determined on the basis of the AU population and the transit trip generation rate. This number indicates the relative weight of an AU and its QSI on the overall QSI.

The final column is the number of transit alternatives available to the AU. The QSI increases implicitly as the number of alternatives increases, so that several inferior transit alternatives may produce a QSI equivalent to that of a single superior transit alternative. The number of transit alternatives can be used to distinguish between these two states and may affect the evaluation of the final QSI for a market segment.

Following the main portion of the Part I output table are two lines which summarize the columnar statistics (where applicable) for the OverAll (O/A) transit analysis area and for the AUTOmobile-equivalent transit service (AUTO). The QSI and QSR from the "O/A" line can be considered to summarily characterize the network scenario. Using these values, the transit service provided by a network scenario can be compared to transit service in other analysis areas as well as to that of other existing or proposed scenarios in the same area.

The overall average walking distance and travel time statistics can be used as benchmarks for comparison with corresponding values from individual AUs and provide explanation of the magnitude of the QSI. A relatively low QSI value can be the result of a relatively high value of either walking distance or travel time. The averages give the TRAM user an indication of how to attempt to improve a transit network scenario.

The "AUTO" line includes the automobile-equivalent QSI, which is the denominator in the ratio used to compute the QSR column. For the "AUTO" line, by definition the QSR is 100% and the average walking distance is zero. The average travel time for the "AUTO" line is the average automobile travel time input to TRAM.

Output Part II (Figure 8) is a route-by-route list of the predicted number of boardings for each stop in the network scenario. In addition to the program heading, the output includes the route number and nominal scheduled frequency for each route.

```
          *******************************************
          *     TRAMD1  (05/85)   OUTPUT  PART II   *
          *******************************************

RUN ID: Example run

USING:   Routes 101 & 102
-------------------------------------------------------------------

  ROUTE:   101     FREQUENCY: EVERY 20 MINUTES

-------------------------------------------------------------------
STOP |         LOCATION        |              BOARDINGS
-----|-------------------------|-----------------------------------
     |                         |  #  0       10        20        30
     |                         |     |        |         |         |
  1  |  Birch  Av    Oak   St  | 16. |****************
  2  |  Birch  Av    Fir   St  | 12. |************
999  |  First  Av    Main  St  |  0. |
     |                         |     |        |         |         |
     |                         |     0       10        20        30
-------------------------------------------------------------------

          TOTAL BOARDINGS :  28.
```

```
          *******************************************
          *     TRAMD1  (05/85)   OUTPUT  PART II   *
          *******************************************

RUN ID: Example run

USING:   Routes 101 & 102
-------------------------------------------------------------------

  ROUTE:   102     FREQUENCY: EVERY 10 MINUTES

-------------------------------------------------------------------
STOP |         LOCATION        |              BOARDINGS
-----|-------------------------|-----------------------------------
     |                         |  #  0       10        20        30
     |                         |     |        |         |         |
  3  |  Spruce Av    Oak   St  |  9. |*********
  4  |  Pine   Av    Fir   St  |  6. |******
999  |  First  Av    Main  St  |  0. |
     |                         |     |        |         |         |
     |                         |     0       10        20        30
-------------------------------------------------------------------

          TOTAL BOARDINGS :  15.
```

Figure 8 - Example TRAM output Part II

The transit stops on each route are listed in the order that they were input in the network scenario descriptions. There is one line for each stop, consisting of the stop number, stop location, and the number of boardings predicted. The number of boardings, which is the total for the morning peak period, is output in both numerical and graphical form. (The destination stop is listed for completeness only, and the boardings at that stop are not indicated.)

Part II of the output gives the user an indication of the probable distribution of transit users to the transit stops in the network scenario. The graphical output shows clearly the uniformity or lack thereof for such a distribution, and a heavy concentration of boardings at a particular stop will be quite evident. The user may adjust the network scenario in response to the output, depending on the objectives of the transit system.

In Figure 9, the results from Output Part II have been transferred to another diagram of the analysis area for clarity. Note that only the total numbers of boardings, in brackets, were output by TRAM; the "distribution" of transit users from each block was calculated manually. It is illustrative to examine the distribution of the transit riders from each block to the two routes; a trade-off exists between Route 101 and Route 102, the former being faster and requiring no transfer, but offering less frequent service.

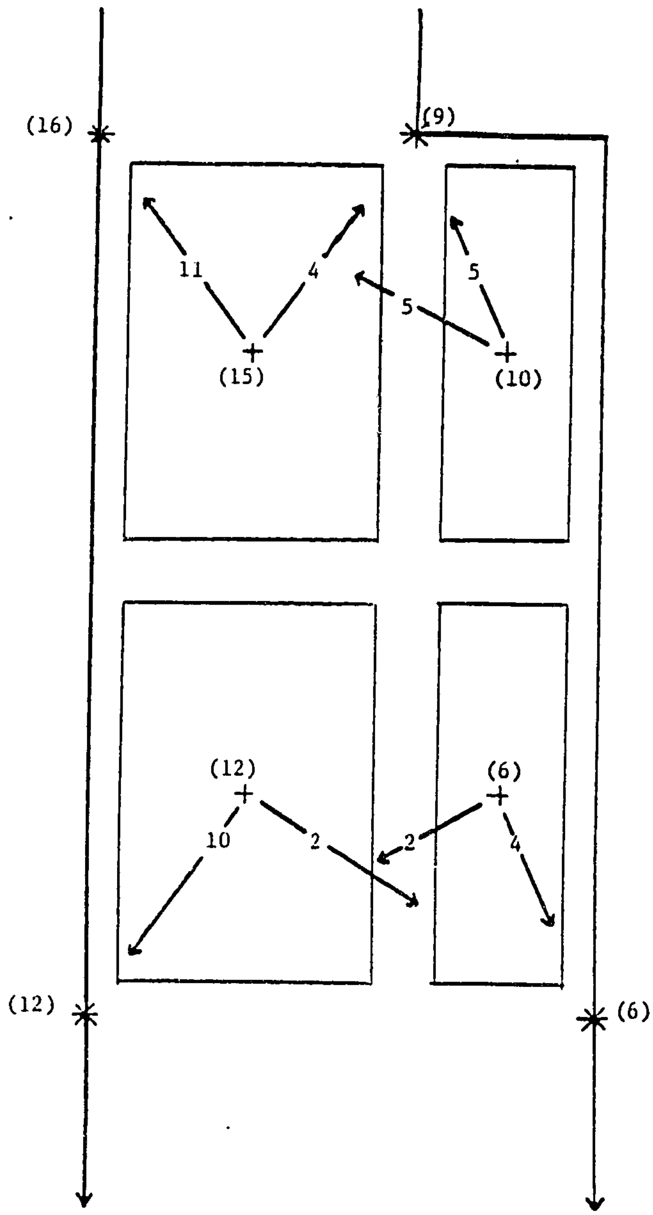


Figure 9 - Example assignment of boardings

VII. Data Collection

This chapter describes the collection of data required for validation of the Transit Route Analysis Model. The chapter summarizes the method, preparation, and execution of the data collection effort. The full description is available elsewhere (Cooper, 1986).

A. Survey Method

The data required for the validation of TRAM were obtained through investigation of the activity of morning downtown commuters boarding at transit stops.

Several methods of collecting the TRAM validation data were considered, each a combination of either active or passive survey techniques and either on-board or at-stop survey administration. Active survey techniques involve oral interviews or written questionnaires in which subjects actively participate; passive survey techniques are merely observational and do not directly involve the subject of the survey. On-board survey administration requires that one or more surveyors administer the survey while on board transit; at-stop survey administration requires the surveyor(s) to administer the survey to subjects at the transit stop.

The passive survey techniques which were considered involved a surveyor simply counting the number of individuals boarding at each transit stop. Although passive survey techniques are generally simple to execute, unobtrusive to passengers, and may have minimal manpower requirements, they are not adequate to allow micro-level validation of TRAM. Further, the counts resulting from a passive survey include transit users other than downtown commuters. Thus, validation of TRAM at even the macroscopic level would necessitate the assumption of distributions of trip purpose and trip destination for the surveyed transit users.

The active survey techniques which were considered involved either an oral interview or a written questionnaire designed to obtain the information required for the microscopic-level validation of TRAM. The active survey technique explicitly determines trip purpose and destination so that no assumptions are needed. Since the information required for the validation of TRAM is relatively simple, the oral interview is ideal. Interviews are generally less complex, require less manpower, and are less obtrusive to passengers than written questionnaires.

On-board surveys have two main advantages over at-stop surveys. First, it has been shown that transit passengers tend to minimize waiting time by arriving at the transit stop just before the scheduled transit arrival time (Gill, 1969). Thus, an at-stop surveyor is idle much of the time between buses, then very busy just before a bus arrives, and may be unable to properly survey all boarding passengers before the bus leaves. Second, unless the transit route to be surveyed is quite short, the manpower requirements of the on-board survey are considerably less than the at-stop survey. Therefore, it was decided to administer an "on-board interview" survey to collect the data required for the validation of TRAM.

As noted previously, three study areas were selected as survey locations: Capilano, Beverly and Clareview. Figure 10 shows the transit routes serving each area. A series of "neighborhood fact sheets", providing details of land use and demographics for the study areas, is contained in Appendix B.

The criteria for choosing the study areas were:

(a) They are bounded by well-defined barriers, with a limited number of transit exit points.

(b) They have various subdivision plans (traditional simple grid, modern crescent-dominated, etc.).

(c) They have a practical number of transit routes (for data collection).

(d) They have various transit route complexities (simple straight-line, convoluted, looping, etc.).

(e) Their CBD transit routes involve various combinations of transfers, LRT use, and direct routes.

B. Survey Preparation

To ensure the feasibility of administering an on-board interview survey, a minimum of one route from each study area was monitored during the morning peak period. The monitoring consisted of either riding or driving behind as many buses as possible on the selected route. The number of

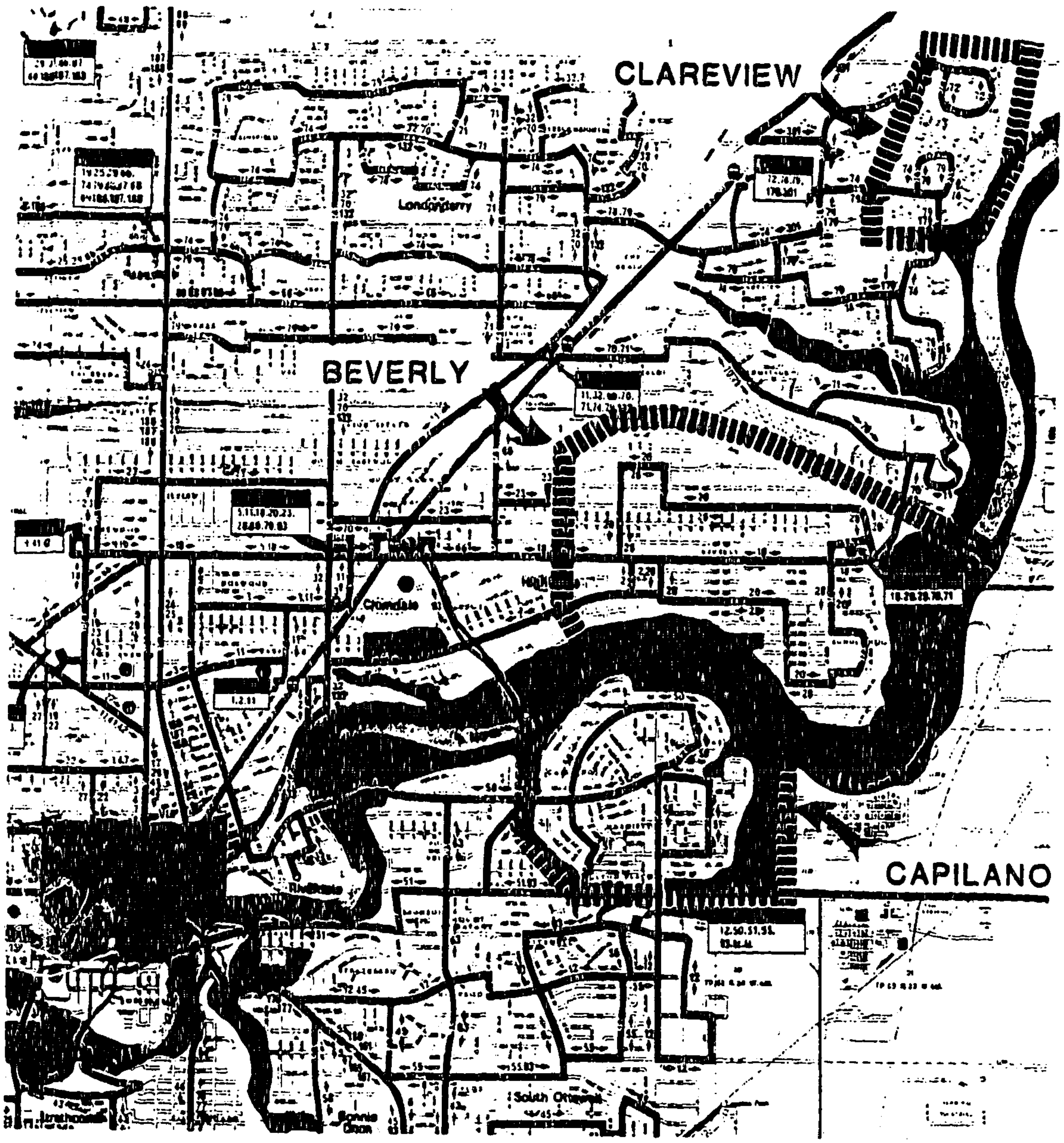


Figure 10 - Transit routes in study areas

individuals boarding and alighting at each transit stop and the time of arrival at each stop were recorded. This resulted in an indication of the maximum number of boardings at any one stop, the distribution of boardings along the route, and the average time interval between successive stops along the route.

From this preliminary investigation, it was evident that the on-board interview survey was feasible. Frequently only one or two passengers would board at a transit stop, and the time interval to the next occupied stop appeared to allow sufficient time for the required passenger interviews. It was noted that on one or two peak runs along each route, the number of boardings and their dense distribution along the route would make the interview survey difficult to execute. However, this problem was not judged to be serious enough to make the plan infeasible.

The preliminary study also reconfirmed various assumptions regarding the operations of the transit routes. For example, it was confirmed that many people arrive at their bus stop just as the bus arrives, supporting the rejection of the at-stop survey administration.

A further preliminary study involved a cordon survey of all buses leaving the Beverly study area. The purpose of the cordon survey was to determine the manpower requirement for the on-board interview survey in that area, which was dependent on the reliability of the transit system as a means of returning surveyors to the starting point. Several alternative configurations of surveyors, with and without an automobile shuttle, were considered.

Figure 11 presents a list of the survey questions. The survey began with an introductory statement. Then, the questions were posed in order such that only those individuals travelling to work in the downtown are queried about their home address. A procedure is indicated for those instances where the address was not supplied in response to the initial question.

A TRAM Validation Survey Form was prepared and is presented in Figure 12. Space is provided for all essential information, with an allowance for extra comments or information. Short prompts of the survey questions head the columns. "Yes or No" questions require that the appropriate response (**Y** or **N**) be circled, to reduce confusion during the survey and ambiguity during its interpretation.

A group of nine surveyors was recruited. Six of the surveyors were employees of the City of Edmonton who specialize in data collection. Two graduate students and one summer-research student from the University of Alberta completed the group.

An initial meeting was held to acquaint the surveyors with the TRAM Validation Survey. A short explanation of the TRAM modelling procedure was provided as background, so that the purpose of the survey was clear. The chosen survey technique was explained, and the survey questions were introduced. The terms "work" and "downtown" were defined, Survey Questions

GOOD MORNING,

(WE ARE CONDUCTING A SMALL SURVEY THIS MORNING.)

* ARE YOU ON YOUR WAY TO WORK RIGHT NOW ?

(If "no", "THANK YOU";
If "yes", continue)

* DO YOU WORK DOWNTOWN ?

(If "no", "THANK YOU";
If "yes", continue)

* WHAT IS YOUR HOME ADDRESS ?

(Reason - to be able to measure distance to bus stop)

(If refuse, "CAN YOU JUST GIVE ME THE POSTAL CODE ?")

(If refuse, "CAN YOU GIVE ME THE STREET AND AVENUE YOU LIVE ON ?")

THANK YOU VERY MUCH.

Figure 11 - Survey questions

C I T Y O F E D M O N T O N / U N I V E R S I T Y O F A L B E R T A

TRAM Program Verification Survey

Route ______ Run ______ Date __________ Surveyor ______________ Page ____ of ____

Stop No.	Time	# On	# Off	Work?	Down-town?	Address / Postal Code / ST - AVE Coordinates	Notes
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
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				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		
				Y N	Y N		

Notes: ____

Figure 12 - TRAM Validation Survey form

and the surveyors were instructed to make a note of any responses which required interpretation. The survey form was explained in detail and a partially-completed form was provided as an example. Strategies were provided to maximize the efficiency of the survey under high-activity conditions. The surveyors were instructed to ask the survey questions as phrased on the question sheet, to ensure standardization. Identification tags were distributed, and it was made clear that transit inspectors and drivers would be informed of the occurrence of the survey on the appropriate days.

C. Survey Execution

The TRAM Validation Survey was executed on three successive days midweek in late August, 1985. Each of the three survey days recorded activity in one study area, and began at a designated meeting place approximately one-half hour before the beginning of the survey. A briefing meeting described the plans for each day, including duty assignments and procedural details to be remembered. After each survey, a debriefing meeting was held to collect the survey forms. The forms were checked quickly and there was an opportunity for feedback from the surveyors.

During one of the surveys a bus was missed completely, and approximately four passengers on another bus were missed. Based on the assumption that the missed bus carried no more passengers than the most-patronized bus which was surveyed, the maximum effect on the overall results would be four percent. Thus the impact of each of these problems was considered marginal.

Some irregularities were noted during the processing of the survey forms. A follow-up debriefing with each surveyor during the week following the survey resolved many of the problems while the events were still fresh in the memories of those involved. After each survey form was carefully checked and most irregularities clarified, all corrections and assumptions necessary to satisfactorily reconcile the problems on the forms were recorded. The data from the original survey forms were transcribed carefully, in a standard fashion, to new survey forms. A special indication was made if extra comments or information were associated with entries on the original forms. The survey information from the new forms was keypunched to a computer datafile labelled "CTVS" (Coded TRAM Validation Survey) and re-checked carefully.

Over the three-day survey period, the recording of boarding activity at surveyed transit stops yielded a total of 961 events. A total of 874 individuals boarded surveyed buses, of which 833 (or 95%) were interviewed. Of the interviewed passengers, 447 (54%) indicated that they were travelling to work in the CBD.

Some of the survey responses were discarded because they did not provide adequate information to be of use, or were believed to provide incorrect information. For example, data involving unknown, non-existant, or vague addresses were excluded. Also discarded were data involving trips which appeared to be "chained". For example, one trip originated at a home address in Mill Woods but boarded at a transit stop ten kilometres away in Capilano, suggesting an automobile component which renders the trip beyond the scope of this research. Similarly, another trip involving a parent dropping a child at daycare and subsequently re-boarding was excluded.

For purposes of micro-level testing, the remaining survey data were edited to form a list of home addresses and the associated route and stop chosen by each subject. For purposes of macro-level testing, the data were coded by route and stop so that only simple sorting and counting procedures were necessary to tabulate the number of boardings at each stop along the transit routes surveyed.

VIII. Micro-Level Testing (Procedure, Results, & Analysis)

This chapter presents the procedure, results, and analysis of testing the TRAM model at the microscopic level. The testing involved two steps: (a) application of the TRAM model to determine the choice probability of the transit alternatives available to the individuals in the research survey, and (b) comparison of the results of the TRAM model with observations of the actual choice of stop.

The first section of the chapter describes the TRAM model predictions in the three study areas. The next section discusses the method used for comparison of the model results and observations. The results of the comparison are presented and analyzed in the final two sections.

A. TRAM Model Prediction

A modified version of the TRAM program, called TRAM.MICRO, was developed for micro-level testing of the TRAM model. Its product is simply the choice probability of each available transit alternative for each subject. The simpler format of the TRAM.MICRO output is suited to the comparison with observed data.

The TRAM.MICRO program accepts input in the same format as the TRAM program itself, differing only in that the alternatives are associated with an individual at a known address (effectively an aggregation unit of one person). The generation of reasonable alternatives which constitute choice sets for the program input is described generally in the remainder of this section and specifically for each study area in the subsequent sections.

The first step was to plot each transit stop in the study area on a 1:5000 scale area map. Then, the residence of each individual was located on the same area map, in most cases by simply estimating the location by its address. Where an adequate estimation of location was impossible, the address was located precisely by means of a site visit.

Corresponding to the utility function of the TRAM model, the TRAM program requires the input of four attributes for each alternative: (a) the walking distance to the transit stop, (b) the frequency of transit service at the stop, (c) the total transit travel time from the stop to the CBD, and (d) the number of transfers required to travel from the stop to the CBD.

In order to generate choice sets in an objective manner, several criteria were used to aid in the determination of reasonable transit alternatives. The guiding principle was that, to conform with the assumption of the irrelevance of independent alternatives (IIA), the transit alternatives must be "distinct and independent in the eyes of the decision-maker" (Domencich and McFadden, 1975, p. 78). This concept was applied by attempting to generate choice sets which reflected the perspective of a typical transit rider.

Recalling the definition of transit alternatives from Chapter VI, generally each alternative consists of a distinct route. A route is then represented for modelling purposes by a representative "best" transit stop for that route, using an informal and implicit "sub-model" of walking distance minimization. Thus, although the model is technically determining choice probabilities for various transit stops, the stops are representative of a particular route alternative.

Because of the importance of walking distance in the TRAM model, the closest transit alternative was generally the foundation of the choice set. For additional alternatives, only those stops within a reasonable upper limit of walking distance were considered, and only in instances where a benefit of some degree was offered to balance the extra time and effort required to reach a more-distant alternative.

In cases where doubt existed as to whether an alternative would be reasonable or not, the alternative was included in the choice set. The rationale in these cases was that, if the alternative was truly insignificant, the model would assign it a negligible probability; conversely, if the alternative was indeed significant, it ought to be included in the choice set.

Beverly Study Area

Figure 13 shows the six transit routes which serve the Beverly study area. Routes #18, #20, and #28 provide the primary transit service, and travel from the Abbotsfield Transit Centre through the Beverly area to the Coliseum LRT Station where riders transfer to the LRT to complete the trip to the CBD.

Three other routes provide secondary transit service. Route #2 travels from the western edge of Beverly through Highlands to the Stadium LRT Station (where a transfer can be made to LRT) and on to the CBD. Routes #70 and #71 backtrack from the eastern boundary of Beverly northward through Hermitage to the Belvedere LRT Station, where riders transfer to LRT before continuing to the CBD.

It can be seen that, for all subjects north of 118 Avenue, either Route #18 or Route #20 provides the closest transit service, and the other one provides a reasonable alternative. Similarly, Routes #18 and #28 are the two reasonable alternatives for transit riders south of 118 Avenue. In all cases, Routes #20 and #28 also provide service on the reverse loop, but these routes are identical to the forward loop route and always have a greater travel time, so they are never included in the choice sets of alternatives.

The deepest penetration of Route #2 into the Beverly study area is at 118 Avenue and 50 Street. For subjects within a reasonable distance of this intersection, Route #2

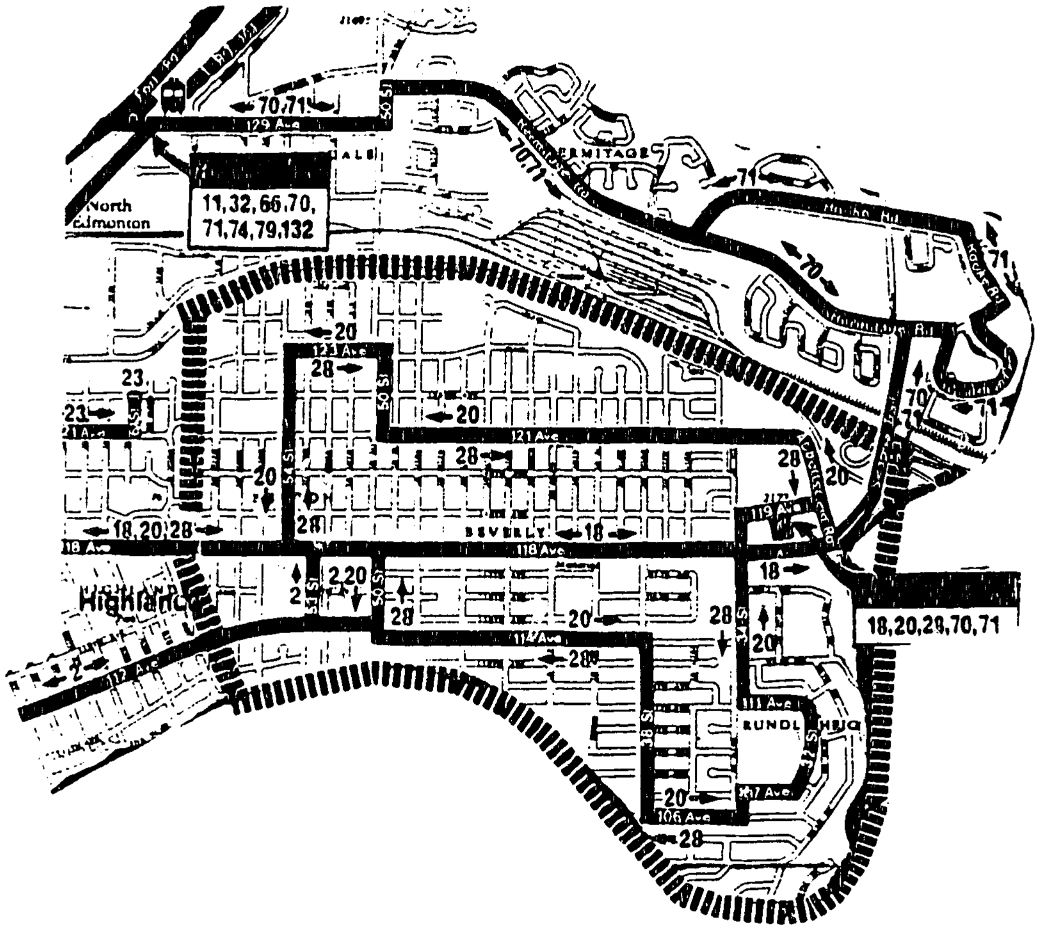

Figure 13 - Transit service in Beverly

was considered a transit alternative in the choice set. It should be noted that, although Route #2 provides the option of direct service to the CBD or a transfer to LRT at Stadium Station, the latter is unreasonable since it saves only two minutes travel time but requires a transfer and therefore an equivalent extra travel time cost of 11.4 minutes (refer to Table 4).

The deepest penetration of Routes #70 and #71 into the Beverly study area is Abbotsfield Transit Centre. Again, those subjects within a reasonable distance of this location were provided with these routes as an alternative. Because of their similarity, the two routes were combined as one alternative with a combined frequency of service and average travel time.

Capilano Study Area

Figure 14 shows the three transit routes which serve the Capilano study area. Routes #50 and #51 provide the primary transit service, and travel through the four sectors of the Capilano area before proceeding directly to the CBD. Route #93 provides secondary transit service, travelling along the south edge of the study area and proceeding northward to Coliseum Station where transit patrons can transfer to the LRT to complete the journey to the CBD.

Because of the well-defined natural boundaries of the Capilano study area and the fact that Routes #50 and #51 are the only routes which provide direct service, these two

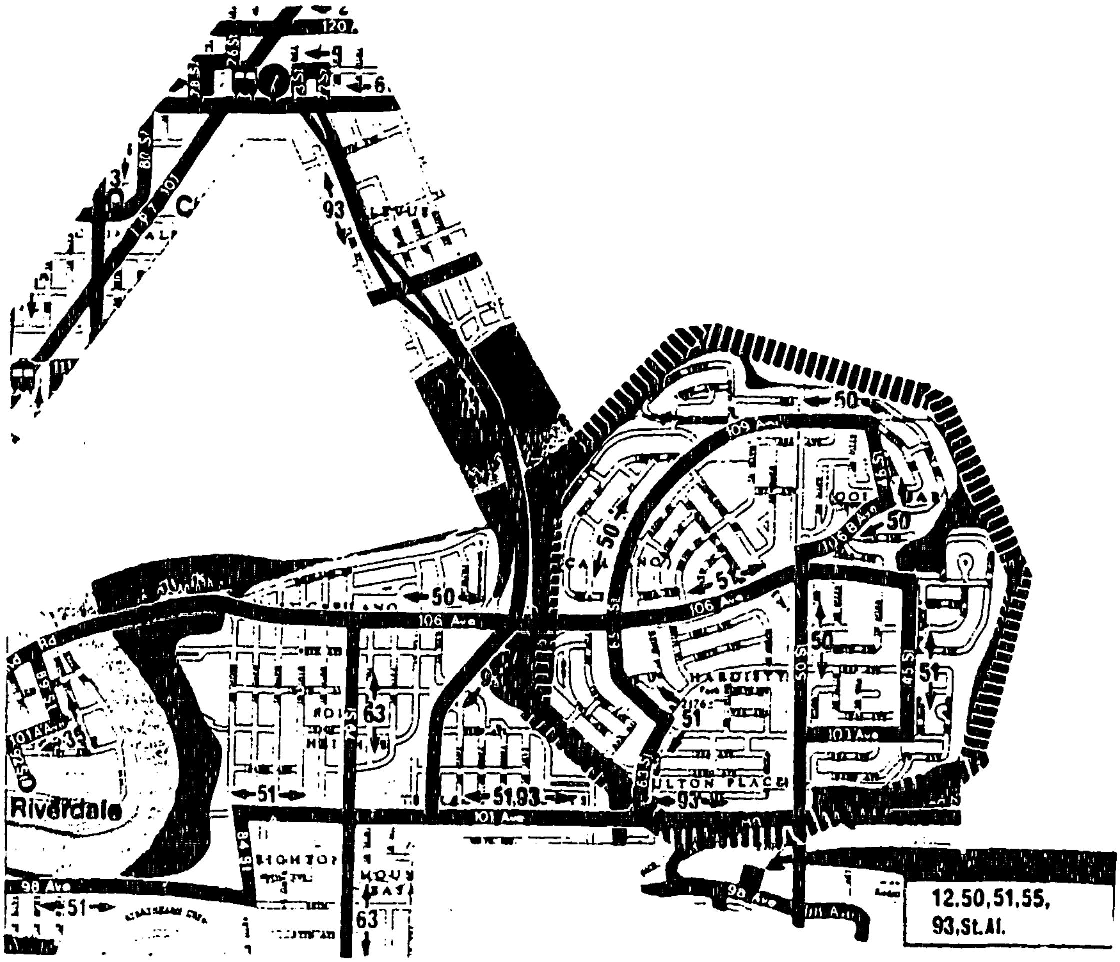

Figure 14 - Transit service in Capilano

routes are the only logical transit alternatives for the majority of the Capilano study area. Transit alternatives which require a transfer at Capilano Mall are redundant since Route #50 (which itself is already included as an alternative) has the fastest travel time from Capilano Mall to the CBD.

Toward the south end of the Capilano study area, the alternative of Route #93 to the Coliseum followed by Route #101 (LRT) to the CBD is a reasonable alternative by virtue of its proximity. Thus, it is included even though its long travel time renders it unlikely to be considered by a significant number of transit patrons.

Clareview Study Area

Figure 15 shows the four transit routes which serve the Clareview study area. Route #72 and #74 provide the primary transit service, travelling through Clareview toward the Clareview LRT Station, where transit riders transfer to the LRT to continue to the CBD. Routes #79 and #179 provide secondary transit service, travelling the reverse direction through Clareview to the Clareview LRT Station.

Clareview was the first study area for which choice sets were generated. Whereas the number of combinations of transit alternatives in the other study areas necessitated limitations on the selection of reasonable alternatives, all four transit routes were included in all choice sets in Clareview. Consequently, even though Routes #79 and #179

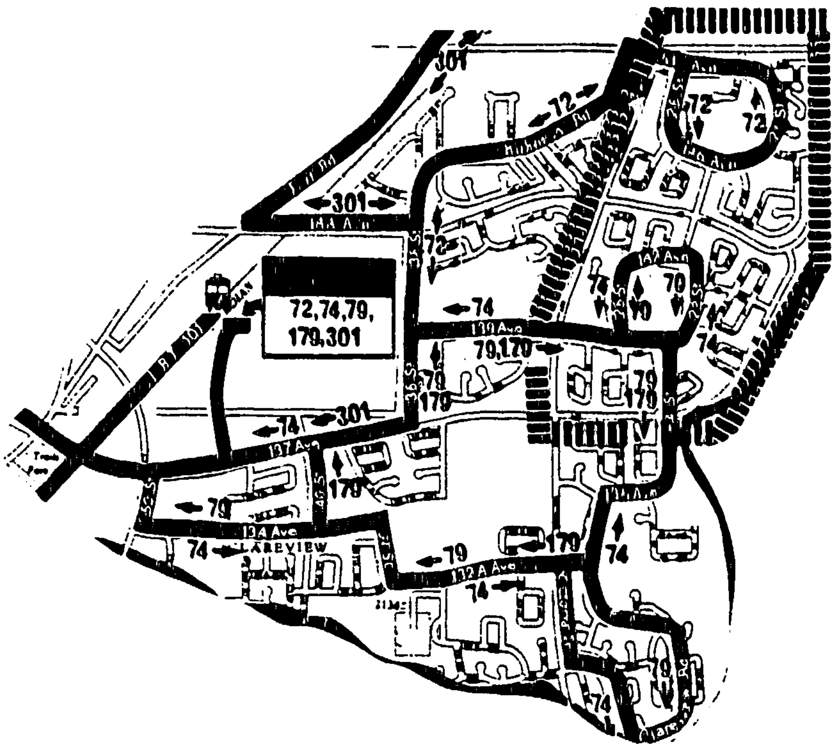

Figure 15 - Transit service in Clareview

travelled the reverse loop of Route #74, they were included as alternatives (whereas reverse loop routes were excluded from choice sets in the other two study areas).

This difference was not considered problematic since it was assumed that unreasonable alternatives are assigned insignificant choice probability by the TRAM model. A limited analysis of the results of some variations in the micro-level choice sets indicated that this assumption did not greatly affect the outcome of the model testing.

B. Method of Comparison

Two different methods are available for comparison of micro-level model predictions and survey observations. The first method is the prediction success method and the second method is the log-likelihood method. The prediction success method (also known as the "%-right" method) is simply a tabulation of the proportion of individuals whose observed choice alternative was correctly assigned the greatest choice probability by the model. The criterion of success is at the route level; in other words, although the actual stop choice and the representative stop used by the model may not be the same, success is achieved if both are representative of the particular transit route alternative.

A major disadvantage of the prediction success method is that it does not distinguish between widely different predictions such as a correct prediction which is assigned a probability of 51% and one which is assigned a probability of 99%. Ben-Akiva and Lerman state that "the insensitivity of the '%-right' statistic, in addition to its potential for completely misleading indications, argue against its use" (Ben-Akiva and Lerman, 1985, p. 92).

The log-likelihood method uses the ρ^2 measure previously explained in Chapter V. It is applied in the same manner, quantifying the degree to which the model-generated choice probabilities are superior to the naive proportional model for which all utility function coefficients are zero. Note that, since the TRAM model specification is constant, there is no need to use $\bar{\rho}^2$ to account for varying numbers of model attributes.

A computer program was written to compare the observed results and predicted results. The comparison program includes the summary statistics "ρ^2" and (for illustrative purposes) "%-correct".

C. Results

The results of the micro-level testing are presented in Table 5. "Equivalent" R^2 values from Figure 2 are provided as a reference. In all three study areas, the ρ^2 values are quite favourable. The %-right measure lends qualified support to this positive assessment.

	BEVERLY	CAPILANO	CLAREVIEW
Number of Observations	118	139	76
Rho-squared	0.474	0.631	0.715
"Equivalent" R-squared	0.87	0.99	1.00
% Correct	78%	85%	93%

Table 5 - Microscopic level testing results

D. Analysis

Overall, the results of the micro-level testing are encouraging. It appears that the modelling of individual transit alternative choice is successfully achieved by the calibrated model.

The ρ^2 results of Table 5 are in fact slightly conservative as a result of a minor difficulty in the application of the TRAM model. In some cases, although the predicted route was correct, the stop actually chosen by the transit user was not the same as the modelled representative stop nor an adjacent stop which could readily be accepted as equivalently representative of the route. This problem was addressed by re-running the model with the original representative stop replaced by the actual chosen stop. Therefore, the ρ^2 statistic was composed of the choice probabilities of several stops determined using modelling assumptions and the choice probability of one stop which evidently was selected (by a transit user) using different assumptions. This tended to decrease artificially and marginally the ρ^2 values.

In assessing the differences in the ρ^2 values for the three study areas, it was noted that there may be a relationship between improving model performance and decreasing surface area and/or population. However, identification and confirmation of such relationships is beyond the scope of this research.

IX. Macro-Level Testing (Procedure)

This chapter describes the procedure for testing the TRAM model at the macroscopic level. The testing procedure involved three steps: (a) prediction of the number of boardings at each transit stop using the TRAM model, (b) prediction of the number of boardings at each transit stop using a model based on catchment areas and trip generation, and (c) comparison of the results of the two predictions with the observed number of boardings at each stop.

Following the sections which describe the model predictions is a brief discussion of two aspects of the comparison of the predictions and observations.

A. TRAM Model Prediction

This section presents the procedure used to generate TRAM model predictions of the number of boardings at each stop along a transit route.

Recall from Chapter VI that AUs of city-block scale were selected for this research. The actual method for generating aggregation units from the raw data involved sorting all household addresses in each study area by postal code. Postal codes generally divide a city block into four sections corresponding to its sides. Examination of postal code maps supplied by Canada Post indicated that this method of grouping would be appropriate for the purposes of this research. A magnetic tape directory of all Alberta postal codes and associated address ranges was obtained (Canada

Post, 1985), and a computer program was prepared to group household addresses into aggregation units by postal code.

The population associated with each aggregation unit was determined from an extract of the 1983 Edmonton Civic Census (City of Edmonton, 1983). The census file indicated the number of persons residing at each household address in the three study areas. A computer program was prepared to combine the census information with the postal code information.

The effect of this procedure was that a group of individuals was simulated as originating from a single point within the aggregation unit. Transit alternatives were assigned to each aggregation unit as if each unit was one individual and in the same manner as described for the micro-level testing. The population of each unit was assumed to originate at the centroid of its postal code range.

The TRAM program requires a representative transit trip generation rate for each study area to combine with the population of each aggregation unit to yield the number of transit users in that AU. The source of the transit trip generation rate used in this research was the Edmonton Regional Travel Model (RTM). The RTM is a UTPS-based traditional four-step transport planning model which the City of Edmonton has maintained since 1981 to aid in forecasting travel patterns for the morning peak period. Every two to three years the RTM is recalibrated to reflect updated travel survey data and to ensure that the model predictions adequately match screenline counts (City of Edmonton, 1984). Each year the Regional Travel Model is fine-tuned to match current screenline counts (City of Edmonton, 1985).

The 1985 Regional Travel Model provides the population and the number of work and post-secondary education transit trips for any given traffic zone or district. The ratio of the number of transit trips to the population is defined as the transit trip generation rate. Generation rates were calculated at both the zone and district levels, and the results were virtually identical.

B. Catchment Area Prediction

The catchment-area (CA) model for prediction of the number of boardings at stops along a transit route was initially considered a simple model which is easily applied but whose results would possibly be inferior to those of a more complex model such as TRAM. Its purpose was to provide a basis against which to compare the performance of the TRAM model, and its use was necessary because adequate statistical techniques for comparison of discrete distributions are unavailable.

The catchment area of a transit stop is defined as the area within which all transit users are assumed to choose that stop. The determination of the catchment area boundaries was quite straightforward, based on considerations of the stop which typical transit users would choose, with the minimization of walking distance as the main criterion. Generally, boundaries parallel to and midway between adjacent transit routes determine which route is chosen; boundaries perpendicular to the route and midway between the stops determine which stop along the route is chosen. The catchment areas form a grid-like pattern which effectively minimizes the walking distance to the transit stop. For example, Figure 16 shows the system of catchment areas defined for this research in a portion of the Beverly study area.

Some catchment area boundaries vary from the grid-like pattern due to complexities such as crescents and ravines. In such instances, where circuitous walking patterns were likely, a more detailed examination was necessary to identify the logical boundary separating the catchments of adjacent stops. The determination of the boundary was based on the minimization of walking distance, and considered the most-probable route choice of individual aggregation units.

In instances where more than one transit route served a particular stop, a proportion of the catchment area population was assigned to each route on the basis of the travel times and service frequencies of the routes. This was done somewhat arbitrarily. For example, if two routes with similar travel times and frequencies serviced a stop, each route was assigned a fifty percent share. If one route had a significant advantage in terms of either attribute, it was assigned a greater proportion.

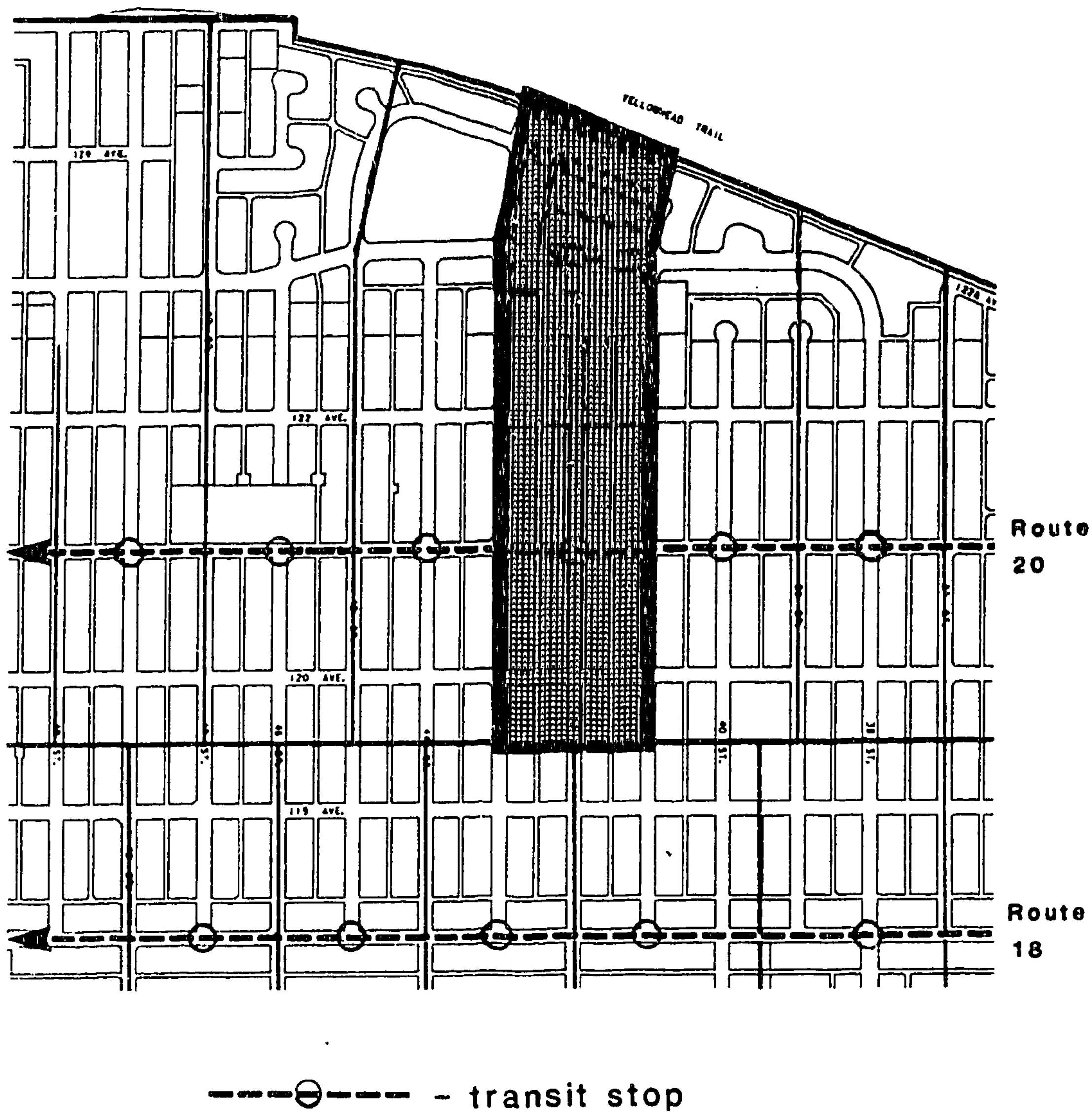

Figure 16 - Example catchment area in Beverly

It is acknowledged that a more accurate treatment of multiple-route stops could be developed. For instance, intuition suggests that the catchment area of a stop served by multiple routes would be larger than otherwise and would intrude upon the regular catchment areas of neighboring stops. However, it is uncertain how much larger it would be and what proportion of the population of the expanded area would find the trade-off between increased service frequency and walking distance attractive. Such considerations were ignored since the CA model was intended only to be a comparitive tool.

A catchment area was determined for each stop along the transit routes in the study areas. The resulting system of catchment areas associated all population within the study areas with a particular transit stop. The population of each catchment area was multiplied by a transit trip generation rate, yielding a prediction of the number of boardings at each stop.

In order to ensure that the catchment area predictions would be useful for purposes of comparison, the transit trip generation rate for each study area was chosen such that the predicted and observed numbers of passengers boarding routes within the entire study area were equal. This trip generation rate was not constrained to be the same as that for the TRAM program usage.

C. Method of Comparison

The method used to compare the predictions and observations of stop-by-stop transit boardings is outlined as the results are presented in the next chapter. However, two features of the method require additional explanation. These are (a) the selection of a comparitive statistical measure and (b) the application of moving averages.

Comparative Statistical Measures

The basic results of the macro-level testing consist of two model predictions and one survey observation of the number of boardings at each stop along a transit route. It is most effective to present these results in graphical form, with the three series of data points connected by lines to produce three separate "distributions" on an ordinal scale.[9]

The evaluation of graphical results is inherently qualitative. In order to maintain objectivity, there is a need to apply a quantitative measure of the degree to which distributions are similar. The determination of a comparative statistical measure appropriate for such a purpose has been addressed by others (Oxlad, 1978; Gipps, 1984), but no particular method has found widespread acceptance.

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[9]The paired t-test cannot be used to treat the data points as successive independent events; this is because a relationship between successive stops exists in that individuals who choose a particular stop by definition do not choose either adjacent stop.

Initially, it was desired that the method quantify the statistical significance of the similarity of the distributions. Oxlad (1978) suggests that the standard Kolmogorov-Smirnov two-sample test would be appropriate and would provide such an indication. However, this method, which is based on the maximum absolute difference between two cumulative distributions, was rejected in this case because of the insufficient number of data points in the subject distributions.

An alternative method which is capable of identifying the statistical significance between distributions is the standard chi-squared (χ^2) measure, which is defined as follows:

$$\chi^2 = \sum_{i=1}^{N} \frac{(O_i - P_i)^2}{P_i}$$

where:

O_i = Observed number of boardings at stop i,

P_i = Predicted number of boardings at stop i, and

N = Number of stops.

However, the chi-squared statistic is used only to test the null hypothesis that there is no difference between two distributions. As noted by Gipps, "when applied in the transport context, the χ^2 test often leads to the rejection of models that (on a subjective basis) appear to fit the data very well" (Gipps, 1984, p. 71). He suggests that, since travel behaviour is so complex, a researcher does not expect a model to match observed behaviour perfectly.

In fact, when the chi-squared measure was calculated for the research distributions, this problem indeed arose. Despite the reasonably good appearance of the distributions, the χ^2 statistic indicated that in all cases there was a large probability that the differences in the distributions could not be attributed to chance alone. That is, the differences were likely caused by "poor" model fit. Although technically correct, this particular information was of little use.

It was felt, however, that the chi-squared measure might be valuable in quantifying the relative performance of the two models. In fact, it was for this purpose that the catchment-area model was used, in order to provide a basis of comparison. It was expected that the TRAM model would exhibit a lower χ^2 when the two models were compared to the observed distribution.

However, it was noted that the predicted value in the denominator of χ^2 is different for each of the two models. Thus, a particular difference $(O_i - P_i)$ contributes more to the chi-squared statistic if the predicted value P_i is less than the observed value O_i than if the reverse is true. This leads to the illogical conclusion that a model over-prediction is intrinsically superior to an under-prediction. Furthermore, if one model under-predicts by, say, twice the amount the other model under-predicts, the effect on the chi-squared statistic is more than doubled since (a) the difference between the two predictions is squared and (b) the numerator is divided by a lesser number.

A modification was made to address some of the problems associated with the standard chi-squared statistic, resulting in a "pseudo-chi-squared" ($p\text{-}\chi^2$) statistic, defined as follows:

$$p\text{-}\chi^2 = \sum_{i=1}^{N} \frac{(O_i - P_i)^2}{O_i}$$

where the symbols are defined as previously described.

In this case, the comparison between the two models is more equitable since the numerator is divided by the same value for each model. However, a serious problem exists when the statistic is applied to cases where the observed values are small, as illustrated in Table 6. Given that there were two stops in the research survey at which zero boardings were recorded, it is unacceptable to use a statistical measure which is so greatly affected by low values of O_i.

Another candidate measure was the standard root-mean-squared (RMS) statistic, defined as follows:

$$RMS = \sqrt{[\sum_{i=1}^{N} (O_i - P_i)^2] / N}$$

where the symbols are defined as previously described.

The RMS statistic does not exhibit the problems of the chi-squared measures since the denominator is the same for each model and is generally of reasonable magnitude (i.e. somewhat greater than two). The RMS value is intuitively attractive since it attempts to represent the "typical"

OBSERVED VALUE O(i)	EFFECT ON TERM IN p-CHI-SQUARED
2	HALVED
1	UNCHANGED
0.5	DOUBLED
0	INFINITY

Table 6 - Effect of small observed values on p-Chi-squared

difference between observations and predictions over the entire series of stops.

However, a disadvantage of the RMS value is that pairs of data which differ by more than unity are weighted much more heavily than those which differ by unity or less. While this is not intuitively unacceptable, in the context of this research there is no valid reason that a difference $(O_i - P_i)$ of two or three boardings should be weighted four or nine times as heavily as a difference of one boarding.

The statistic which was developed and selected for this research was a variation of RMS, labelled the "average absolute difference" ($\bar{\Delta}$), and defined as follows:

$$\bar{\Delta} = [\sum_{i=1}^{N} |(O_i - P_i)|] / N$$

where the symbols are defined as previously described.

The $\bar{\Delta}$ statistic uses absolute values to ensure that the difference $(O_i - P_i)$, whether positive or negative, contributes to the statistic rather than simply cancelling the effect of another difference of opposite sign.

The $\bar{\Delta}$ value also approximates the average difference between the number of boardings observed and predicted at each stop. The major advantage of the statistic is its simplicity. It has none of the disadvantages of the other statistics considered.

Both RMS and $\bar{\Delta}$ quantify the differences between the boarding distributions in a convenient way. Neither measure has any properties which indicate the statistical significance of the similarity of the distributions. There were significant variations in the values of the two statistics for the research distributions because of the extra emphasis which the RMS measure places on large deviations. In some cases, the two statistics gave conflicting results regarding which predicted distribution was better, because of the exaggerated treatment of large discrepancies by RMS. However, for completeness both statistical measures are included in the presentation of the macro-level results.

Moving Averages

Figure 17 provides an example of a common situation in the TRAM coding whereby, for a given transit route, the "closest" transit stop is not unique. This stop-allocation coding dilemma is relevant in all study areas, whether the street structure is grid-like or crescent-like. Assumptions were required to determine the appropriate transit stop, and it is apparent that such assumptions might lead to a misallocation of transit patrons between adjacent stops. By taking the moving average of the predicted boardings at three adjacent transit stops, the impact of these potential errors could be reduced.

Comparisons of predicted and observed distributions were first made directly with the raw data. Moving averages were then applied in two stages to smooth the data. First, a moving average was applied to the stop-by-stop predictions (of both models) in order to smooth potential errors due to

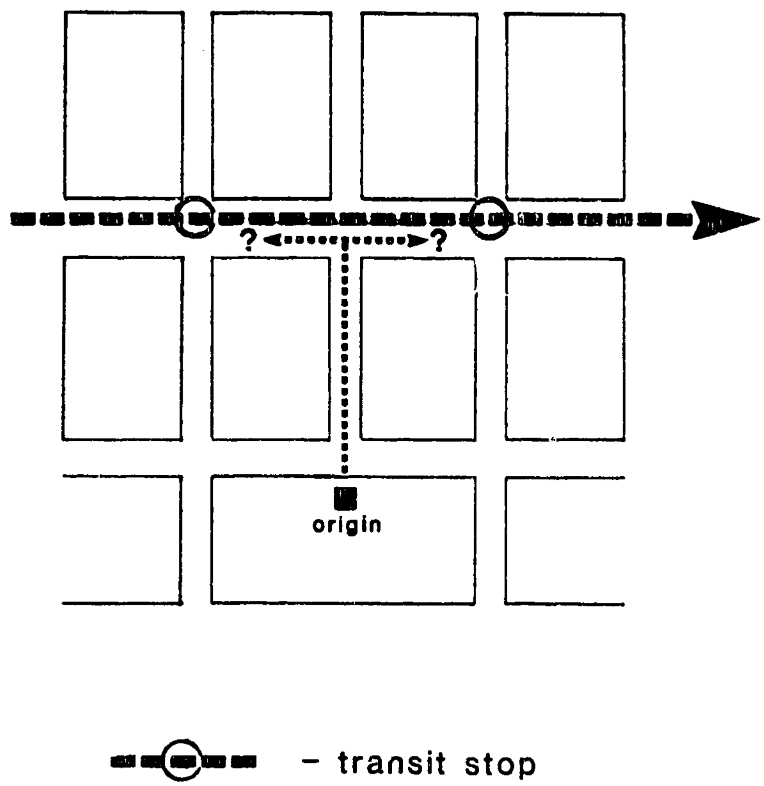

Figure 17 - TRAM coding dilemma

the method used (for the TRAM program) to code adjacent transit stops. This is also consistent with practical use of the model since, if it yields superior results, it is a process which could be easily incorporated to the TRAM program.

Second, the moving average of the survey observations was compared to the moving averages of the model predictions. It is acknowledged that it is impractical to compare moving-averaged survey observations because even if the procedure produced identical results it would require that a practical user somehow "work backwards" to determine non-averaged stop-by-stop boardings. However, the comparison was helpful in examining the overall trends of the predicted and observed distributions; this, in turn, provided an indication of how well the models depict the human behaviour underlying transit route/stop choice.

X. Macro-Level Testing (Results)

This chapter presents the results of testing TRAM at the macroscopic level. The following three aspects of the research observations and predictions are examined for each study area: (a) the total number of transit boardings produced in the study area, (b) the proportion of the total number of boardings attributed to each transit route serving the study area, and (c) the stop-by-stop distribution of boardings on each transit route serving the study area.

The first aspect of comparison is between the number of transit boardings expected from the Regional Travel Model generation rate and the number observed in the research survey. The catchment area predictions are not involved in this comparison.

The second aspect of comparison is the proportioning of the total number of boardings among the transit routes serving each study area. This comparison allows an overall assessment of the model performances with respect to the attraction of alternative routes.

The third aspect of comparison is a detailed examination of the distribution of the number of boardings at each stop along the transit routes. In addition to comparisons of the raw predictions, moving averages are used to smooth the distributions. Qualitative assessments are made of the similarities and differences in the trends of the curves, including cross-comparisons of the performance of catchment-area predictions and TRAM predictions.

Quantitative evaluation of the performance of the predictions is accomplished using two statistical measures of goodness of fit.

Details of these comparisons for the three study areas are provided in the following sections.

A. Transit Trip Generation Predictions

At the current stage of the development of TRAM, the transit trip generation rate is used as a scalar factor to determine the number of transit trips generated by each aggregation unit. The transit trip generation rate is limited to work trips by transit to the downtown in the morning peak period.

Transit trip generation is a multiplicative combination of trip generation and mode split. Therefore, the transit trip generation rate is affected by the factors which influence trip generation (e.g. employment levels, population age distributions, individual incomes) and mode split (e.g. transit captivity, convenience of transit, individual incomes). Although both the propensity to travel and the likelihood of choosing to use transit vary across individuals and households, average values are generally applied at the level of traffic zones or districts. The determination of trip generation and mode split is a discipline in itself, the advancement of which is not an objective of this research.

The initial runs of the TRAM model used transit trip generation rates derived from the Regional Travel Model. To ensure that the other two comparisons would be meaningful, in each case a second run of the TRAM program was executed with a transit trip generation rate adjusted such that the predicted total for the study area matched the observed total. Table 7 shows the proportion of the initial and adjusted transit trip generation rates for the three study areas. In all three instances, the observed generation of transit trips was considerably less than that anticipated on the basis of the RTM, the proportions ranging from 24% to 31%.

The remainder of this section discusses factors relating to the survey observations and the Regional Travel Model which may have contributed to the significant discrepancy revealed by the comparison. Each of the factors tends either to decrease the number of boardings observed in the research survey or increase the number predicted by the RTM generation rate, and contributes to the observed discrepancy.

Data from continuous automatic traffic counters (City of Edmonton, 1988b) indicate that morning peak CBD traffic volumes in August are approximately ten percent less than the annual average. It is reasonable to assume a similar pattern in transit ridership. This would tend to depress the number of transit boardings observed in the TRAM Validation Survey, which took place in the month of August.

	BEVERLY	CAPILANO	CLAREVIEW
Population	17 700	9 400	5 400
(A) TTGR, based on Edmonton RTM (trips/person/2h)	0.040	0.054	0.096
(B) TTGR, based on survey totals (trips/person/2h)	0.012	0.017	0.023
Proportion (B)/(A) * 100%	30%	31%	24%

Note: TTGR = transit trip generation rate

Table 7 - Comparison of transit trip generation rates

"Secondary" transit routes in the study areas were not surveyed because it was assumed that the number of boardings on those routes would be negligible. If the number of such boardings was in fact significant, it would contribute to an under-estimation of the number of transit trips generated. Based on TRAM predictions, it is believed that this factor would be most significant in the Clareview study area, moderately so in the Beverly study area, and marginally so in the Capilano study area.

Of the passengers who boarded the surveyed transit routes, 95% were successfully interviewed. However, a proportion of the remaining five percent would presumably have been travelling to work in the CBD. This factor would have artificially decreased the observed number of transit boardings by approximately three percent.

The TRAM survey and predictions were based on a two-hour morning peak period. The RTM is based on one hour which would represent the peak hour of the peak period, as opposed to simply one-half of a uniform peak period. Therefore, the factor of two used to "convert" the RTM trip rate for use with TRAM would lead to artificially high boarding expectations.

The RTM is calibrated by adjusting trip generation, trip distribution, mode split, and trip assignment to obtain modelled flows across major screenlines that are within ten percent of observed flows. As such, the products of the RTM are at a significantly coarser level than individual neighborhoods and transit routes. For example, the final calibrated RTM yielded flows across the CBD screenline which were 3.7% greater than the observed flows (City of Edmonton, 1985). The transit mode split values used to generate the transit flows were themselves rounded to the nearest five percent. Discussions with Transportation Department staff indicated that "hidden" within the LRT ridership screenline counts is an over-prediction of trips from Clareview and under-prediction of trips from neighboring Londonderry. These factors would all contribute to the discrepancies in the results of Table 7.

As noted previously, the RTM undergoes an annual process of updating and revision in an effort to improve the similarity of observed and predicted flows. Comparison of the 1985 revalidated trip tables to those of subsequent years shows that the total trip generation in Clareview has been adjusted downward since 1985. This would suggest that the 1985 values, which were used for this research, were excessive.

Although the discrepancies in the trip generation rates are considerable, it is emphasized that the selection of a transit trip generation rate is merely a scalar factor which can be adjusted as required to match observed flows. It does not affect the calculations involved with the determination of utilities, choice-probabilities, or composite utilities.

B. Route Proportion Predictions

This aspect of comparison provides an overall assessment of the performance of the TRAM model and the catchment area model relative to the survey observations. It provides an indication of whether or not the models successfully apportioned the appropriate level of boardings to each of the surveyed routes.

Recall from Chapter VIII that each of the study areas was serviced by one or more secondary transit routes which were considered much less important than the routes which were surveyed. Although the existence of the secondary routes was easily facilitated in the TRAM modelling, the CA model predictions were based on arbitrary estimates of the probable usage of the additional routes. The actual number of boardings on these routes was not recorded, so that validation of the predictions of either model in this regard is not possible. It is important to note that the total number of boardings upon which the following proportions are based does not include the secondary routes, so that their influence is not accounted for in the comparison. Since there is an unknown factor involved, the level of detail of this comparison is limited.

Figure 18 presents a bar graph of the proportions of total transit boardings associated with each primary transit route in the Beverly study area, for the survey observations and both models.[10] The graph indicates that the model

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[10]Note that the total number of boardings is slightly different in each case because of rounding of the trip

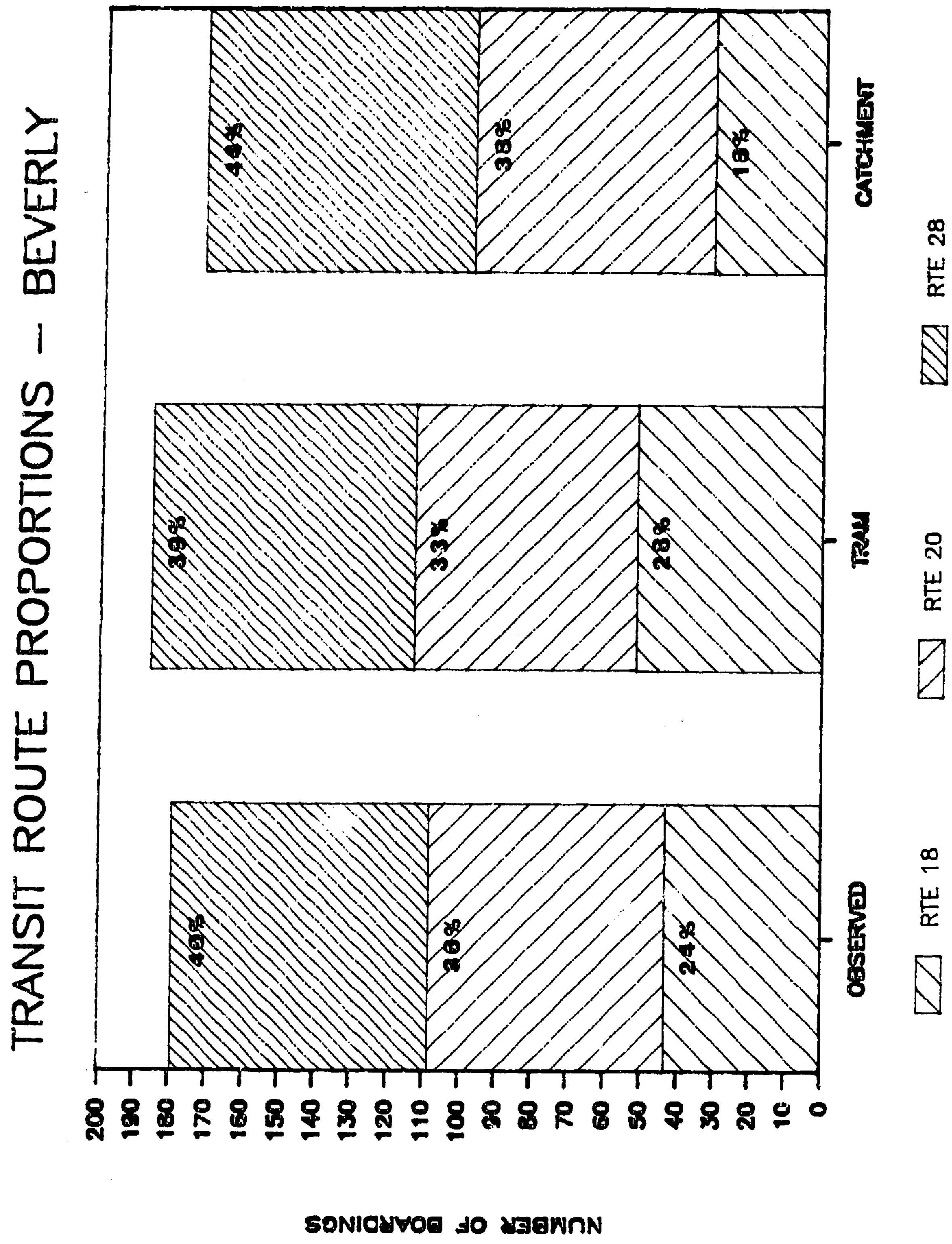

Figure 18 — Transit route proportions in Beverly

predictions are within the same range as the survey observations. However, the second bar shows that the TRAM model slightly over-predicts the proportion of boardings attributed to Route #18 and under-predicts the proportions attributed to Routes #20 and #28. The third bar shows that the catchment-area model under-predicts the Route #18 proportion and over-predicts the Route #20 and #28 proportions.

Recalling the structure of the transit routes in the Beverly study area (see Figure 19), it is noted that Route #18 provides direct, straight-line service from Abbotsfield Transit Centre to the Coliseum L.R.T. Station at a ten-minute frequency. Routes #20 and #28 are similar (and distinctly different from Route #18) in that they deviate from 118 Avenue, looping through North and South Beverly, respectively, at a twelve-minute frequency. Route #18 has a distinct travel-time advantage east of the region where the routes begin to converge (approximately 50 Street).

As an example of the influence of this transit route structure, consider transit patrons situated near Point "A" in Figure 19. It is intuitive that some of these transit patrons may choose Route #18 instead of Route #20, even though it is slightly further away, because its relative advantages of travel time and frequency offset the extra walking distance.

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[10](cont'd) generation rates.

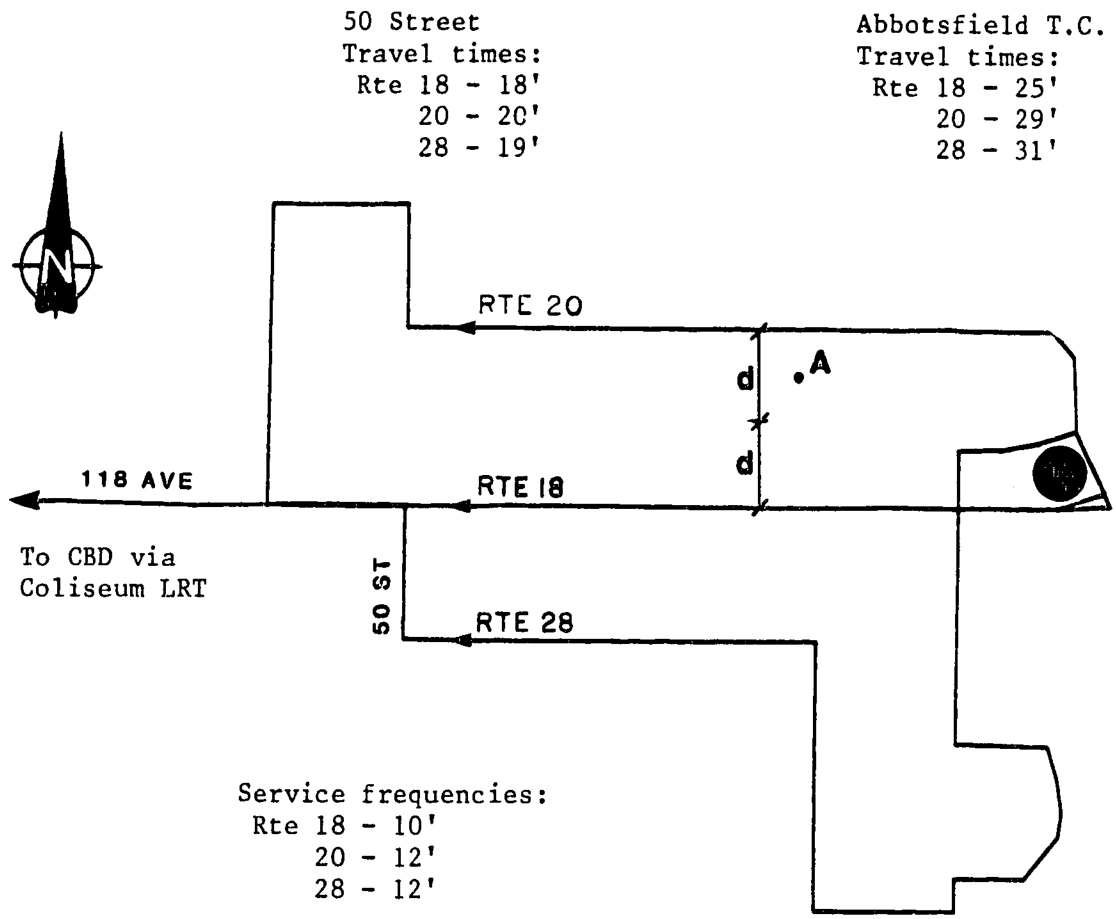

Figure 19 - Service frequencies & travel times
to CBD from Beverly

Figure 18 indicates that the TRAM model provides a better representation of the interaction of the routes since it accounts for differences in travel time and service frequency, whereas the CA model does not. In terms of catchment-area, it appears that the true catchment-area of Route #18 is larger than that which results from the criterion of walking distance minimization used by the CA model, and that the TRAM model effectively expands the catchment-area of Route #18. (In fact, the proportion is a bit too large, which suggests there may be error present in the TRAM model calibration.)

Figures 20 and 21 present bar graphs of route proportions for the Capilano and Clareview study areas, respectively. In both cases, the proportions of both model predictions are similar to those of the survey observations.

Recalling the structure of the transit routes in the Capilano and Clareview study areas, it is noted that the structure is quite different from that of the Beverly study area. Whereas the transit routes in Beverly run parallel to one another and effectively compete for patronage, the transit routes in Capilano and Clareview have a more obvious "area of influence" and do not exhibit the same tendency to compete for ridership.

As shown in Figure 22, the Capilano study area is broken into quadrants by two arterial roads: 50 Street and 106 Avenue. Either Route #50 or #51 (but only one of them) services each quadrant directly. Otherwise, the routes

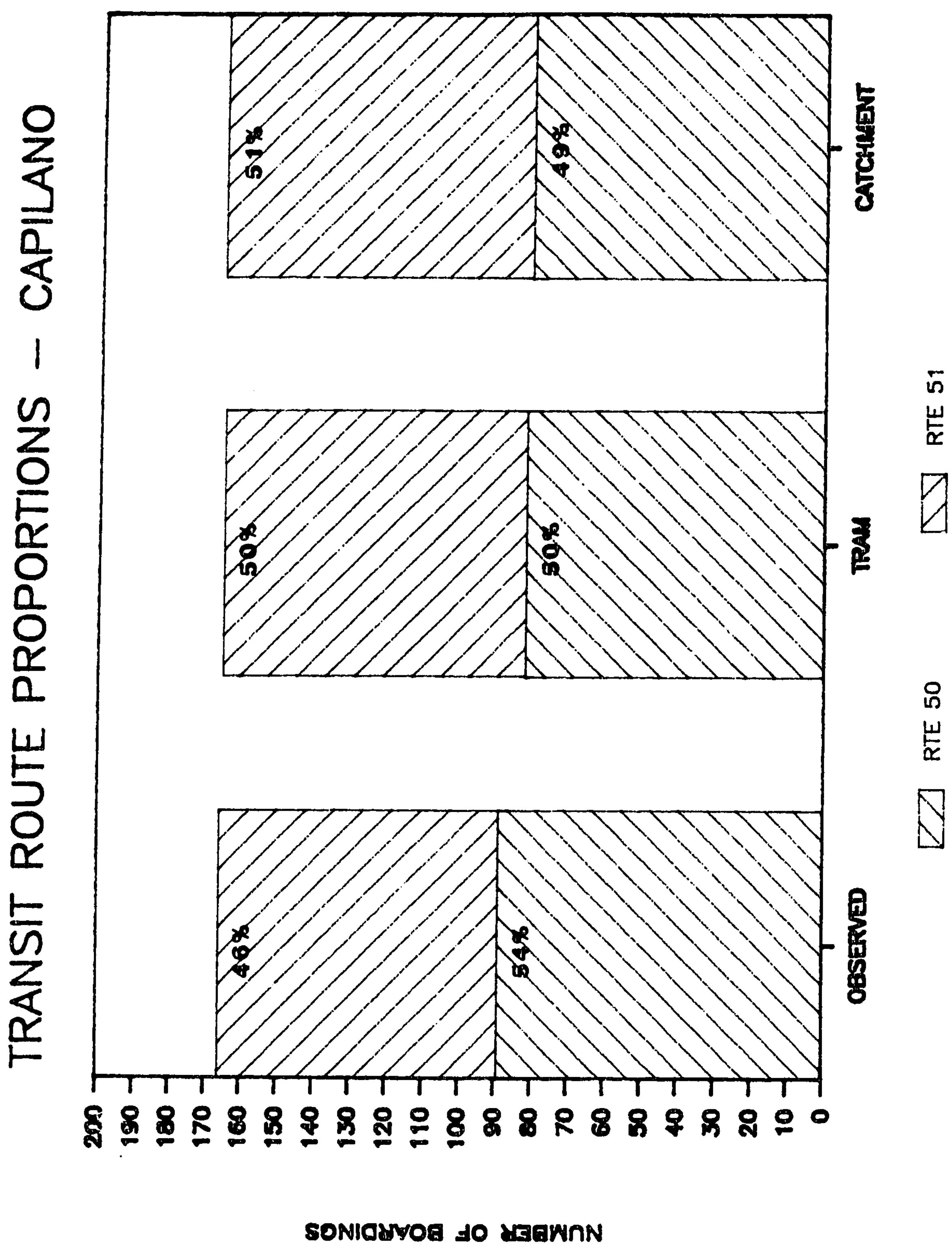

Figure 20 - Transit route proportions in Capilano

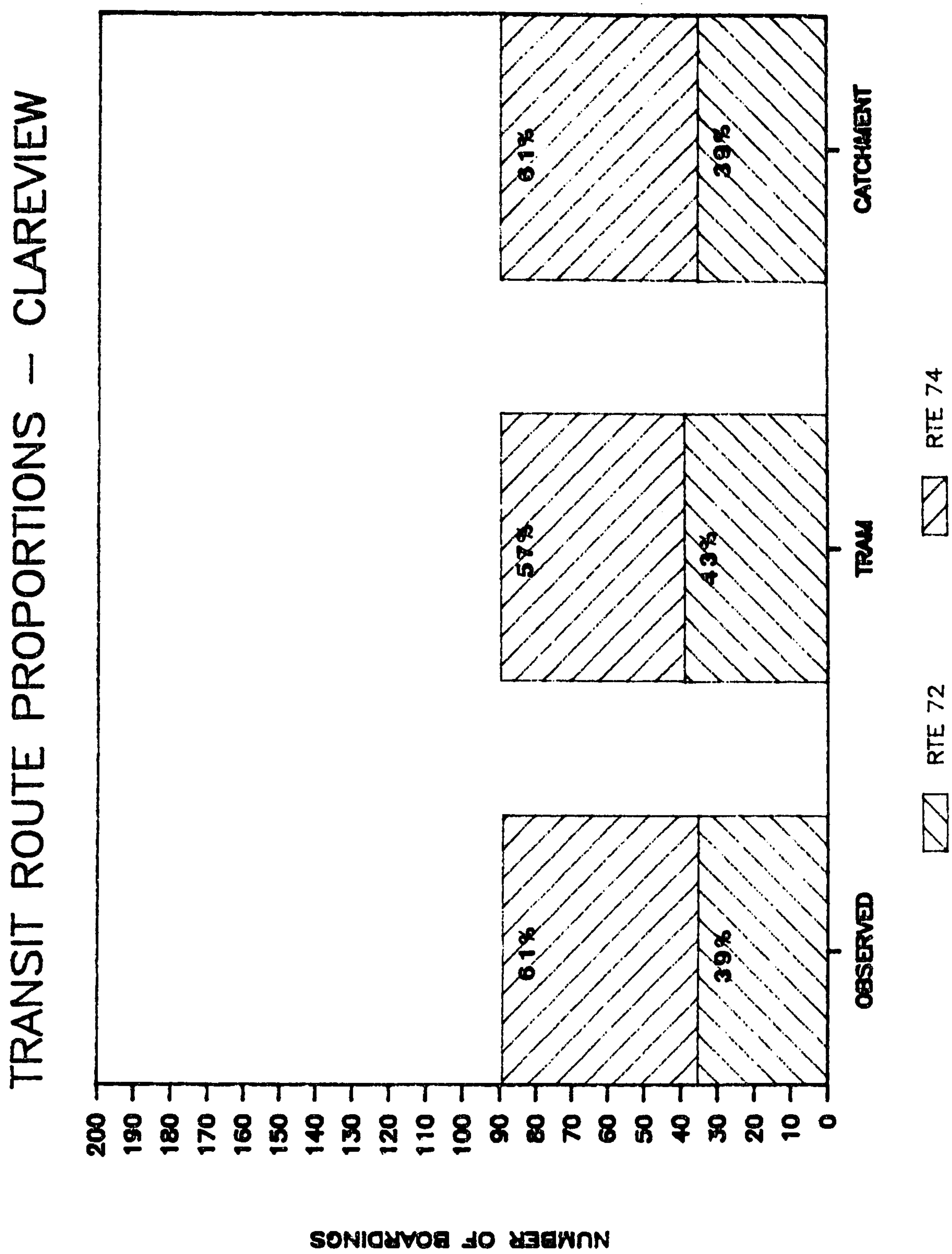

Figure 21 - Transit route proportions in Clareview

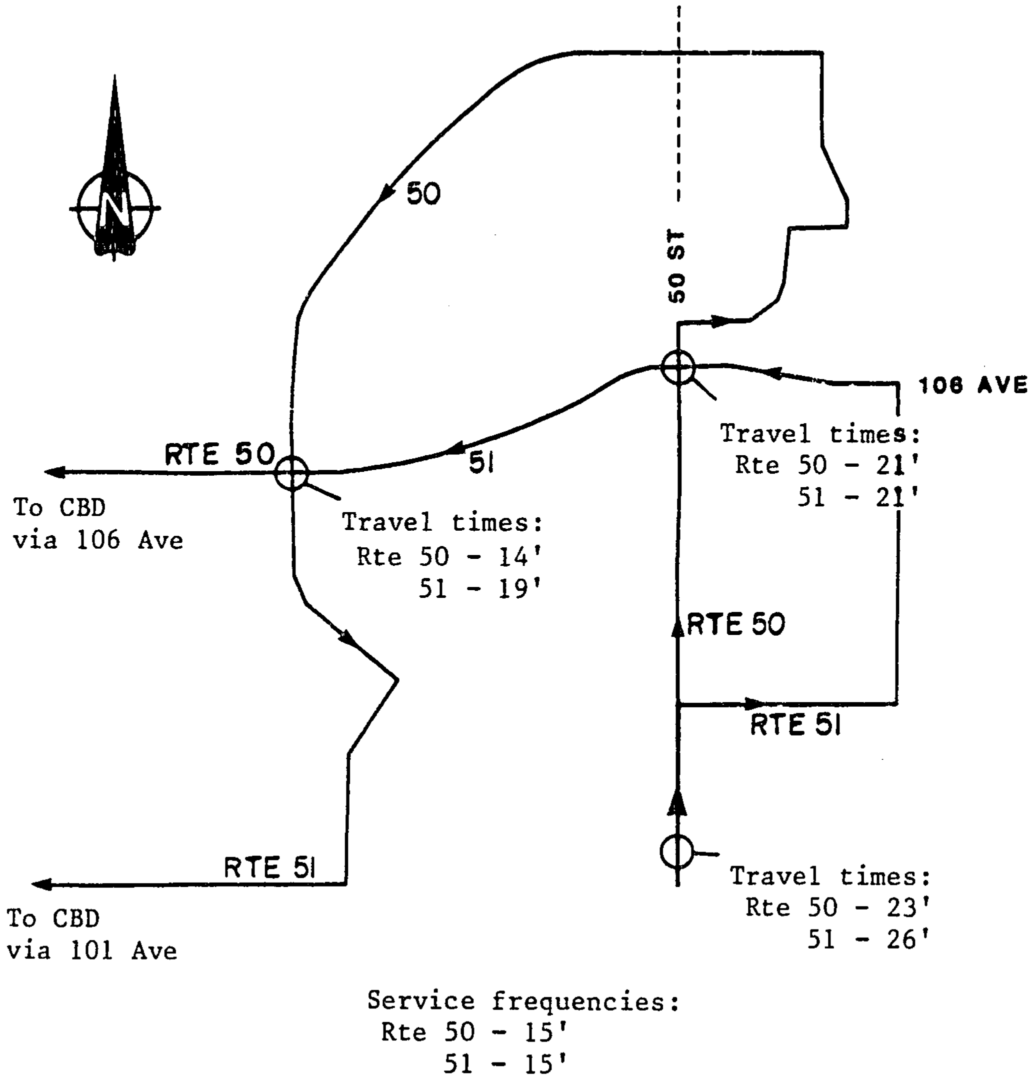

Figure 22 - Service frequencies & travel times to CBD from Capilano

remain on the arterials, travelling the shortest path to begin serving a quadrant. Since the two routes are similar in terms of travel time and service frequency, the closest route is generally the obvious "best" choice. The lack of variability in factors other than walking distance yields model predictions which are nearly identical.

Figure 23 shows that the Clareview study area is bisected into a north half and a south half by an arterial road (144 Avenue). Route #72 is the only transit route which provides direct service in the north half of the study area. Route #74 is one of three routes serving the south half, all of which travel on a large loop through the surrounding region. However, Route #74 is superior to the others in terms of travel time because the study area is located near the end of its loop and it is at the beginning of the loops for the other routes. Thus, in both halves of the Clareview study area, there is effectively only one obvious "best" transit alternative.

To summarize the situation for Capilano and Clareview, since there is little competition among the routes in either study area, it is generally quite obvious which route is chosen by a particular individual or aggregation unit. Therefore, it is not surprising that both models do a good job of proportioning boardings among the routes and that the catchment-area model performs at least as well as the TRAM model.

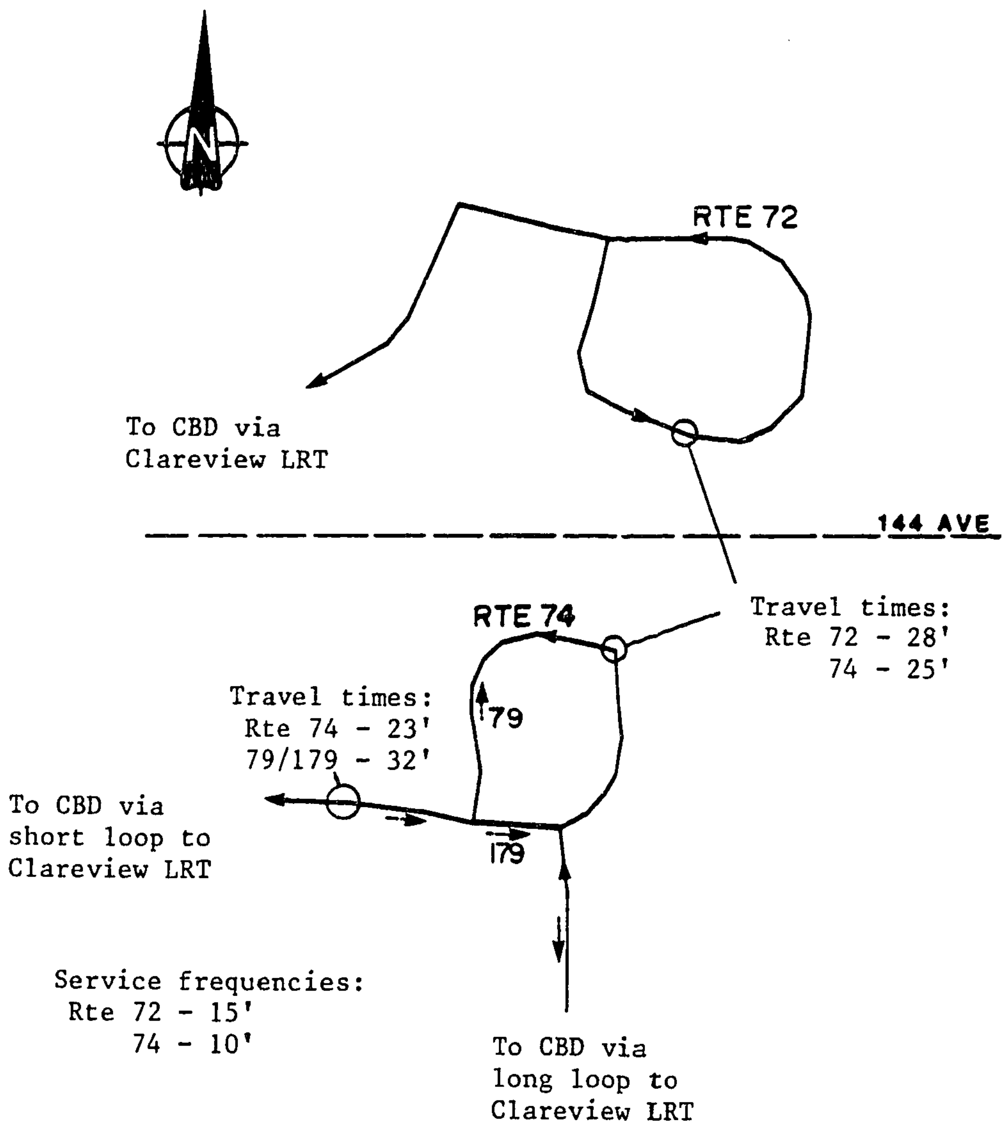

Figure 23 - Service frequencies & travel times
to CBD from Clareview

C. Stop-By-Stop Transit Boardings

This section compares the number of transit boardings observed in the survey to the numbers predicted by the two models on a stop-by-stop basis along the transit routes in the study areas. Figure 24 depicts the hierarchy of the organization of the results as described in the three subsequent sections. This research was carried out in three study areas, encompassing a total of seven transit routes. For each route there are three graphs, each of which depicts three distributions (survey observations, TRAM predictions, and CA predictions). The first graph, labelled "(a)", presents raw observations versus raw predictions; the second graph, labelled "(b)", presents raw observations versus moving-averaged predictions; the third graph, labelled "(c)", presents moving-averaged observations versus moving-averaged predictions. In the following sections, these graphs are referred to as "raw", "partially-smoothed", and "fully-smoothed", respectively. Furthermore, each graph shows the root-mean-squared (RMS) value and the average absolute difference ($\bar{\Delta}$) value for the differences between each model and the survey observations.

It is noted that to allow the most objective assessment all of the graphs would be of the same scale, even if they were hard to read and interpret as a result. However, the graphs are included to allow visual evaluation, whereas the purpose of the statistical measures is to provide an objective perspective. Therefore, the graphs are presented

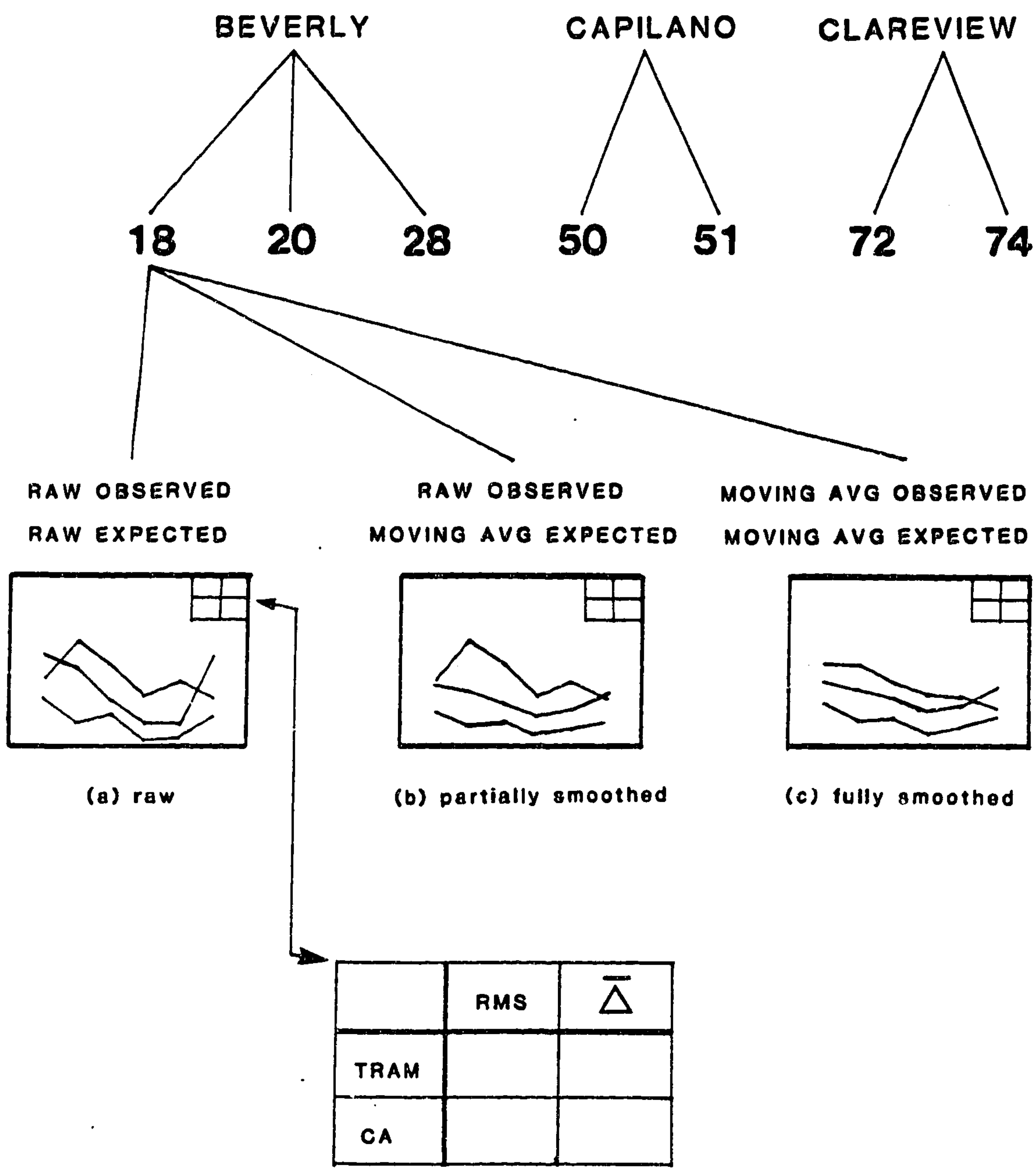

Figure 24 - Organization of stop-by-stop results

at scales which are convenient and easily viewed.

In fact, all the graphs are of acceptable appearance when presented on a vertical scale with a maximum value of 20 boardings. With respect to the horizontal axis, the graphs are presented with the number of stops varying from 7 to 22 along a constant distance of approximately 18cm.[11] Fortunately, most of the variation in "number of stops per route" is among study areas, and the routes within each study area are similar. In each case, the stops are shown on the graphs as if they were spaced equally and linearly even though neither is true in reality. These factors should be kept in mind when comparing results from one study area to another.

Beverly Study Area

Figures 25(a) to 25(c) present the raw, partially-smoothed, and fully-smoothed results for Route #18 in the Beverly study area. Similarly, Figures 26(a-c) and 27(a-c) present the results for Routes #20 and #28, respectively.

<u>Route #18</u>

The results shown in Figures 25(a-c) do not represent the most favourable performance of either the TRAM model or the CA model. The raw results (Figure 25-a) show that neither model is very similar in shape to the observed

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[11]Stop numbers commence at the furthest point from the CBD and increase as the route travels toward the CBD.

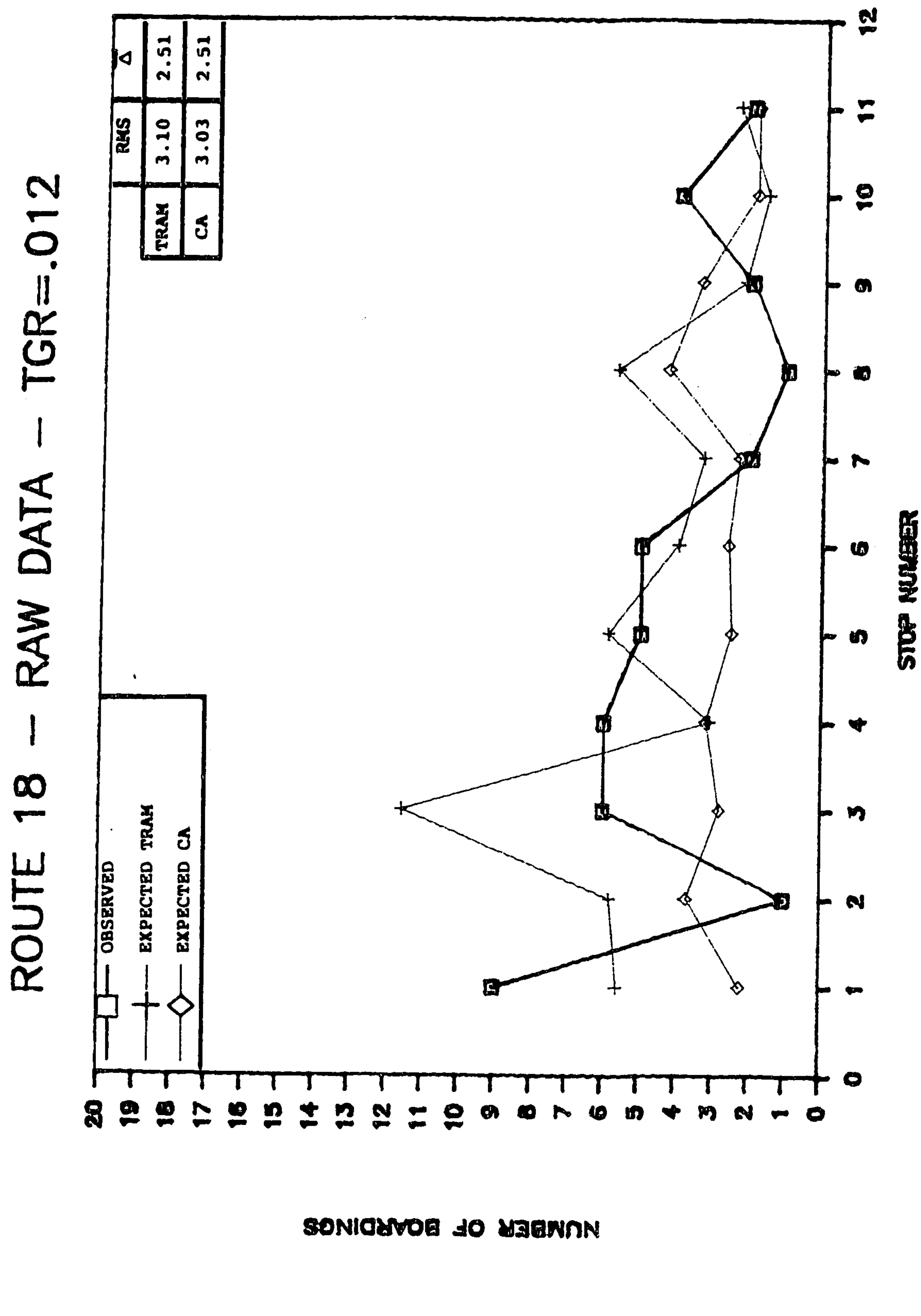


Figure 25(a) - Route 18 raw results

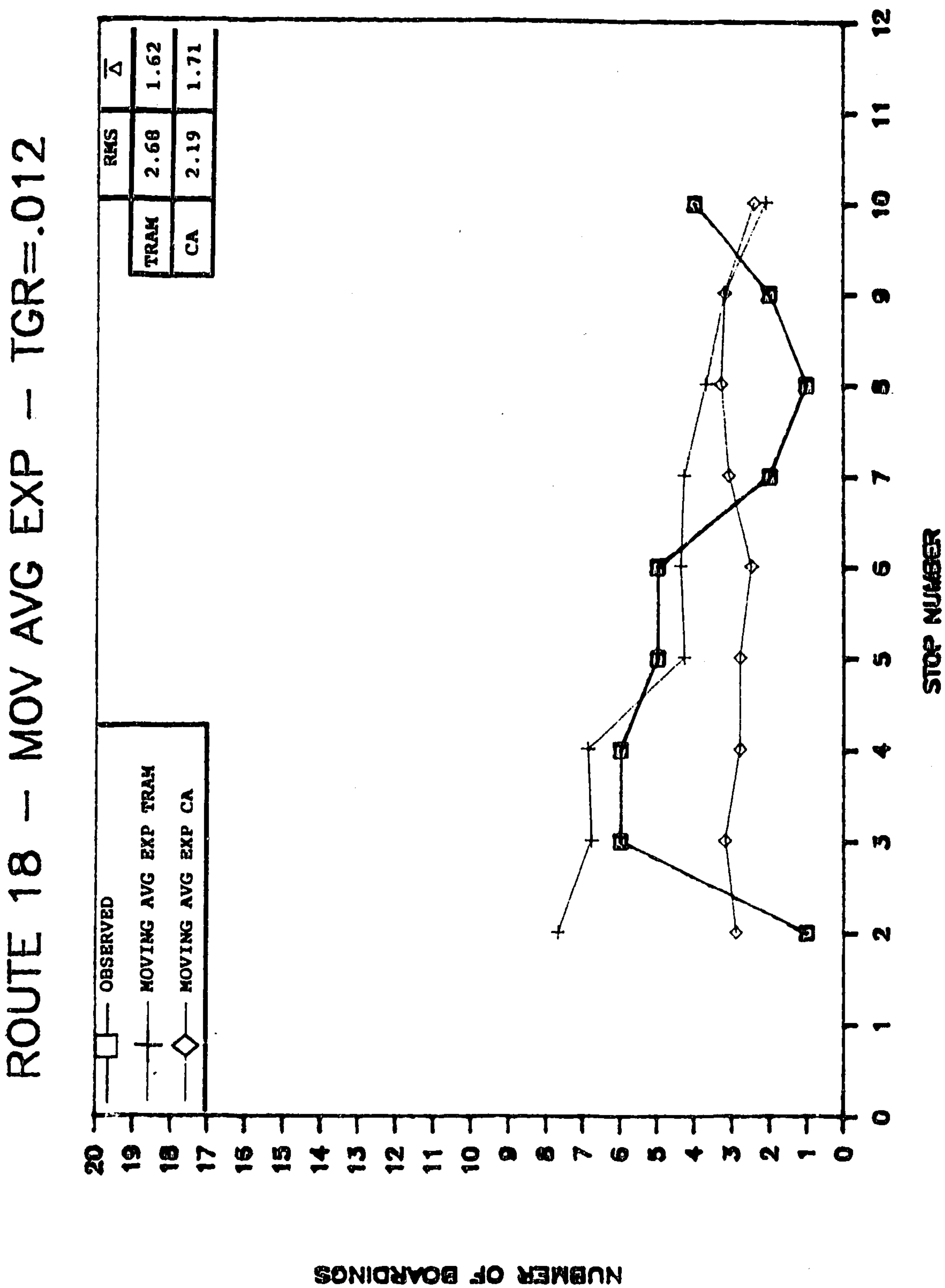


Figure 25(b) - Route 18 partially smoothed results

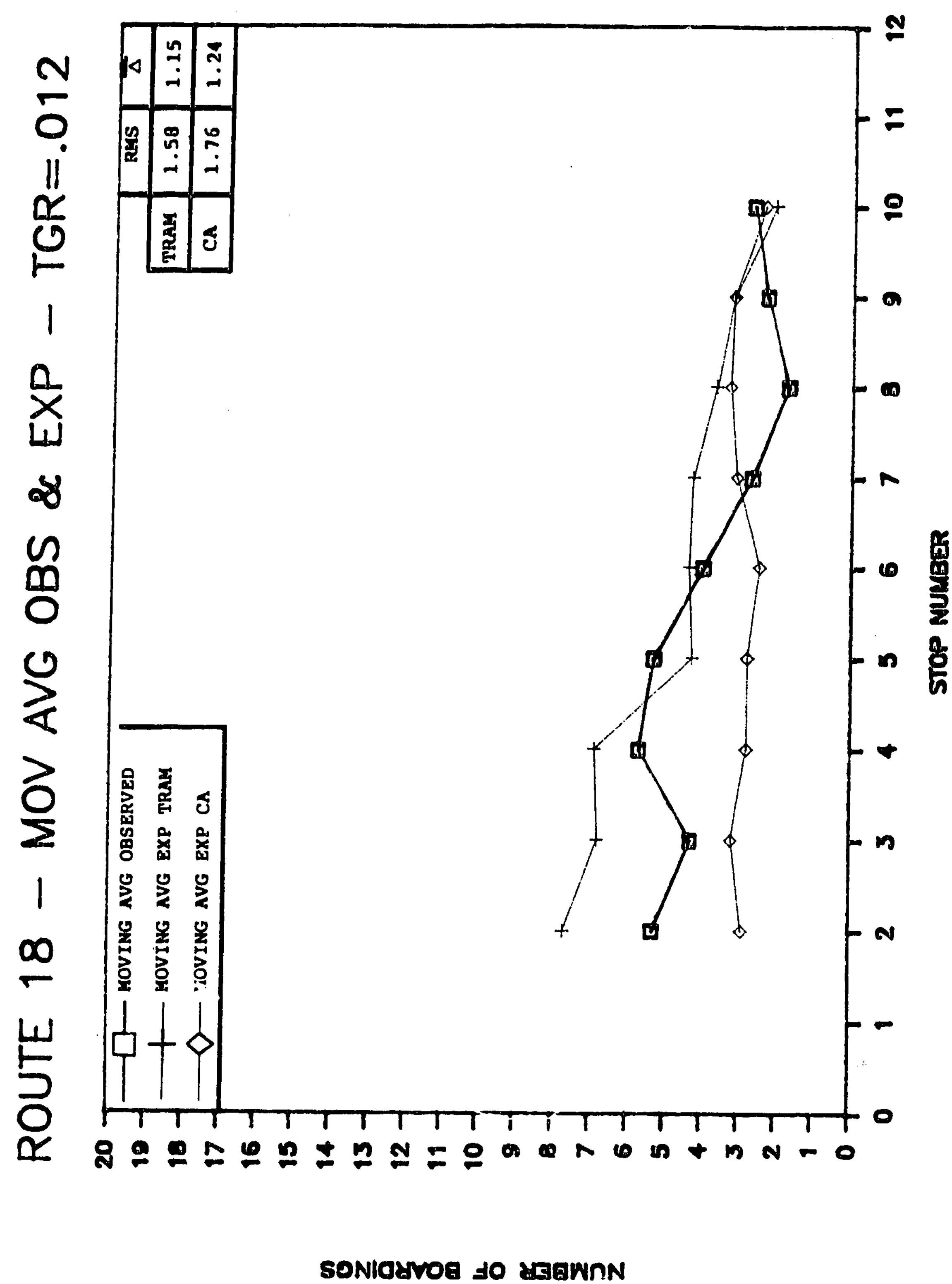


Figure 25(c) - Route 18 fully smoothed results

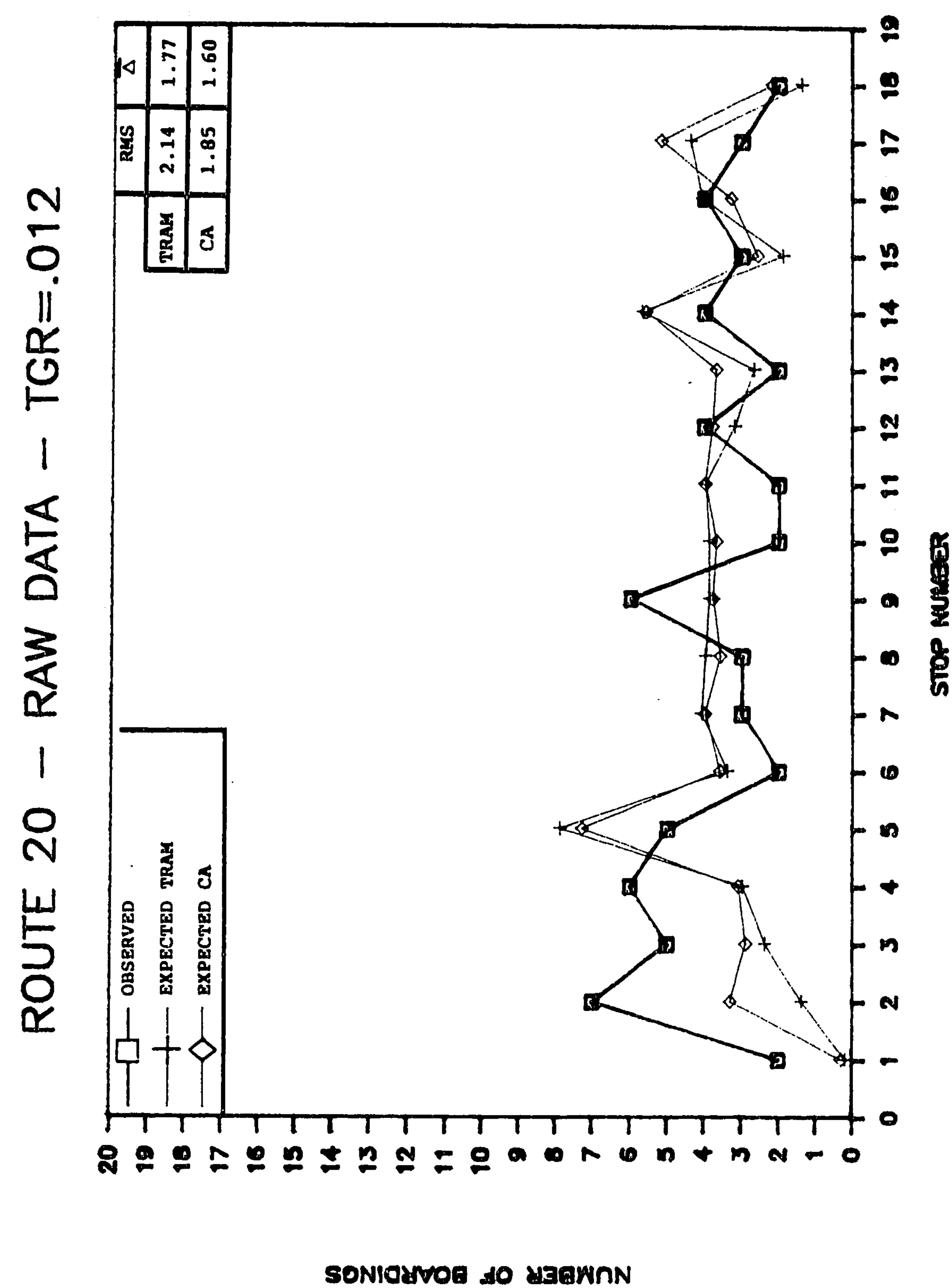


Figure 26(a) - Route 20 raw results

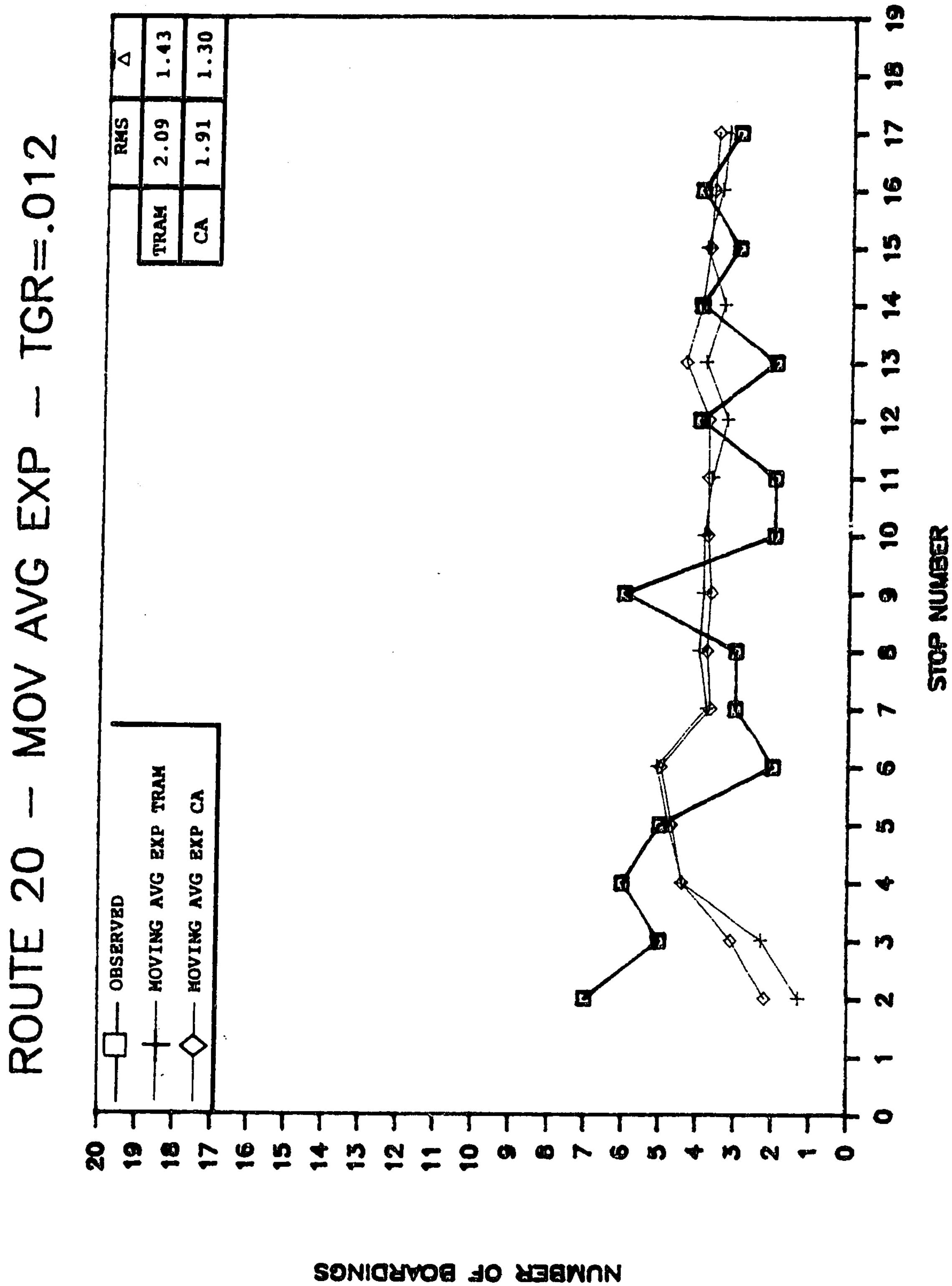


Figure 26(b) - Route 20 partially smoothed results

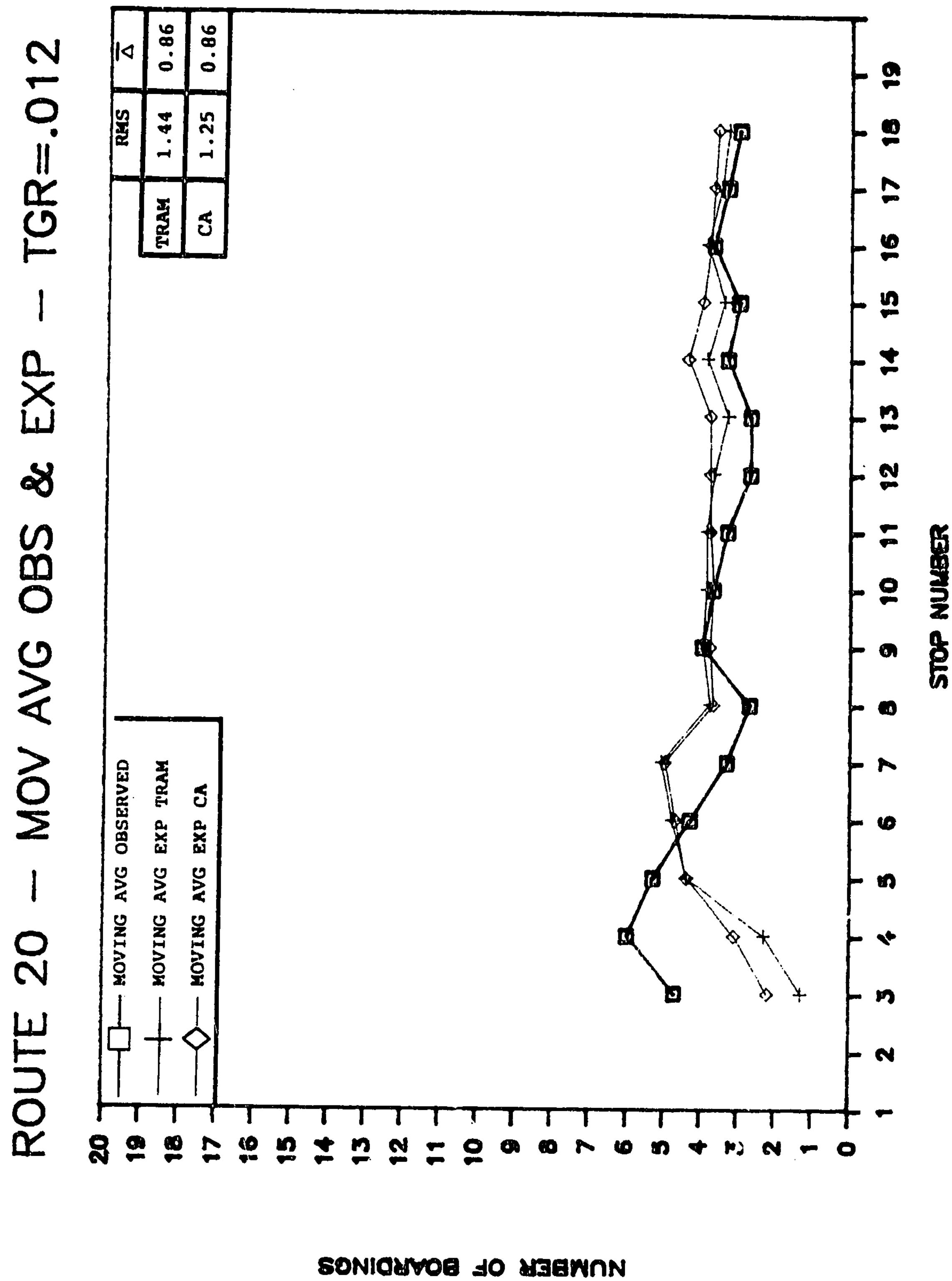


Figure 26(c) - Route 20 fully smoothed results

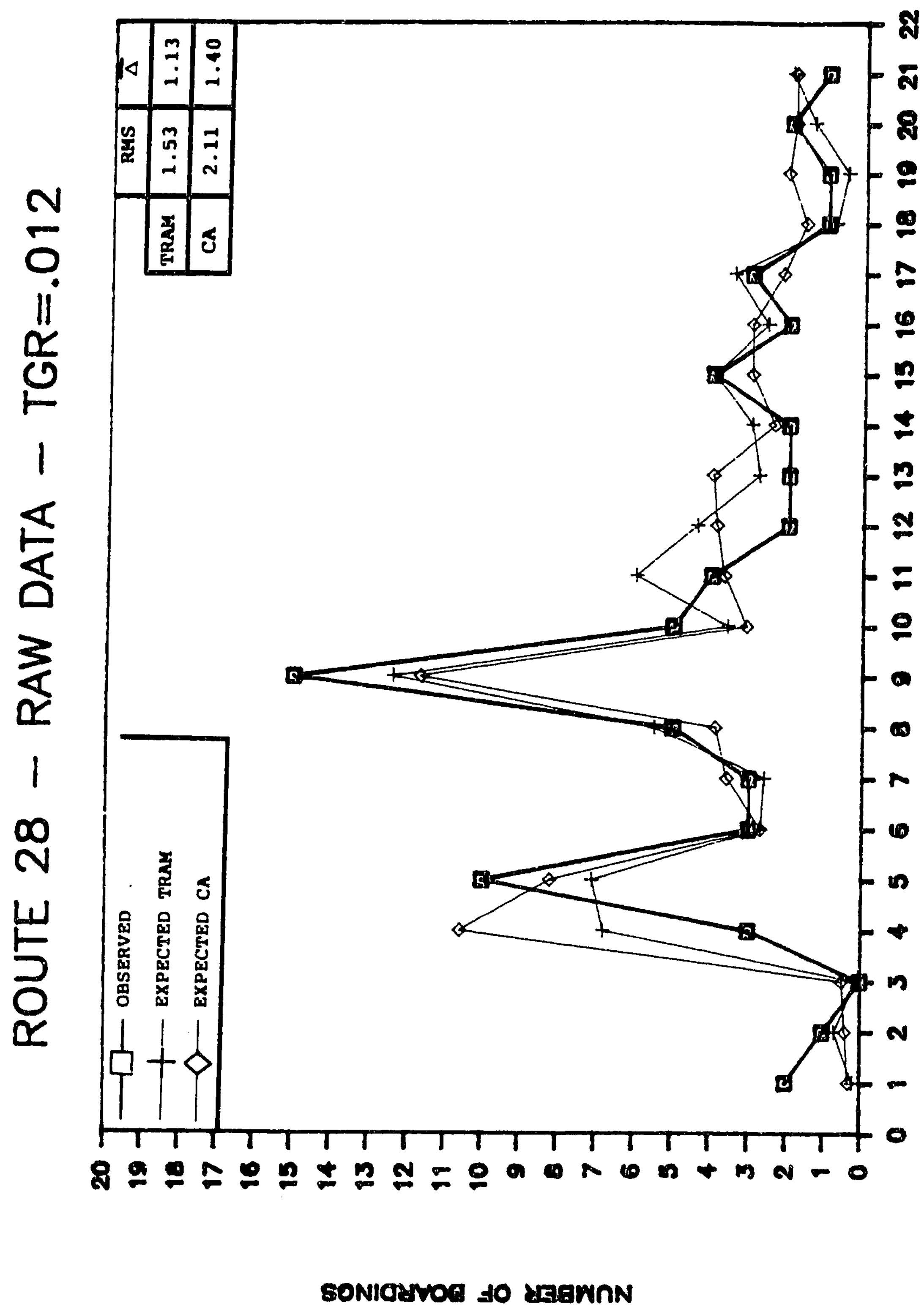


Figure 27(a) - Route 28 raw results

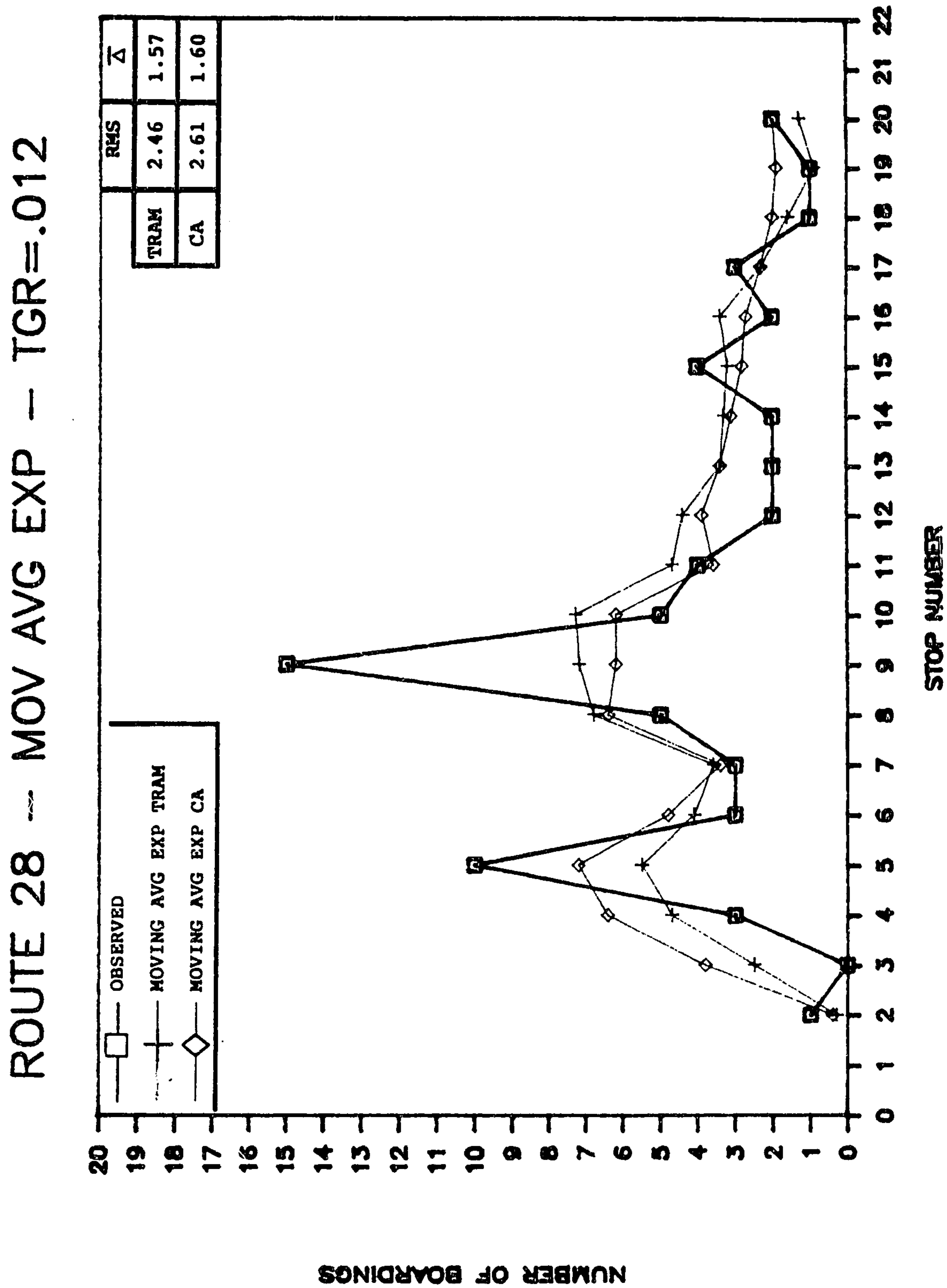


Figure 27(b) - Route 28 partially smoothed results

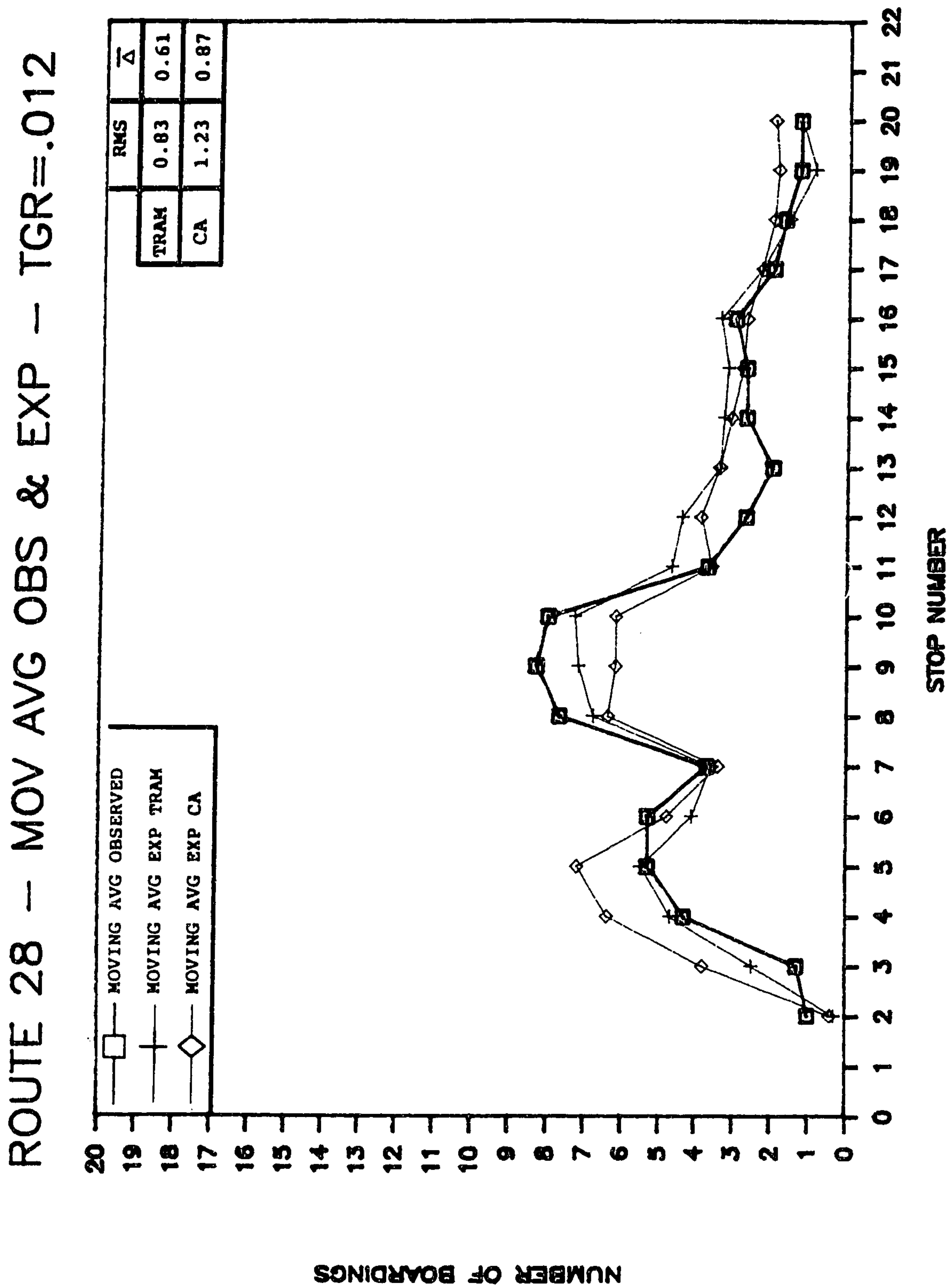


Figure 27(c) - Route 28 fully smoothed results

distribution. The TRAM model appears to be more variable, suggesting that it is more sensitive to factors which affect transit route/stop choice; the CA distribution is somewhat flat and does not seem to capture stop-by-stop variations. However, the comparative statistics indicate that in quantitative terms the performances of the two models are nearly identical.

The raw results exhibit the general TRAM over-prediction and CA under-prediction (of Route #18 versus Routes #20 and #28) which was observed in the route proportion comparisons. Further, it is noted that neither TRAM nor the CA model are successful in predicting the number of boardings at Stop #1 (Abbotsfield Transit Centre).

The partially-smoothed results (Figure 25-b) appear no more impressive than the raw results. However, they are superior quantitatively because the influence of the poor model performances at Stop #1 are excluded. Note that while the RMS measure indicates that the catchment-area model is performing better, the $\bar{\Delta}$ measure indicates the opposite. This illustrates a phenomenon whereby the influence of one large error (the TRAM prediction differs significantly from the observed value at Stop #1) is squared, and thus excessively magnified without justification.

The fully-smoothed results (Figure 25-c) exhibit a similarity in the downward trend of the observations and TRAM predictions along the route. The TRAM results appear to be superior to the predictions of the CA model, which are flatter and less responsive. The quanitative measures support this observation, but are not conclusive.

Route #20

The salient feature of the results shown in Figures 26(a-c) is the similarity of the predictions of the two models. In fact, there is a greater similarity between the models themselves than with the observed distribution of boardings.

The raw results (Figure 26-a) show that, in this case, the distribution of observed boardings is more variable than the models. Neither model matches the observed curve completely. However, in quantitative terms both models perform better than they did for Route #18. Again, the boardings at Abbotsfield Transit Centre (Stop #1) are under-predicted and there is no compensatory over-prediction of boardings at subsequent stops.

The partially-smoothed and fully-smoothed results (Figures 26-b, 26-c) emphasize the similarity between the distributions predicted by the two models. By taking the moving average of the predicted distributions, the observed distribution appears even more variable in comparison. The fully-smoothed results exhibit good similarity of trend between predicted and observed distributions.

Route #28

The results shown in Figures 27(a-c) are among the best of the research in terms of similarity between predictions and observations. The TRAM predictions are superior to CA predictions according to both quantitative measures.

The raw results, shown in Figure 27(a), exhibit remarkable similarity in the predicted and observed distributions. In particular, the models correctly predicted two sharp peaks at Stops #5 and #9. According to the quantitative measures, the overall performance of the TRAM model is superior to that of the catchment-area model; this superiority is particularly evident toward the latter half of the route. However, similar to the other results in the Beverly study area, both models under-predict the number of boardings of Route #28 at Abbotsfield Transit Centre (Stop #1).

Partial smoothing of the results (Figure 27-b) detracts from the excellent fit exhibited by the raw results. The similarities of the distributions are decreased, both in qualitative and quantitative terms.

The fully smoothed results (Figure 27-c) exhibit an excellent fit by both models, with TRAM performing better statistically. However, it is noted that the smoothing of the results does not add any new dimension to the results, and the benefits of the smoothing are minimal.

Capilano Study Area

Figures 28(a) to 28(c) present the raw, partially-smoothed, and fully-smoothed results for Route #50 in the Capilano study area. Similarly, Figures 29(a-c)

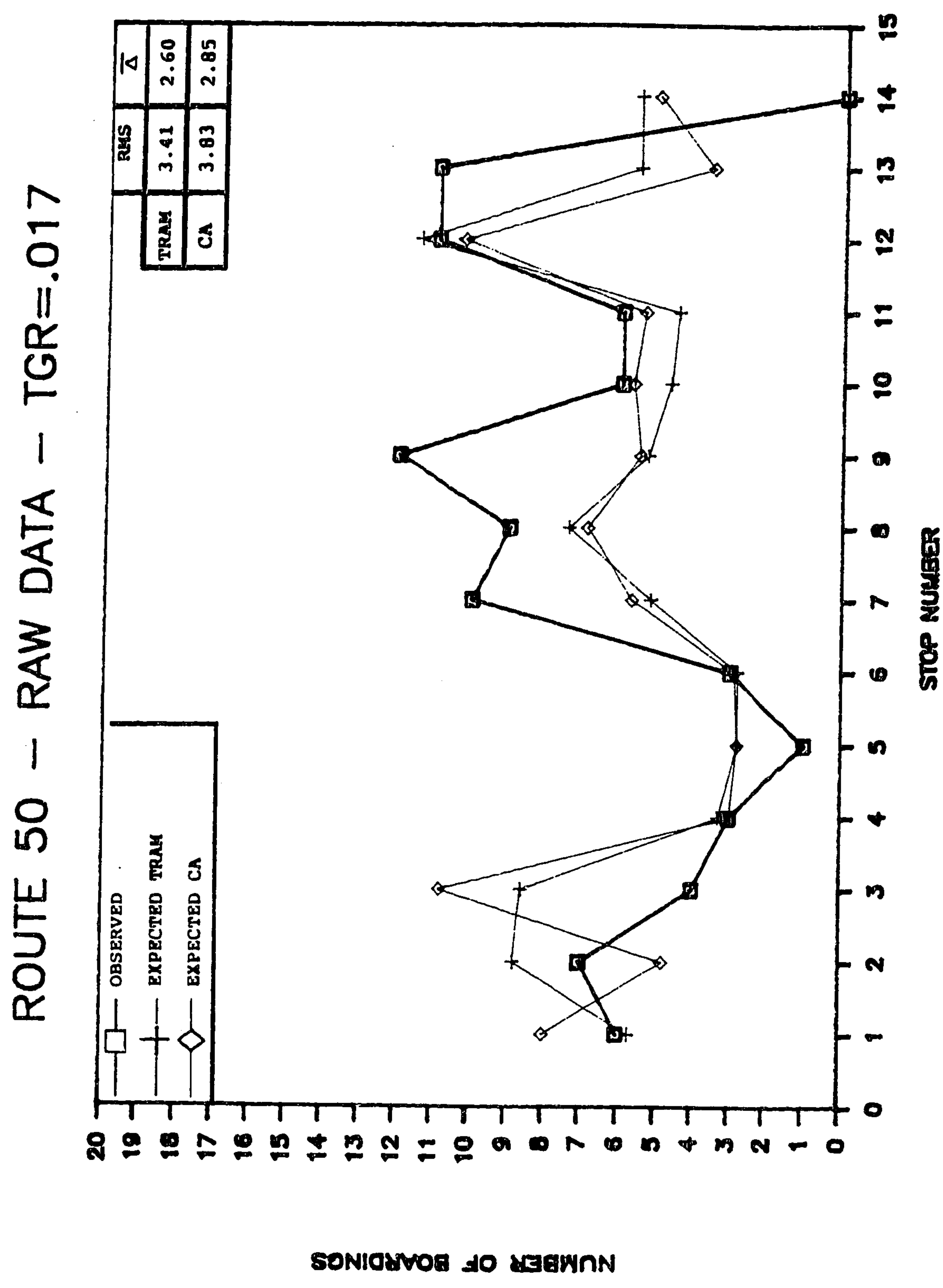


Figure 28(a) - Route 50 raw results

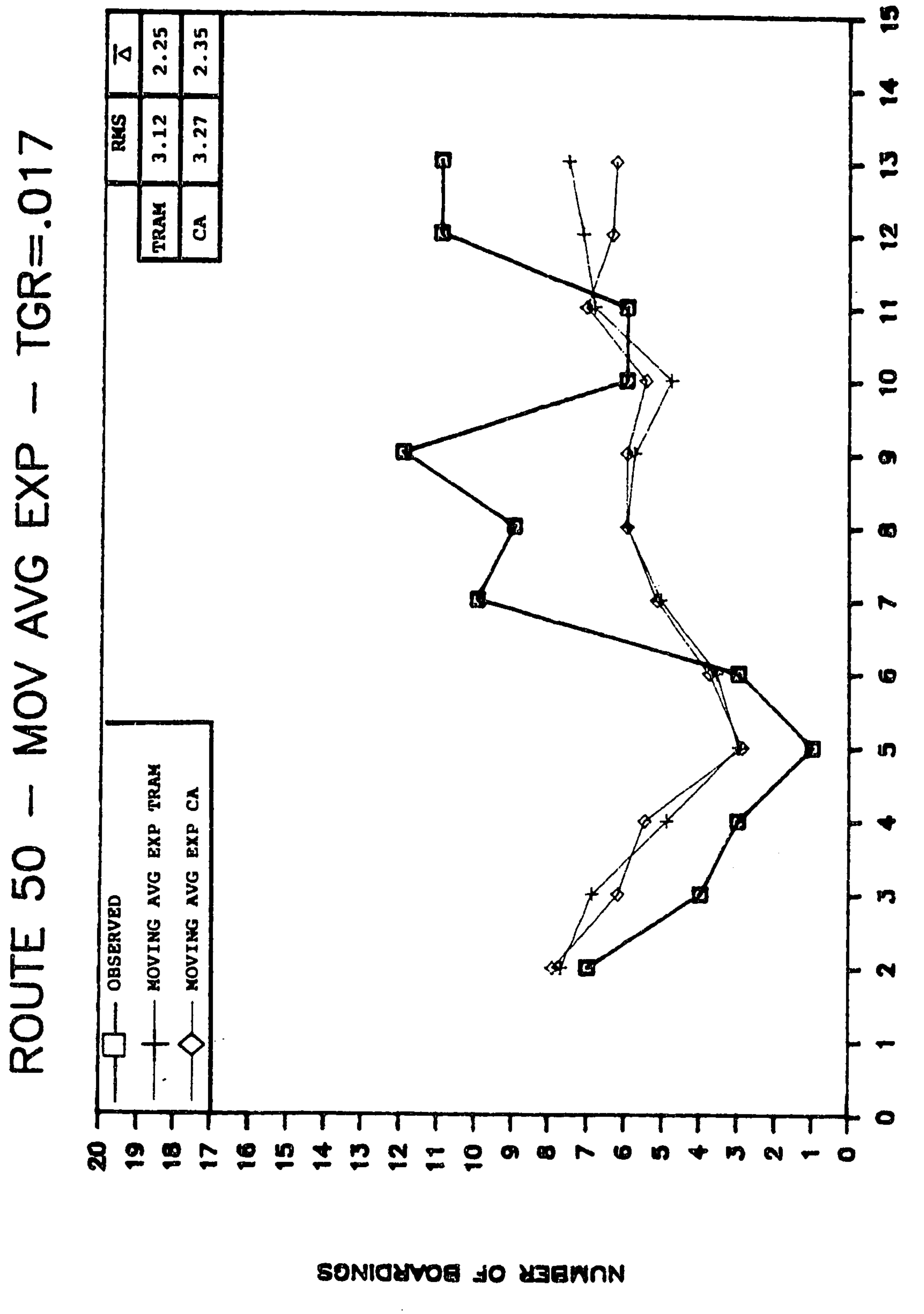


Figure 28(b) - Route 50 partially smoothed results

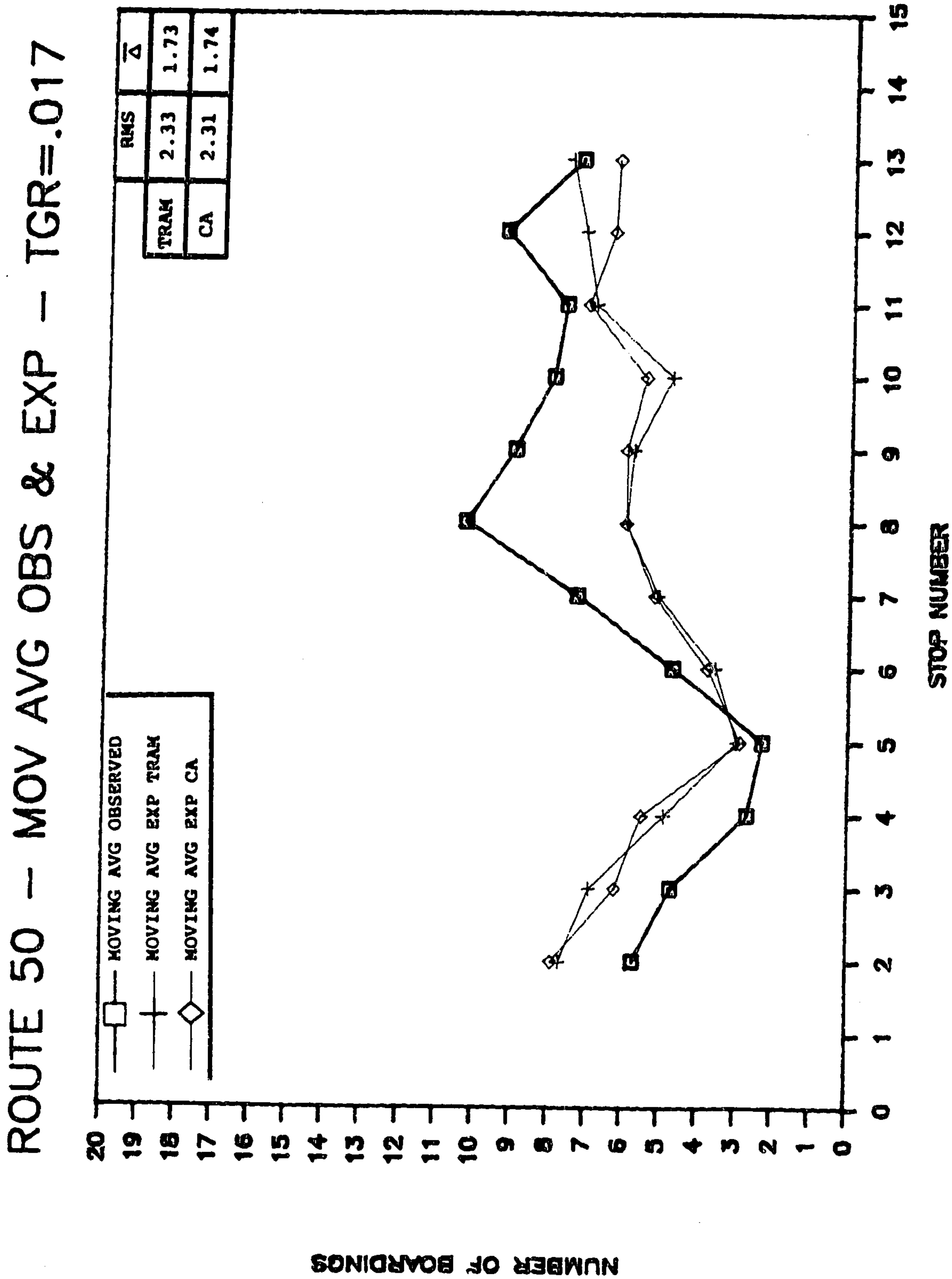


Figure 28(c) - Route 50 fully smoothed results

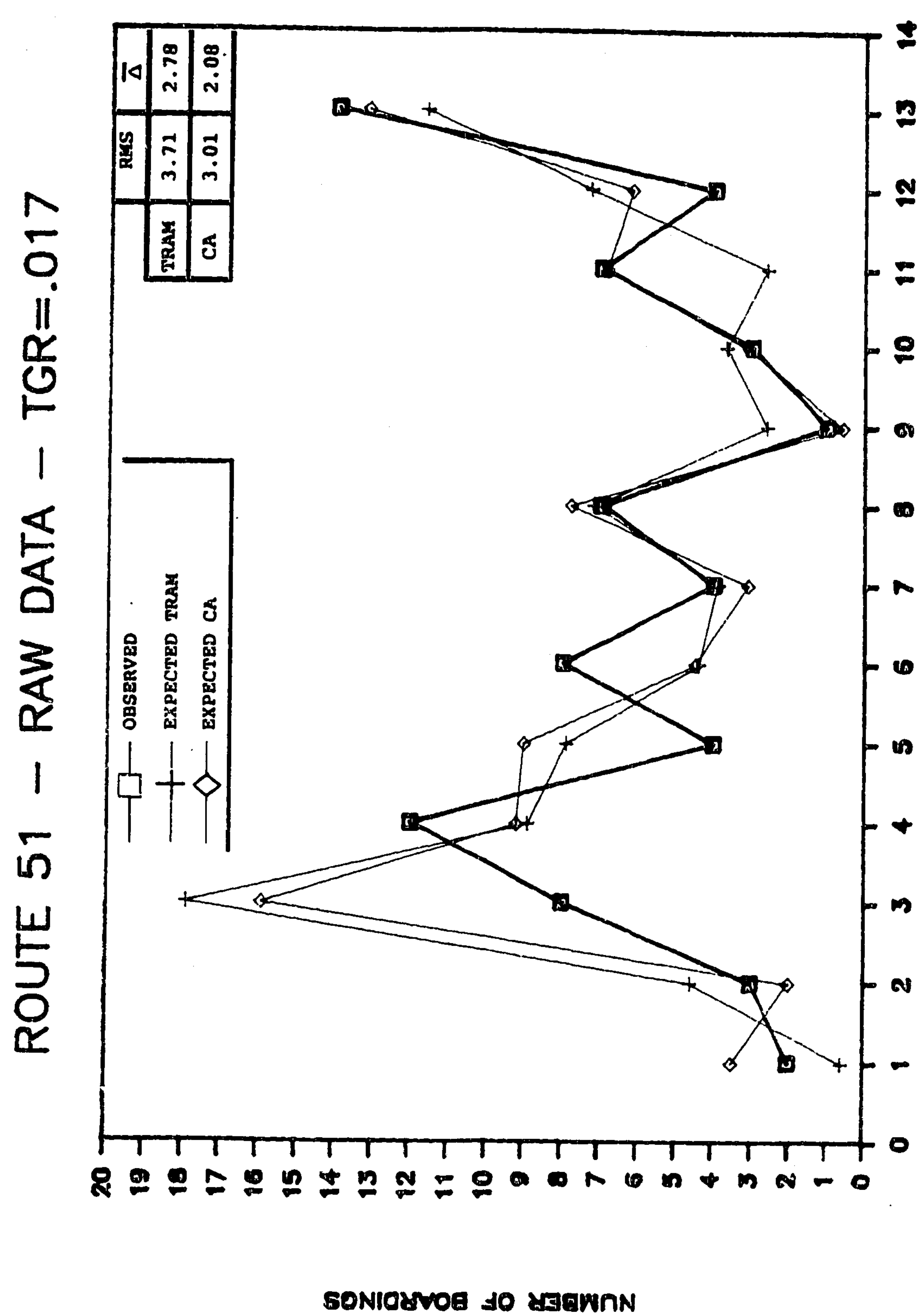


Figure 29(a) - Route 51 raw results

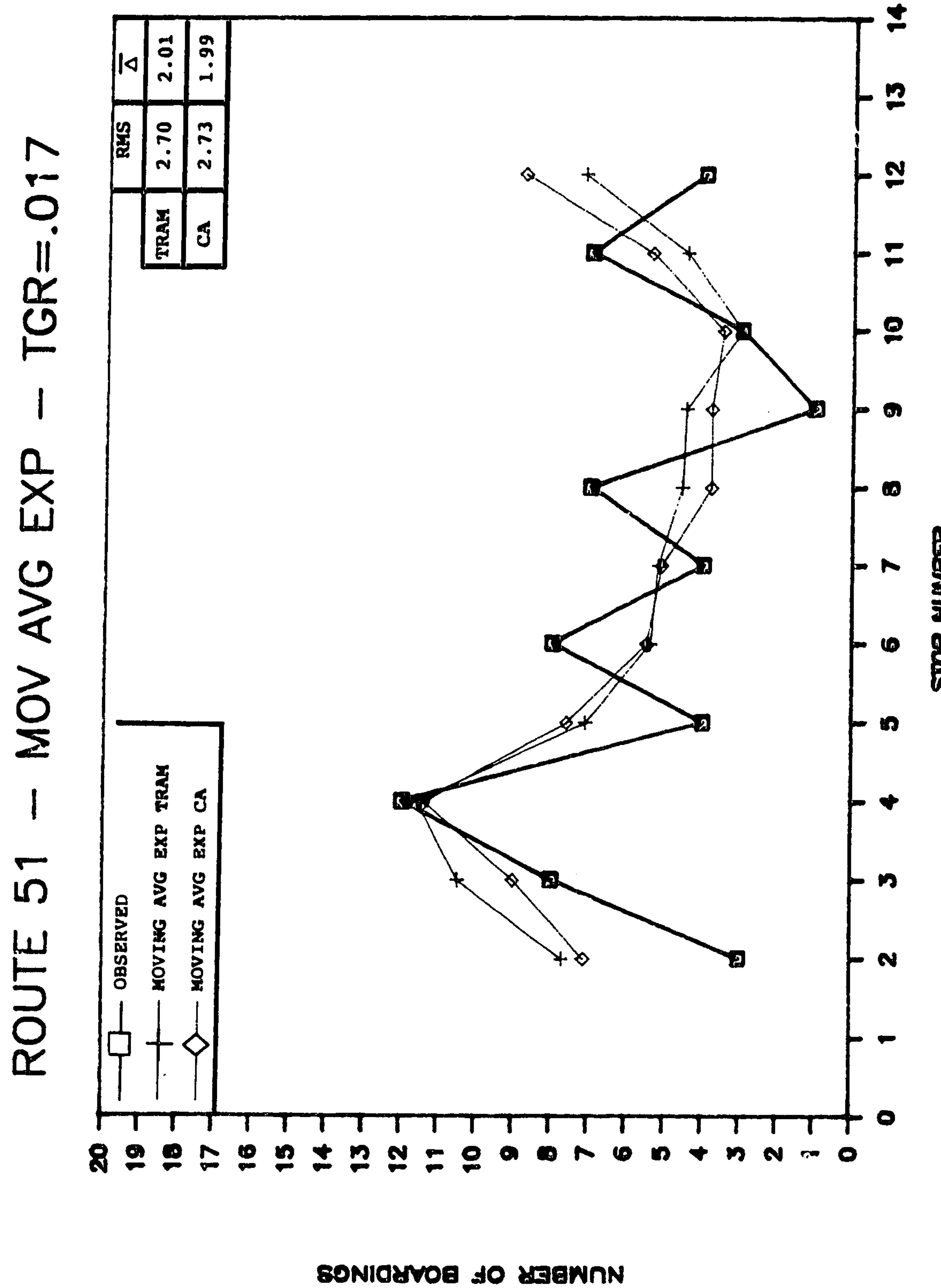


Figure 29(b) - Route 51 partially smoothed results

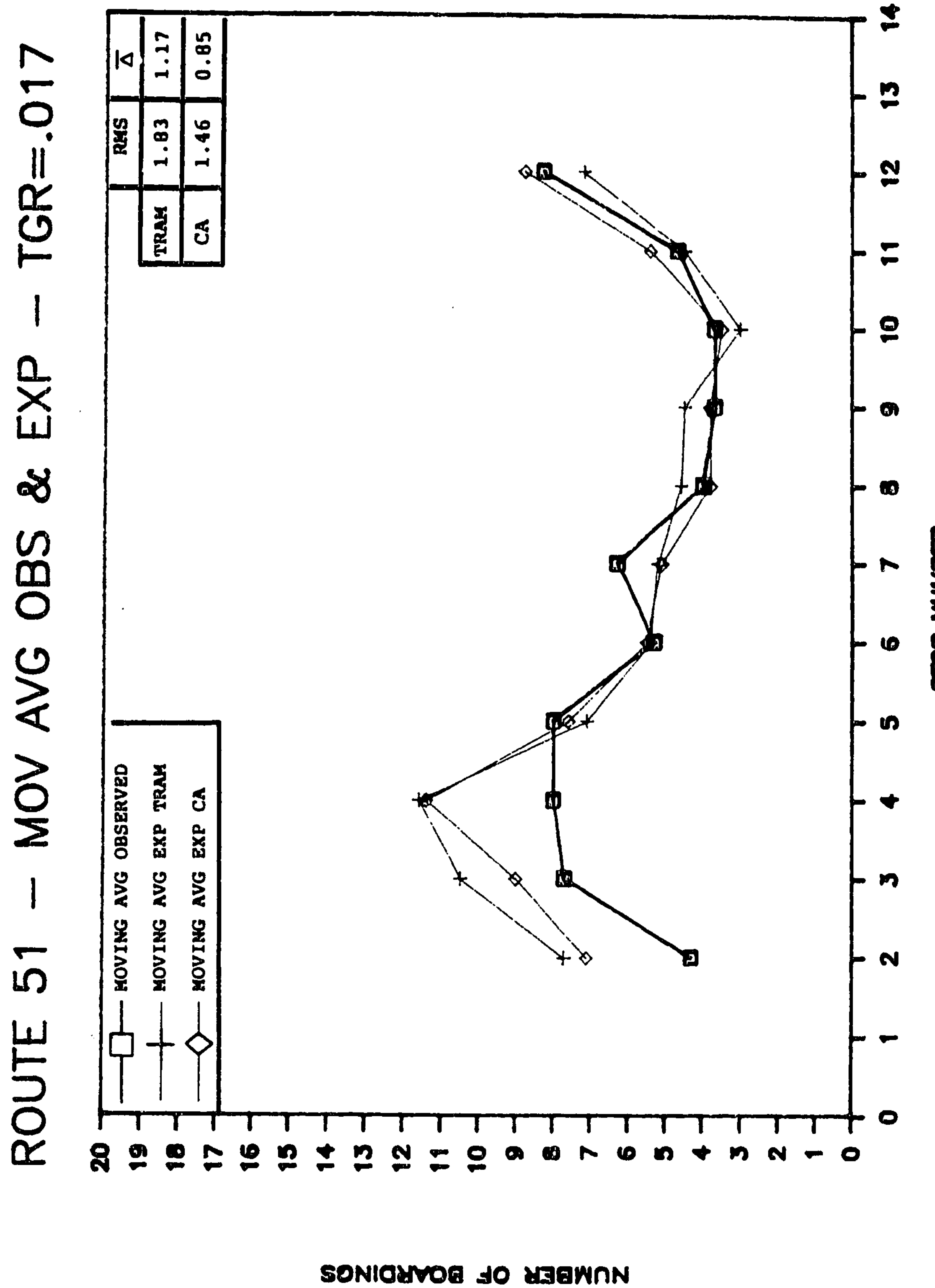


Figure 29(c) - Route 51 fully smoothed results

present the results for Route #51.

Route #50

The results shown in Figures 28(a-c) exhibit some agreement between the performance of the models and the observations, with much similarity between the two models themselves.

The raw results (Figure 28-a) show that the TRAM distribution and the CA distribution are quite similar. Both distributions follow the trend of the observed distribution fairly well in terms of general increasing and decreasing tendencies.

The partially-smoothed results (Figure 28-b) do not exhibit as much agreement between observed and predicted distributions, since the distributions were already reasonably similar without smoothing. Even though the distributions appear worse, they are better in quantitative terms because the influence the endpoints (where there were relatively large discrepancies) are excluded.

The fully-smoothed results (Figure 28-c) emphasize the similarity of the TRAM and CA predictions. Nonetheless, both models follow the general trend of the observed pattern of boardings, decreasing up to Stop #5 and increasing thereafter.

A peculiarity is noted in the raw results for Route #50 (Figure 28-a). It can be seen that the observed number of boardings at the final two stops is fourteen and zero, respectively, whereas the TRAM model predicts seven and seven, respectively. The observed number of boardings appeared so unusual that the two stops were monitored during a supplementary morning peak to confirm the behaviour.

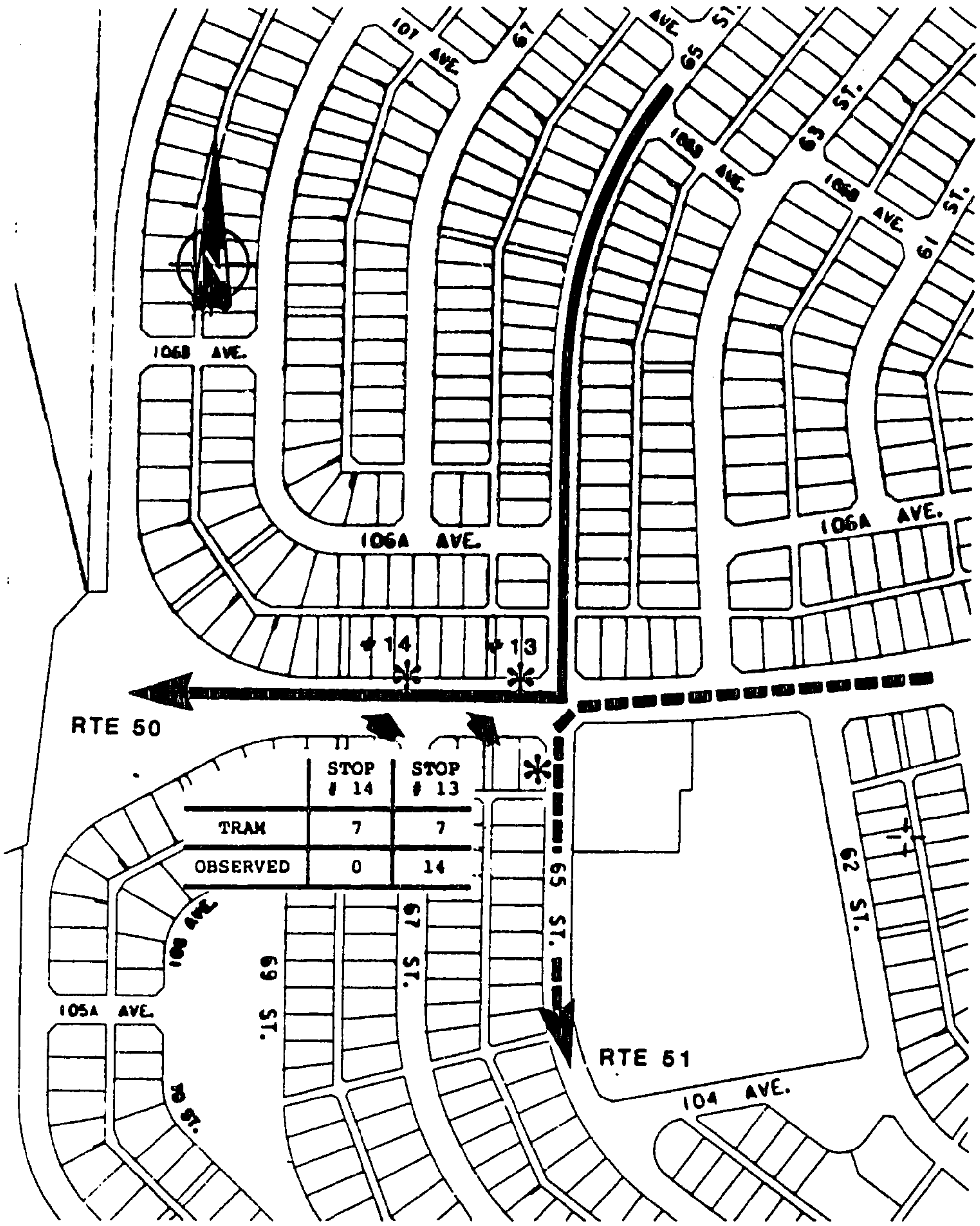
It appears that TRAM correctly generates the total number of boardings for the pair of stops, but distributes them evenly to uphold the logic of the choice of the closest stop (refer to Figure 30). In fact, most transit users were observed to walk from west to east past Stop #14 to board at Stop #13. Although there is a shelter at Stop #13, the weather conditions were not inclement during either period of observation and people were not making particular use of the shelter. The reason for this seemingly peculiar behaviour remains unknown.

Route #51

The distributions of observations and predictions are fairly similar for the raw results (Figure 29-a). Again, the models are very similar to each other, but the quantitative measures reveal that the performance of the CA model is better than that of the TRAM model. All three distributions exhibit localized variability while following a broader "increasing - decreasing - increasing" pattern.

The partially-smoothed results (Figure 29-b) are not helpful in comparing the distributions since the three distributions were reasonably similar before smoothing.

The fully-smoothed results (Figure 29-c) clearly show the similarity of the three distributions, especially beyond Stop #5. The quantitative measures show that the simple CA



	STOP # 14	STOP # 13
TRAM	7	7
OBSERVED	0	14

Figure 30 - Final two stops on Route 50

model outperforms TRAM in the treatment of Route #51.

Clareview Study Area

Figures 31(a) to 31(c) present the raw, partially-smoothed, and fully-smoothed results for Route #72 in the Clareview study area. Similarly, Figures 32(a-c) present the results for Route #74.

Due to the small number of bus stops involved in the Clareview study area, it is somewhat difficult to draw meaningful conclusions. One must avoid the tendency to over-analyze variations in a seven-stop distribution which would appear less significant if the seven stops were merely a portion of a twenty-stop distribution.

Route #72

The results shown in Figures 31(a-c) exhibit some similarity between the performance of the models and the observations. However, as with some of the other routes, there appears to be at least an equal degree of similarity between the predictions of the two models themselves as between the predictions and the observations. The fully-smoothed results indicate that the general trend is slightly better represented by the CA model. Quantitatively, the CA predictions are superior to the TRAM predictions in two of three cases.

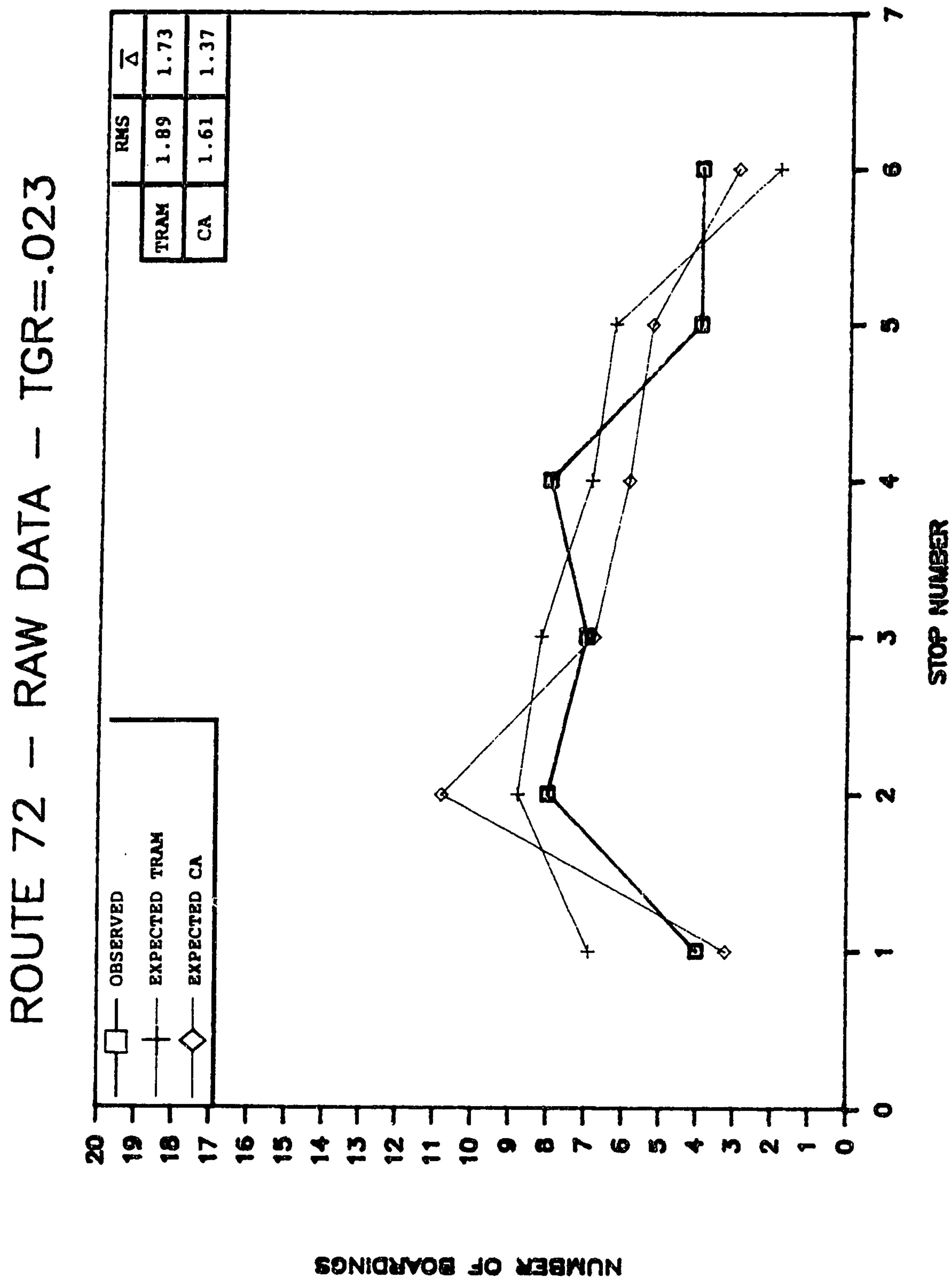


Figure 31(a) - Route 72 raw results

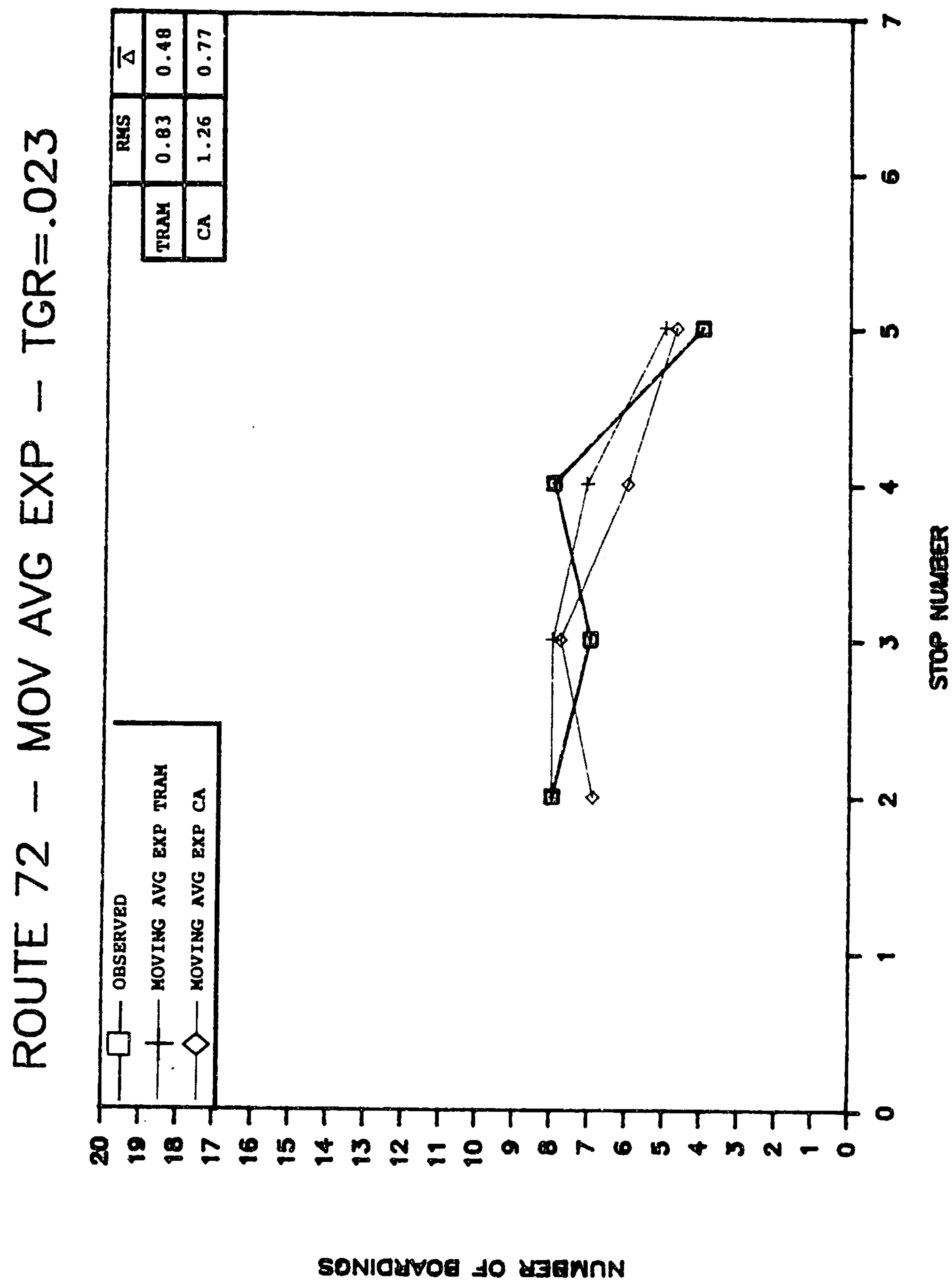


Figure 31(b) - Route 72 partially smoothed results

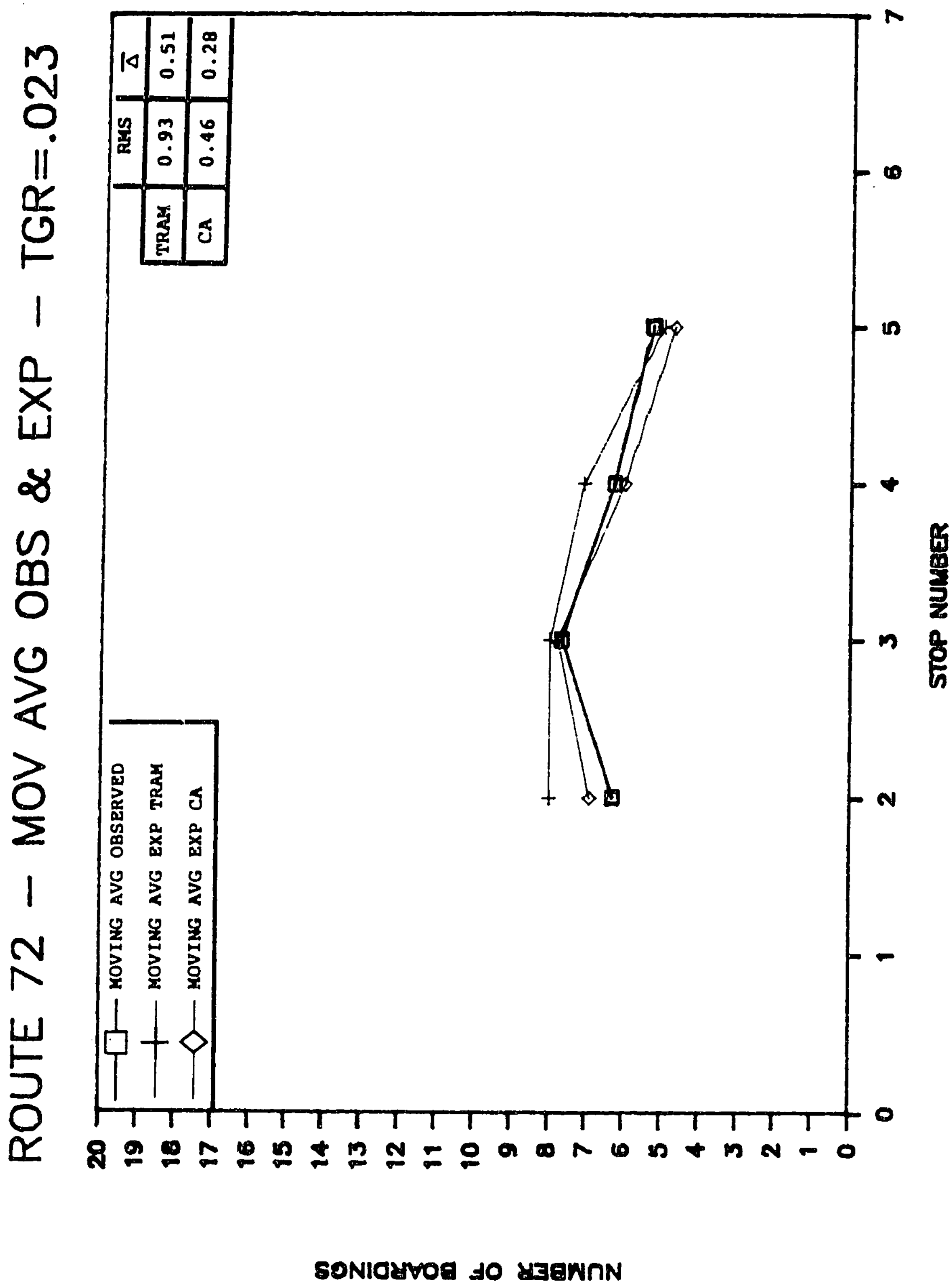


Figure 31(c) - Route 72 fully smoothed results

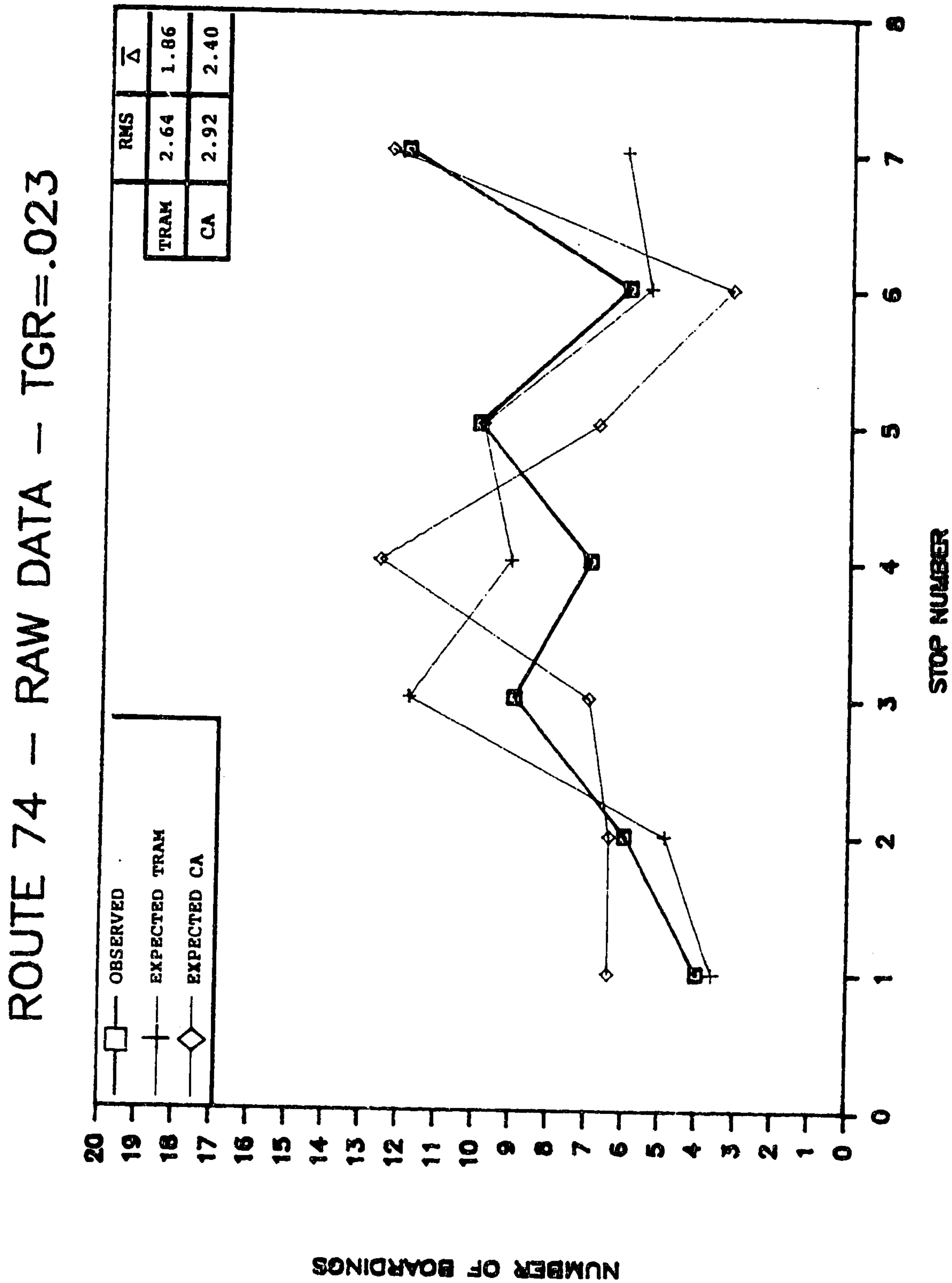


Figure 32(a) - Route 74 raw results

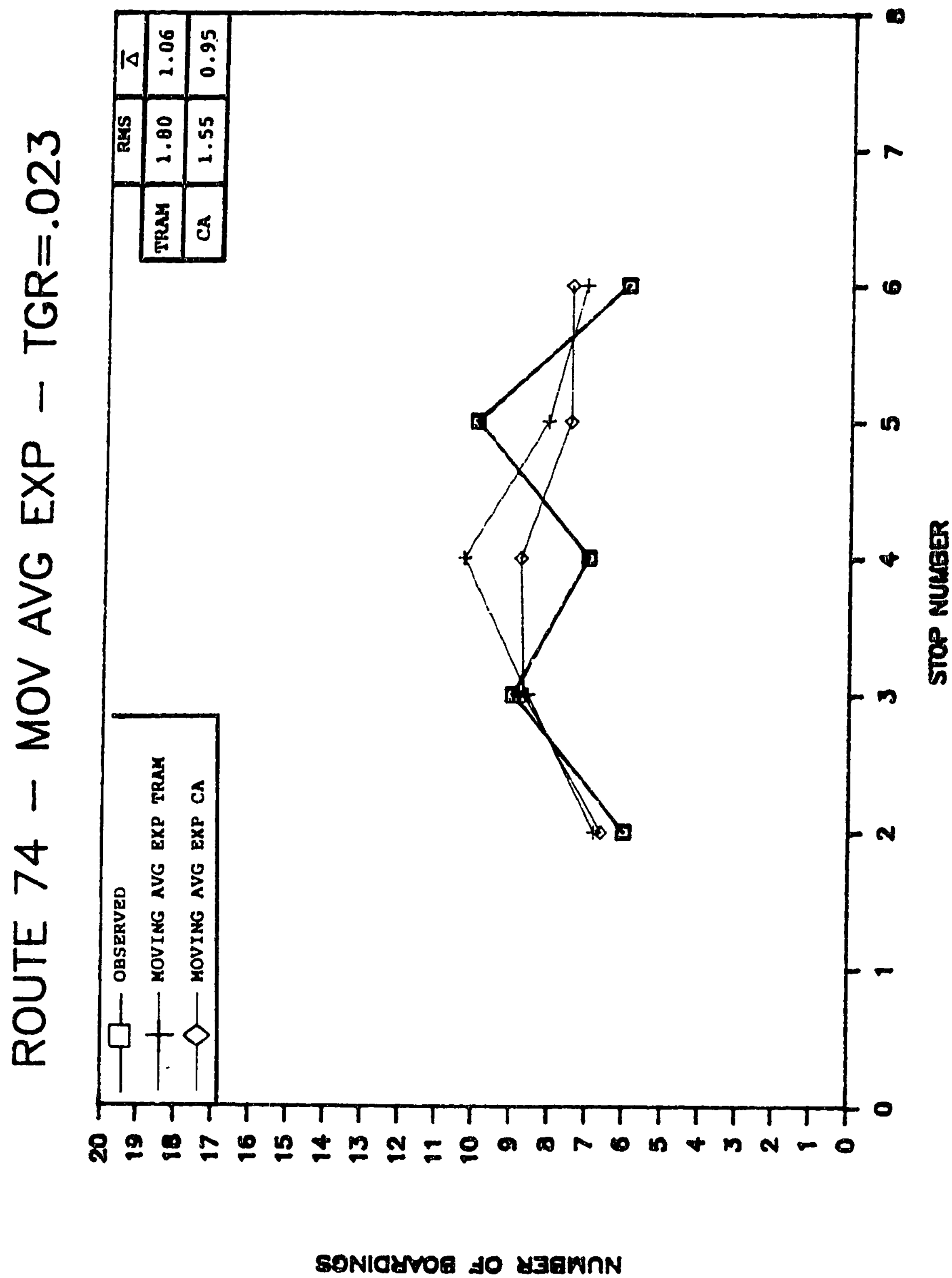


Figure 32(b) - Route 74 partially smoothed results

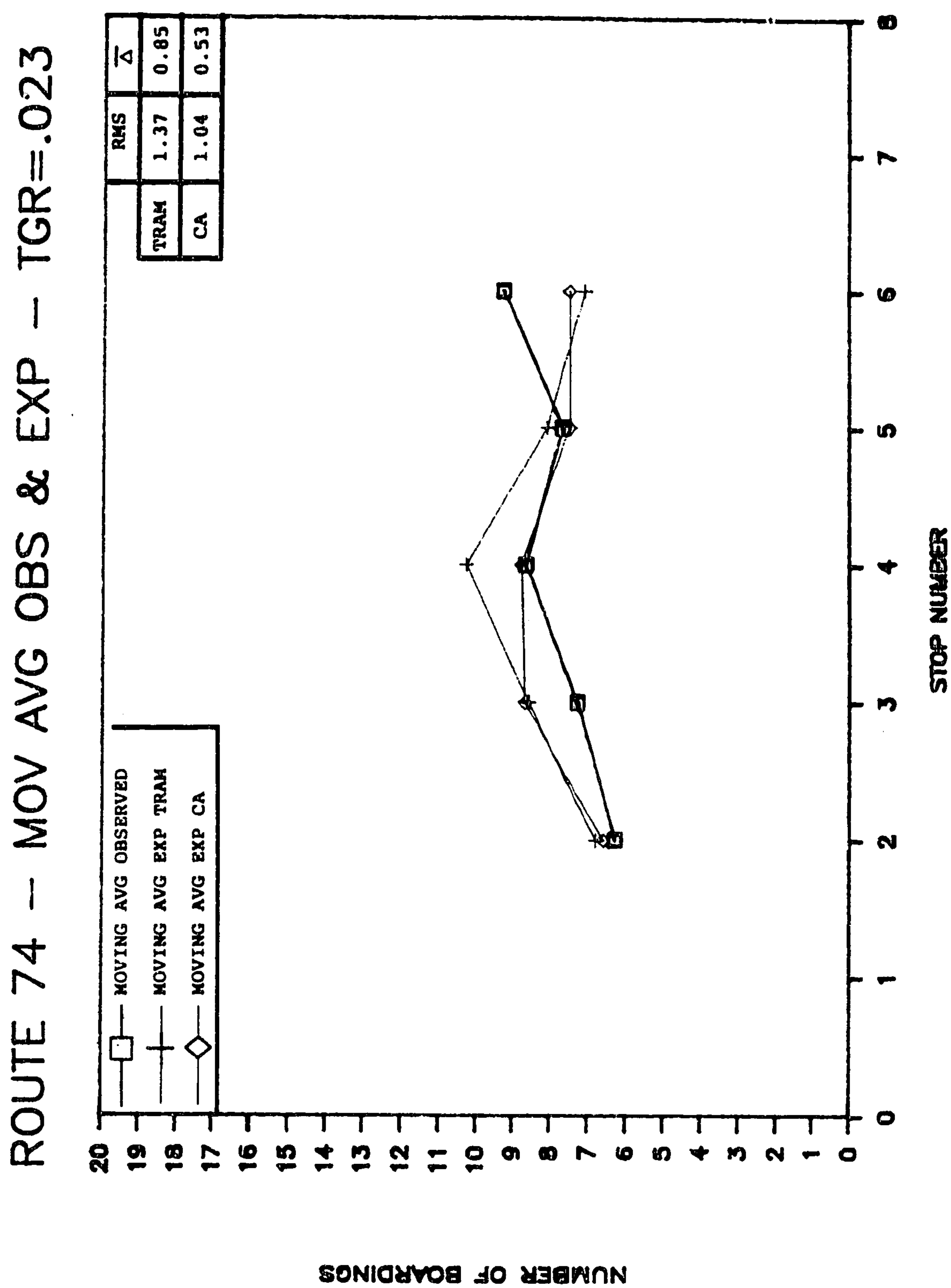


Figure 32(c) - Route 74 fully smoothed results

Route #74

The raw results (Figure 32-a) initially appear to be three quite variable and relatively dissimilar distributions. However, the appearance of the TRAM results is superior to the CA results; in quantitative terms the results are reasonably good, with TRAM providing superior predictions. The two models appear to vary in different patterns rather than simply mirroring each other as they did for other study routes; however, this phenomenon did occur for other study areas, but it was less apparent because there were more stops comprising the routes.

The partial-smoothing shown in Figure 32(b) is an improvement upon the raw results, but presents only a limited number of data points upon which to draw conclusions. In this case, the CA model is quantitatively superior to TRAM.

In Figure 32(c), with fully-smoothed results, both models do a good job of prediction. Again, the CA model is superior in quantitative terms.

XI. Macro-Level Testing (Analysis)

The results of the macro-level testing are generally less favourable than those of the micro-level testing. The performance of the TRAM model relative to the catchment area model was not as good as expected. This chapter adresses in more detail six issues arising from the macro-level testing.

(1) The raw results for Route #18 (Figure 25-a) show that both the TRAM model and CA model underpredict the Abbotsfield Transit Centre (Stop #1) and overpredict the subsequent stop. In fact, the number of boardings at the Abbotsfield Transit Centre was underpredicted for all three routes in Beverly. Although not specifically monitored, park-and-ride, kiss-and-ride, and transfer trips did not appear to contribute to the total number of boardings. This suggests that there may be a particular attraction associated with transit centres.

The attraction might reflect the fact that several routes usually converge at transit centres, often incorporating a layover which allows patrons to wait while sitting on the bus rather than standing at the bus stop. A future calibration of the utility function for the transit choice behaviour model should include a dummy variable specific to whether or not the stop is also a transit centre. Noteably, no such adjustment can be attempted for the CA model.

(2) Beyond the under-prediction of the transit centre, the raw results of Route #20 (Figure 26-a) indicate that

both models tend to under-predict the entire medium-density area (from Stop #1 to Stop #5) and overpredict the low-density area (beyond Stop #5). This tendency also exists for the other Beverly routes, but is less pronounced. Using the rationale that the residents of the medium-density area are generally less-affluent and are less likely to own a private automobile, it was thought that they might exhibit a greater propensity to use transit. Test runs of both models were performed with the transit trip generation rate for the medium-density area increased by up to twenty percent and the transit trip generation rate for the low-density area adjusted to maintain the same total number of boardings. The results of the test with a twenty percent adjustment are shown in Figures 33(a-c) to 35(a-c), which correspond directly to Figures 25(a-c) to 27(a-c).It can be seen that the change in the results is minimal, and neither model is affected in a consistent manner. The original runs of the model which used only one transit trip generation rate appear to be of equal value.

Increases greater than twenty percent were not tested, since the rate of change was so slow that the imbalance in the trip generation rates between the two densities would have become unreasonable before any significant improvement occurred.

(3) The raw results of Route 20 (Figure 26-a) also exhibit a phenomenon which probably, but un-verifiably, occurs elsewhere in the study results: at Stop #9, the

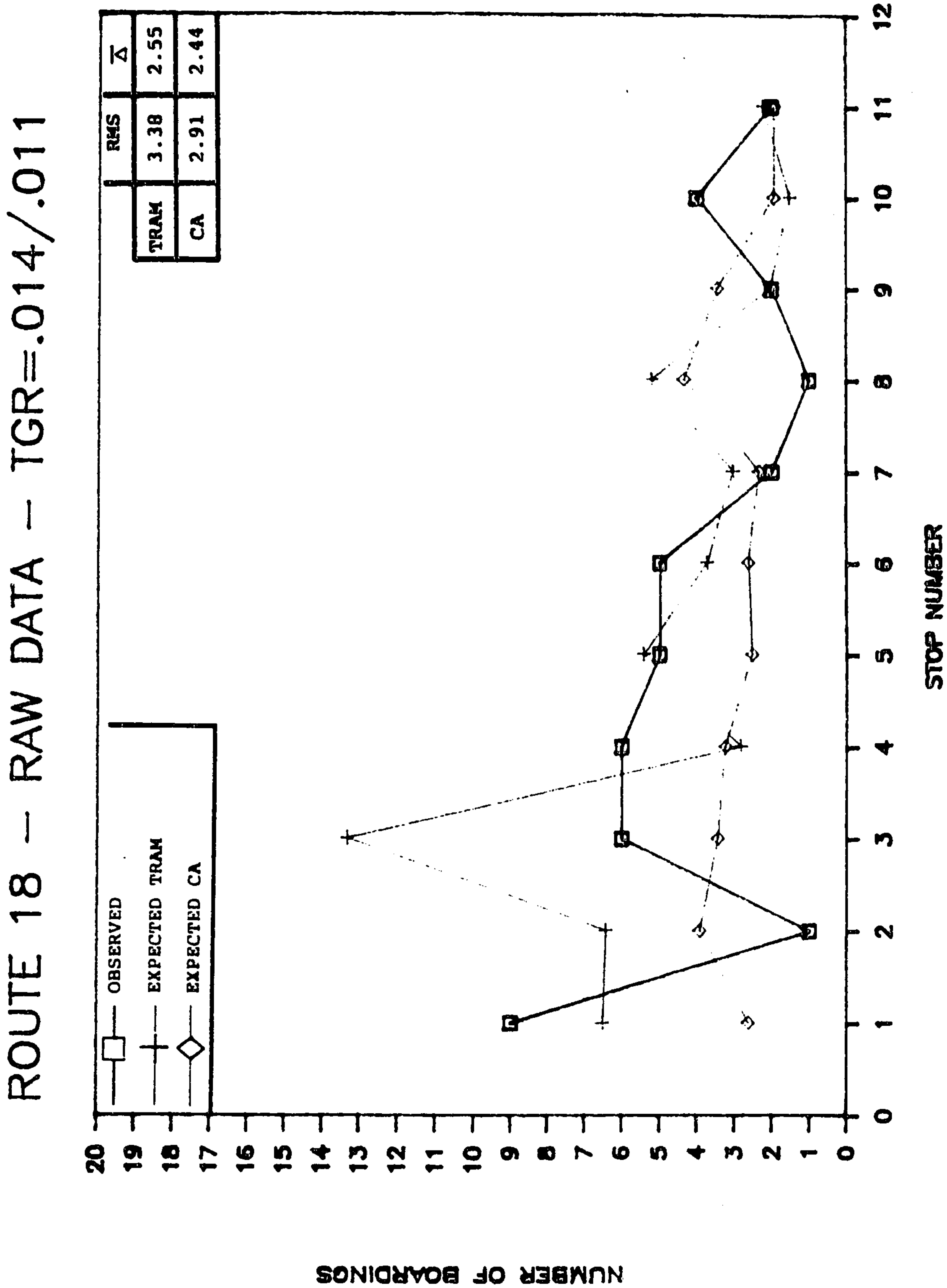


Figure 33(a) Density-sensitive TGR, Route 18 raw results

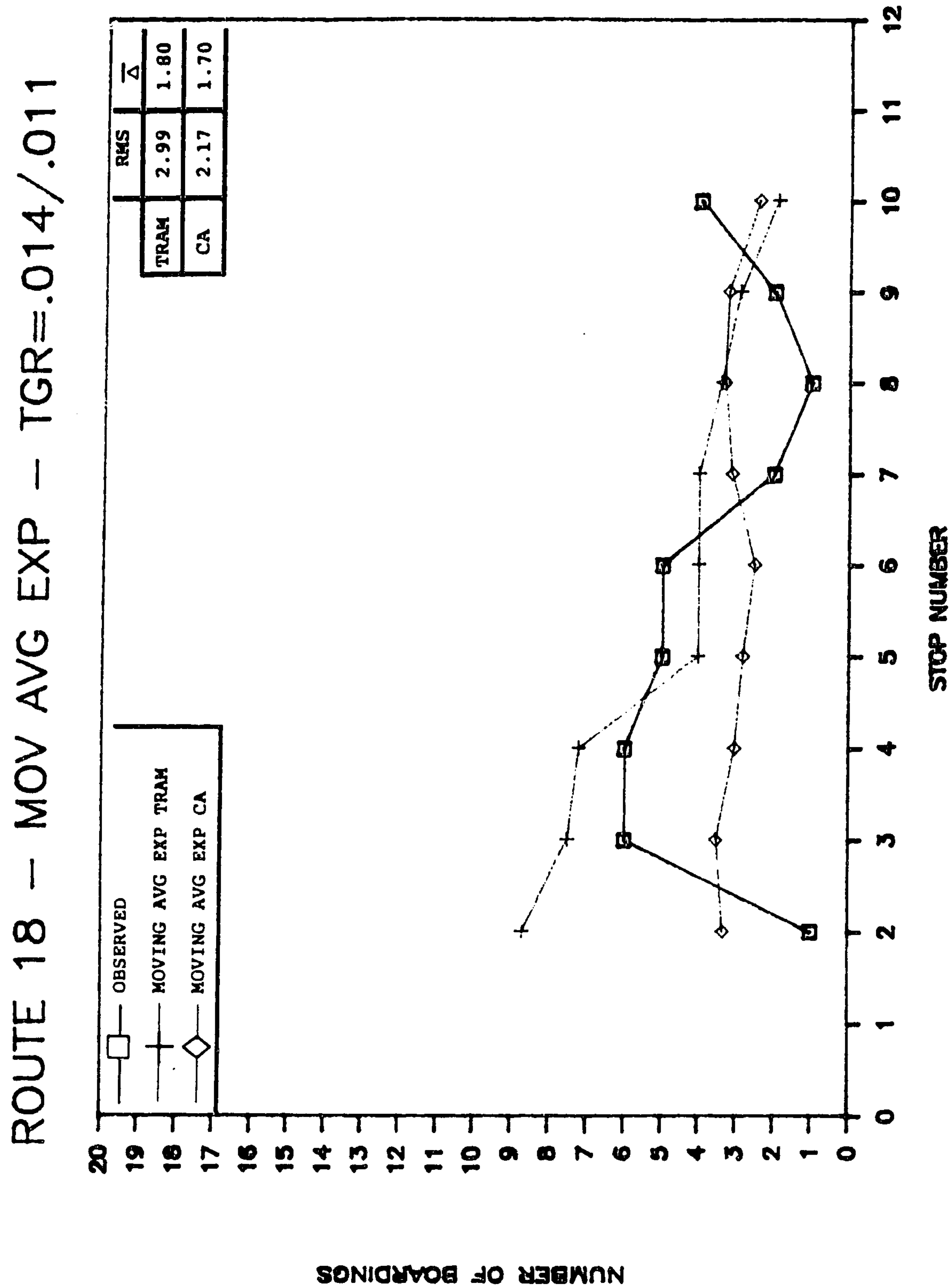


Figure 33(b) Density-sensitive TGR,
Route 18 partially smoothed results

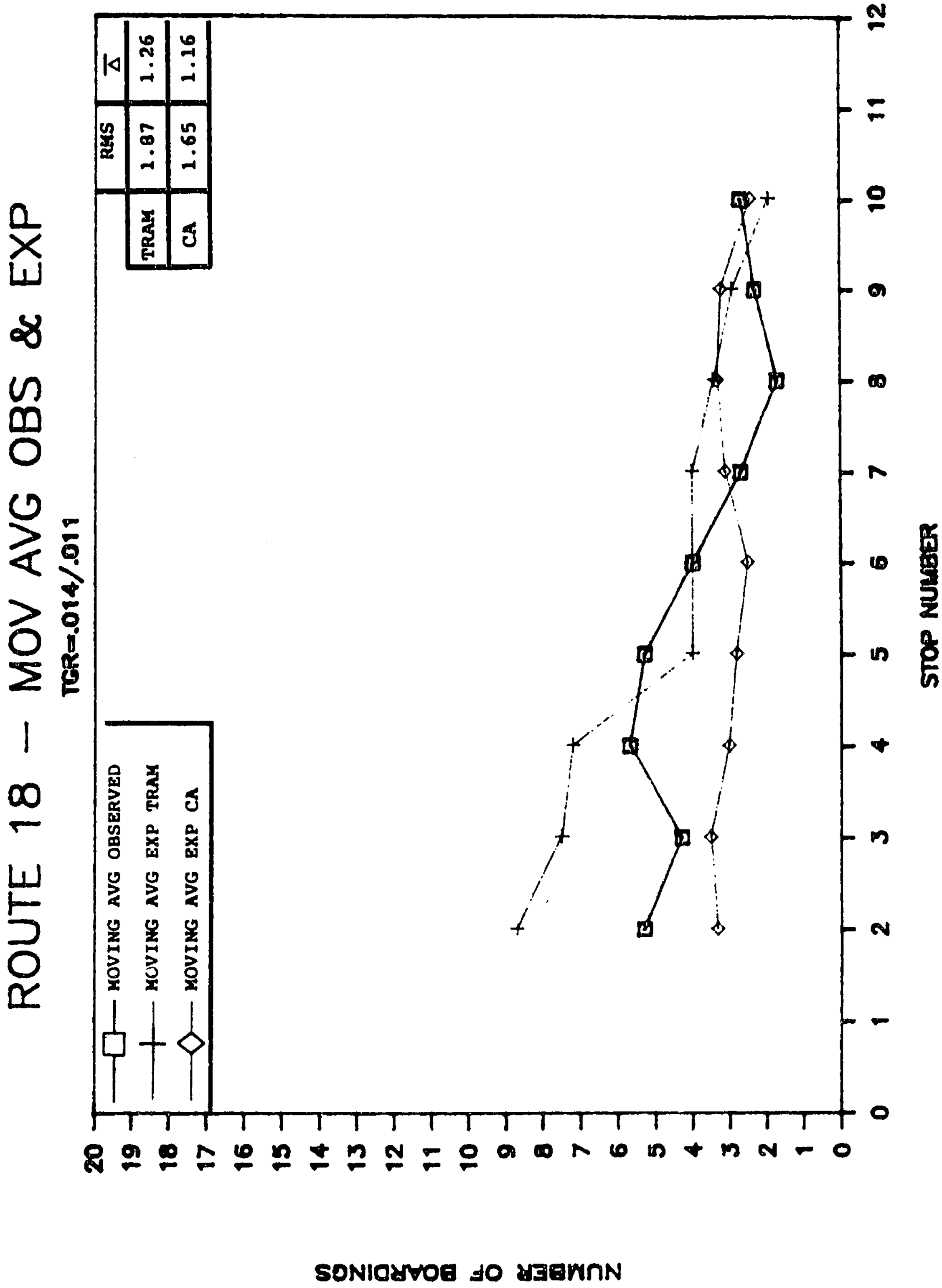


Figure 33(c) Density-sensitive TGR,
Route 18 fully smoothed results

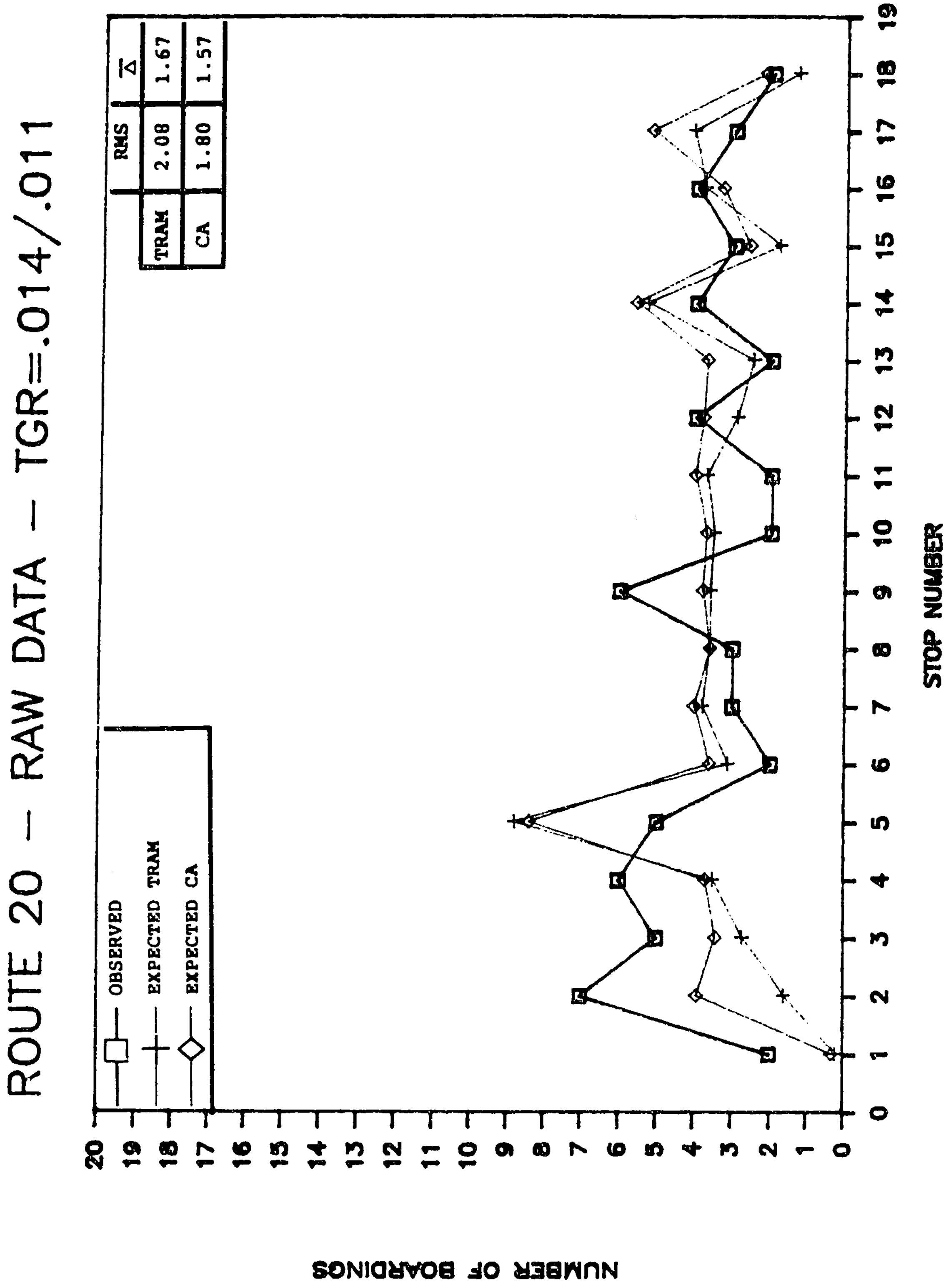


Figure 34(a) Density-sensitive TGR, Route 20 raw results

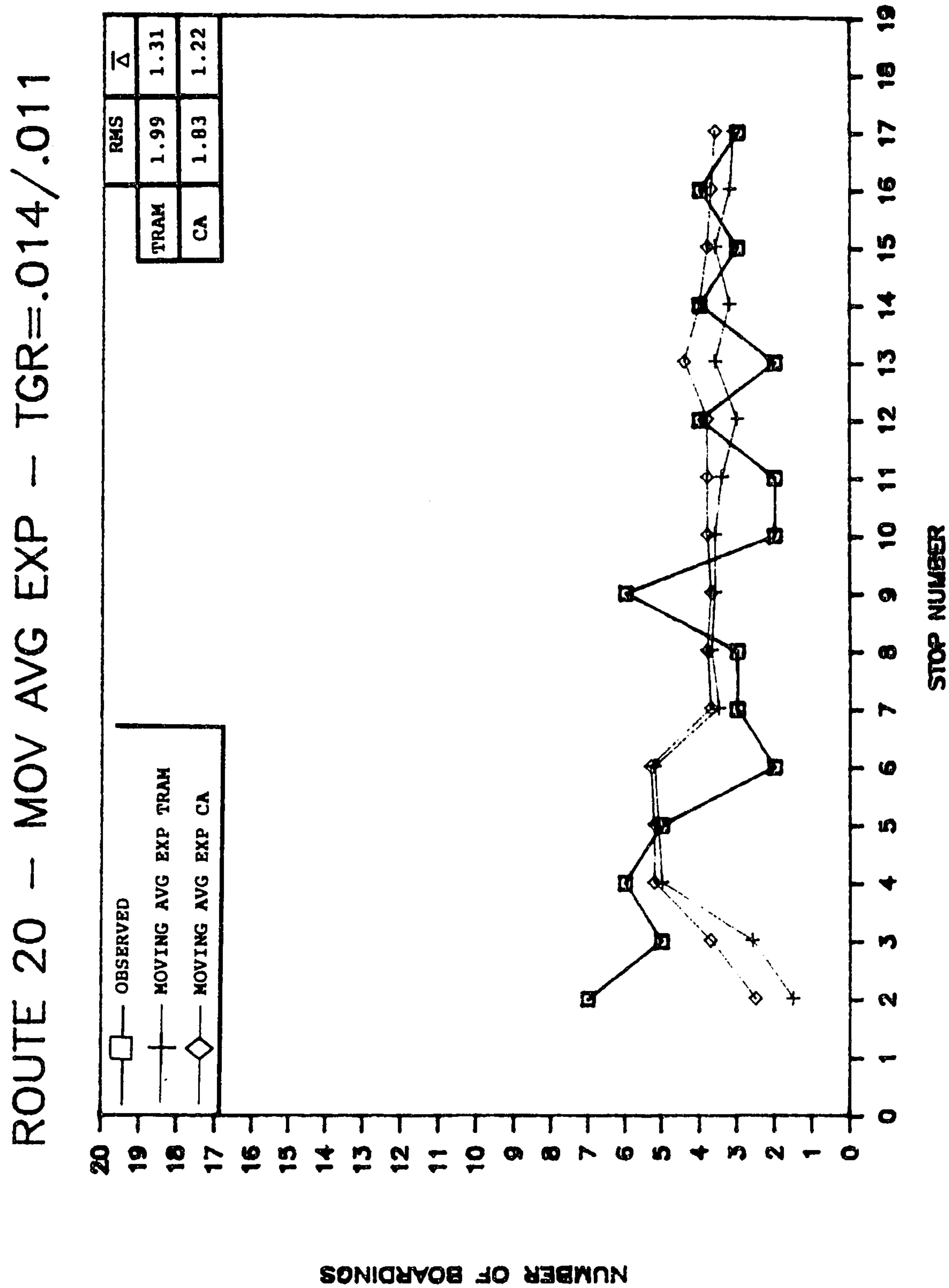


Figure 34(b) Density-sensitive TGR,
Route 20 partially smoothed results

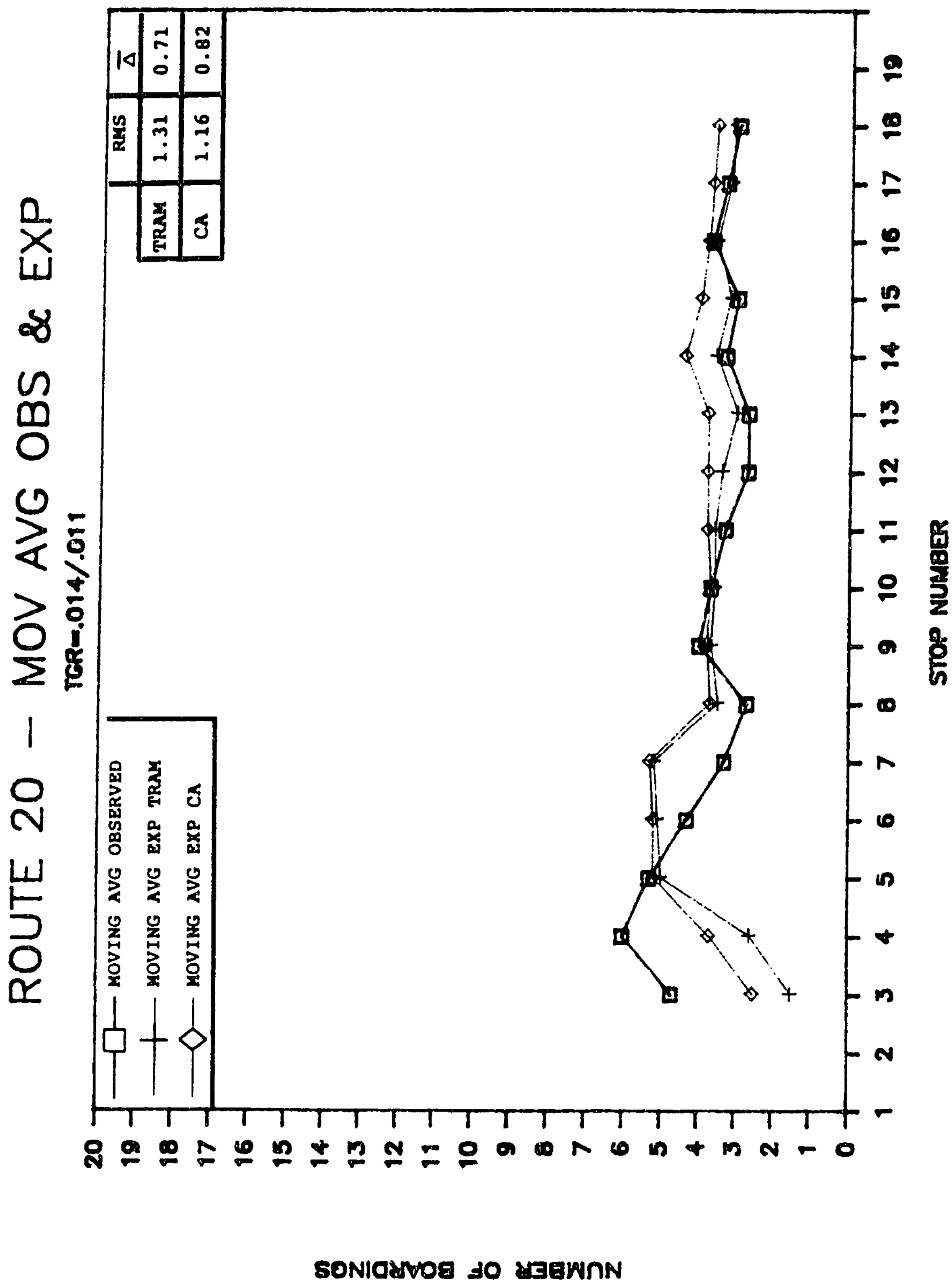


Figure 34(c) Density-sensitive TGR,
Route 20 fully smoothed results

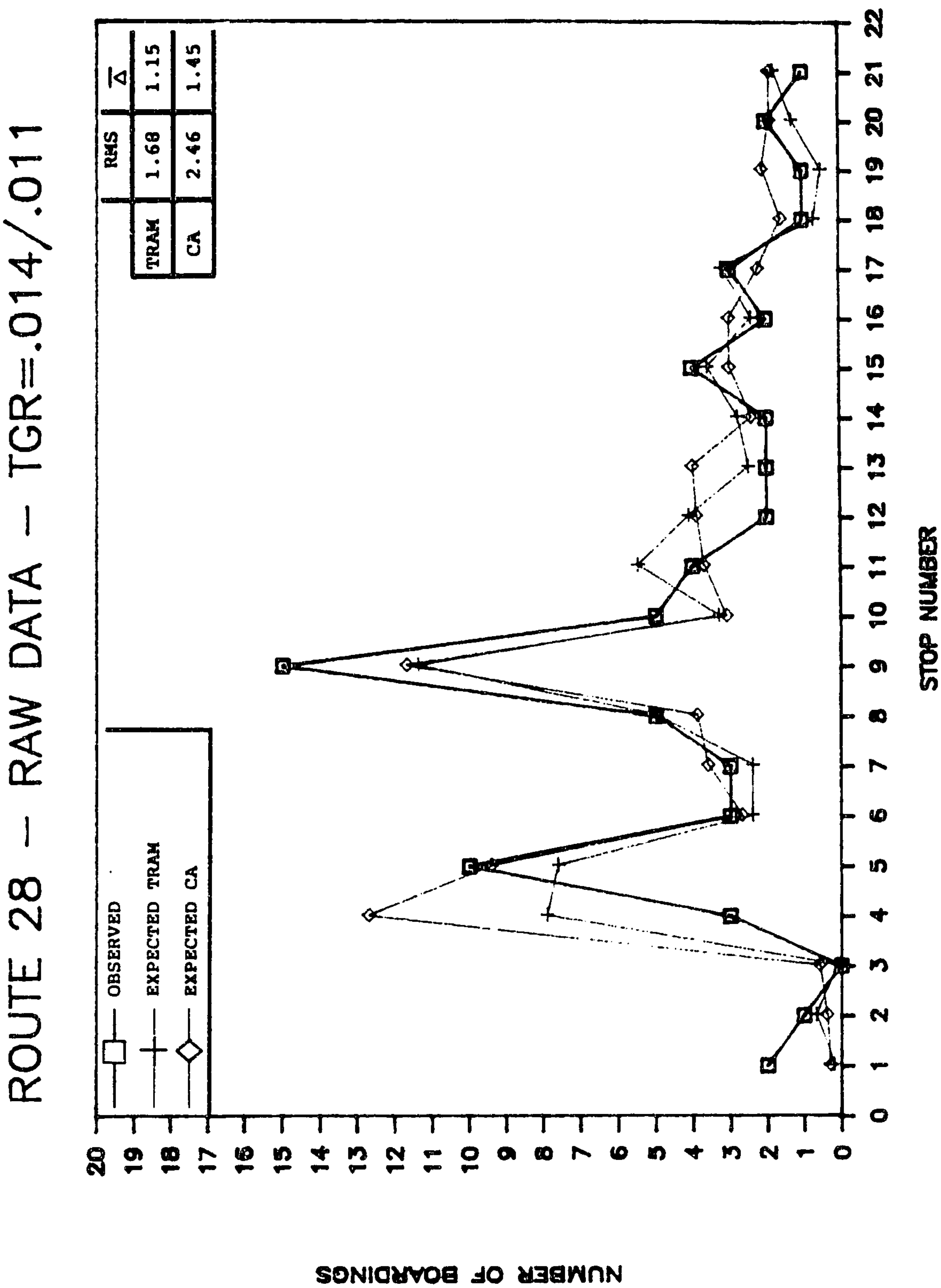


Figure 35(a) Density-sensitive TGR, Route 28 raw results

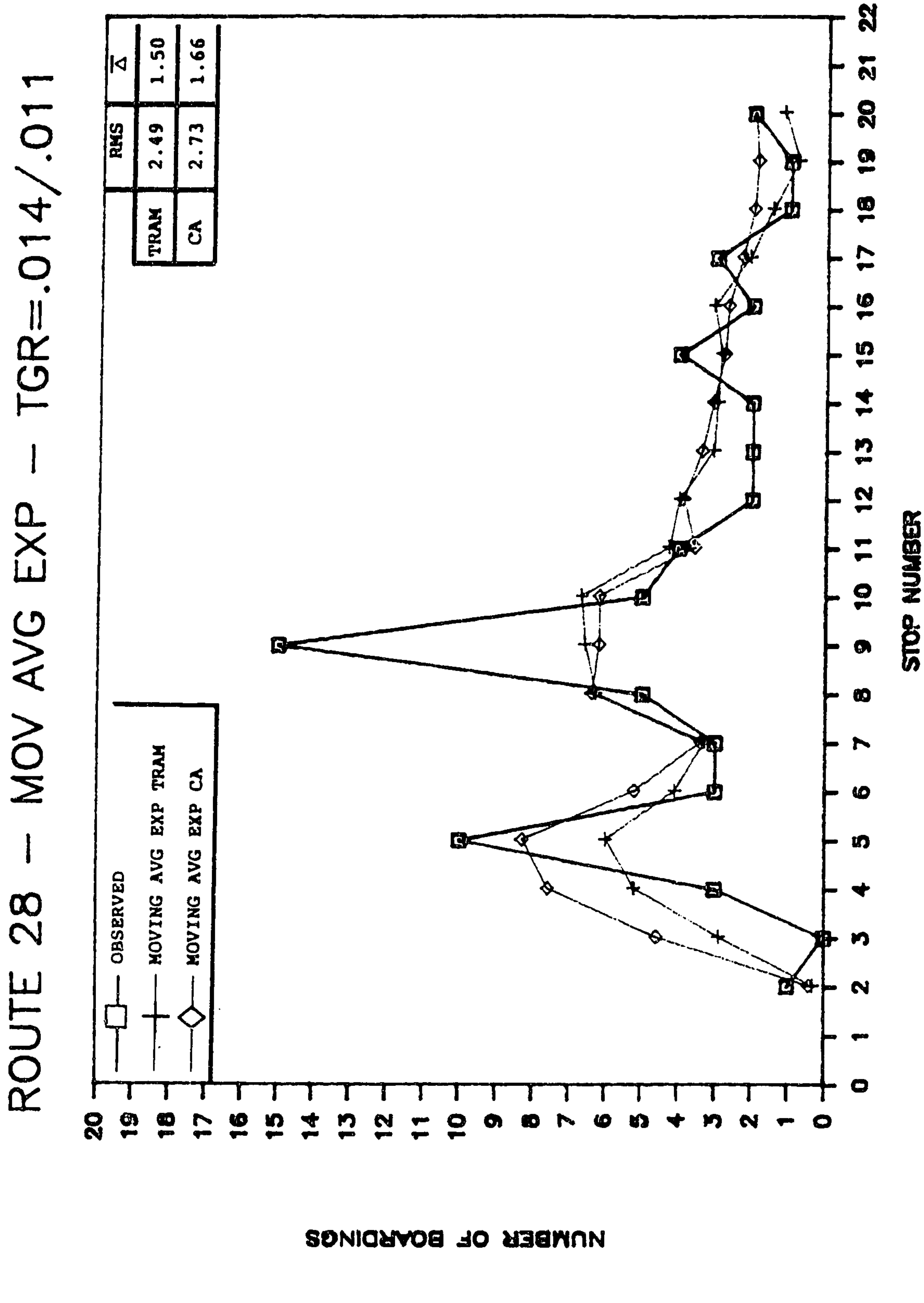


Figure 35(b) Density-sensitive TGR,
Route 28 partially smoothed results

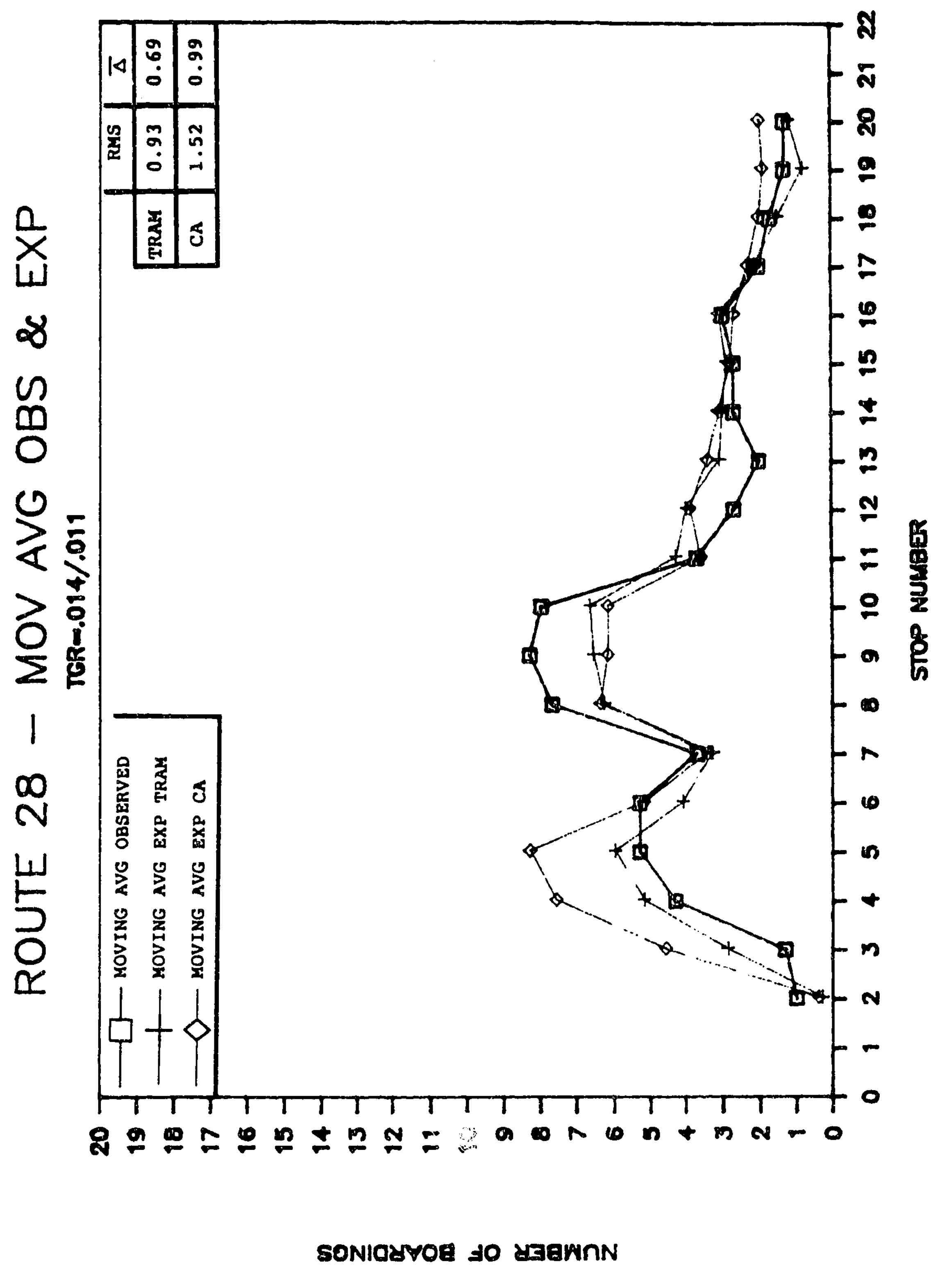


Figure 35(c) Density-sensitive TGR,
Route 28 fully smoothed results

survey observations increase abruptly with no corresponding movement in either of the model predictions. Although this may simply be a random fluctuation, it appears that there may be a significant unknown factor which exists in reality but is not reflected by the models. One way to address this problem would be to add further variables to the TRAM utility function. This would be possible if the unknown factor was tangible, such as the existence of a convenient fence on which to lean or a protective shelter in which to wait. However, this approach is not feasible if the unknown factor is not readily identifiable and is perhaps something more obscure such as a vicious dog which diverts people from an adjacent stop.

(4) An overall examination of the raw results reveals that, in most cases, the two predicted distributions fall approximately within an "envelope" about the observed distribution. It is suggested that this degree of fit may be sufficient for many purposes. Two good examples of the envelope concept are Figures 28(a) and 31(a), which show the raw results of Routes #50 and #72. In both cases, although the quantitative assessment indicates only a fair fit, it can be seen that all three distributions exhibit increasing and decreasing trends at roughly the same location and of roughly the same magnitude.

Envelopes of plus-or-minus various percentages were simulated numerically in order to determine the proportion of the observed boarding values that would fall within the specified envelope. The results of this analysis are shown in Table 8. It can be seen that, for these particular graphs, a vertical envelope of plus-or-minus forty percent is necessary to encompass more than half of the observed data points. However, this particular method of simulation represents a strict vertical envelope, as shown in Figure 36(a). More difficult to simulate numerically, but quite easy to visualize, is a perpendicular envelope as shown in Figure 36(b). It is this type of envelope which would appear to be appropriate for the research data.

(5) The results of the model predictions can also be represented in a cumulative format. This would be a practical idea since it could be combined with a simple model of alighting behaviour, deducting a certain number of riders at schools, shopping malls, etc., to produce *bona fide* route profiles. For example, Figure 37 is equivalent to the Route #18 raw results shown in Figure 25-a (except that the catchment-area predictions are excluded for simplicity).[12]

It can be seen that the differences between the observed distribution and the distribution predicted by TRAM appear to be much less significant than in the basic distribution. In practical terms, the results shown in Figure 37 would adequately determine the maximum load point and should yield the correct decision regarding the number of buses required to service the demand.

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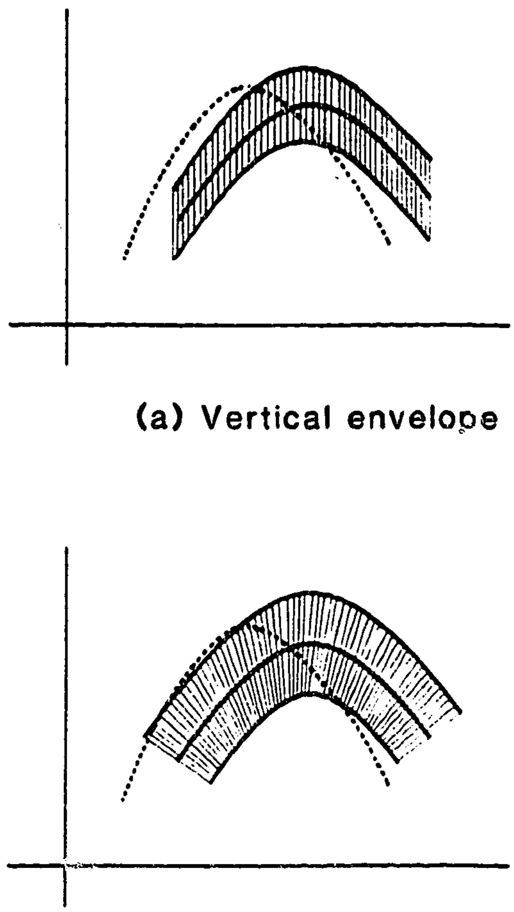
[12]It should be noted that the raw results for Route 18 were among the poorer results of the TRAM predictions.

VERTICAL ENVELOPE (+/- x PERCENT)	PROPORTION OF OBSERVED VALUES WITHIN ENVELOPE (%)
10	13
15	19
20	26
25	38
30	43
40	54
50	68

NOTE: Total number of observed values = 90

Table 8 - Numerical simulation of vertical envelopes



(a) Vertical envelope

(b) Perpendicular envelope

Figure 36 - Vertical and perpendicular envelopes

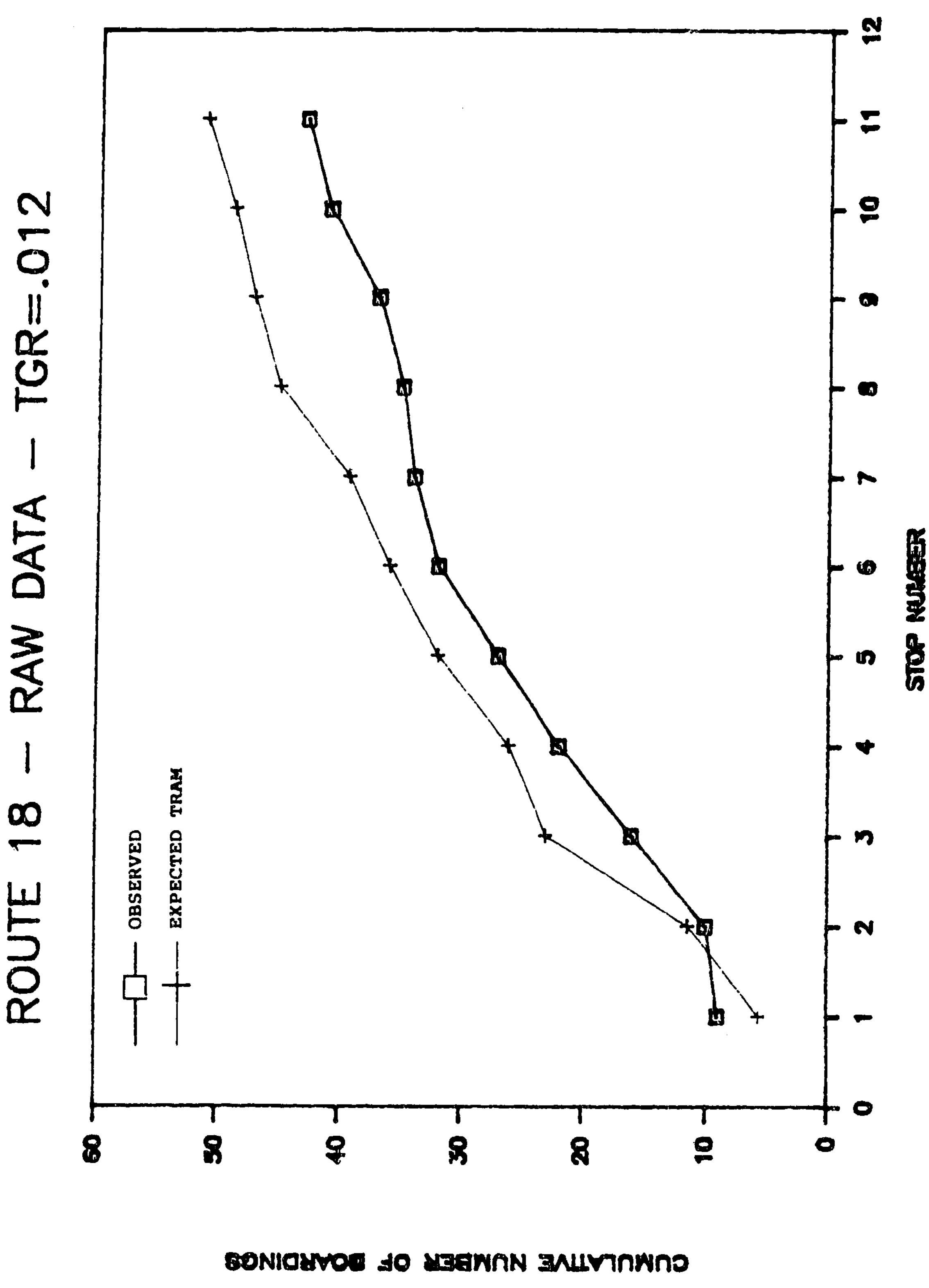


Figure 37 - Route 18 cumulative raw results

(6) A general evaluation of the merits of the smoothing provided by moving averages indicates that the basic raw-result graphs (labelled "a" in the figures) are most appropriate. In many cases, partial smoothing (application of moving averages to the model predictions only) detracted from favourable model performances by altering the predicted boarding distributions while leaving the observed distribution unchanged. Although by definition full smoothing (application of moving averages to both predictions and observations) results in greater similarity between boarding distributions, the difficulty of converting averaged boardings to individual stop-by-stop boardings makes full smoothing impractical.

Additionally, since this research constrained the total number of transit boardings to be equal, the results of full smoothing are one step toward the extreme of the concept whereby the result is three flat and nearly-identical boarding distributions. The stop-by-stop results for Routes #72 and #74 (Figures 31 and 32) illustrate this tendency, wherein the variability of the raw results contrasts with the similarity and flatness of the fully smoothed results.

XII. Discussion

This chapter presents discussion of some observations which can be drawn from the results of the testing, and discusses the assessment of transit service quality using TRAM.

Overall, the research indicates that the TRAM model provides a reasonably good representation of the behaviour of a particular transit market segment, specifically morning downtown transit commuters. However, the research survey also showed that other market segments (such as non-CBD workers and schoolchildren) contribute significantly to the total transit ridership in the morning peak. This is an important fact which should be recognized if TRAM is applied in a practical situation.

An observation arising from the application of the TRAM and catchment area models is that a good knowledge is required of the neighborhood in which the models are being applied. Frequent assumptions regarding probable walking-distance short-cuts and reasonable transit alternatives are required both for input to the TRAM program and construction of the catchment-area boundaries.

The research showed that the catchment-area model also provides a reasonable representation of transit commuter patterns. In general, the selected study areas and routes were quite simply structured. In all cases, the number of transfers was identical and the route frequencies were identical or very similar. The travel times of the various alternatives were usually similar. Thus, the primary source of variability in a choice set of transit alternatives was the walking distance. Since the CA model (by definition) minimizes the walking distance without consideration of other factors, it is not surprising that its performance is roughly equivalent to that of the TRAM model.

The lack of variability among the alternatives in the study areas is, in retrospect, a fault of the design of the research. Nonetheless, the TRAM predictions presented in this research are considered test cases for application of the model and the program. It is left to a subsequent researcher to test the TRAM model in a manner which better exercises its strengths and demonstrates its hypothesized capabilities to model more complex situations, particularly those where the input variables of the CA model do not address the differences among the alternatives.

As noted, possibly the most influential factor in explaining the performance of the TRAM model is that it was not applied to a situation complex enough to demonstrate its hypothesized superiority. However, a further contributing factor may have been that the TRAM model was calibrated from the revealed preferences of a total of 121 individuals. Research (Koppelman and Chu, 1983) has indicated that this amount of data may not have been sufficient to produce reliable predictions.

The original calibrated TRAM model incorporated the variable of destination-end walking distance. However, to determine a representative destination-end walking distance for an entire AU would require knowledge of each member's work location; this is information which would not be readily available. For testing purposes it was assumed that destination-end walking distance is randomly distributed and therefore on average could be assumed to be the same for all aggregation units and excluded from the TRAM program and subsequent data collection. The sensitivity of the model results to this assumption is not known and is left for future research.

Notwithstanding the similarity of the macro-level results of the TRAM and CA models, the favourable results of the micro-level application of TRAM are indicative that the "behavioral" aspect of the TRAM model is sound. Thus, although the research indicates that the CA model adequately represents patterns of transit boardings, only the Quality of Service Index of the TRAM model can be used to determine and maximize the transit service quality perceived by transit users. This capability to assess which of two transit network scenarios is "better" is important in the context of practical transit planning issues involving route alterations in existing or newly developing areas.

A specific example illustrates a potential application of this aspect of the TRAM model. In recent years there has been considerable debate regarding the alignment of the southward extension of Edmonton's Light Rail Transit system (Bakker, 1985). One alignment scenario follows an existing rail right-of-way, travels through an industrial area, and would need to be completely constructed before significant fare-generation could take place. The other scenario would necessitate the demolition of numerous houses, would travel through an existing residential community, but could be built in stages, each of which would begin producing revenue upon completion.

Each of these scenarios is characterized by variables resulting from policy decisions such as the feeder route structure, the proportion of direct buses and LRT-feeder buses, construction staging, and LRT frequency. Each scenario is accompanied by a known cost, and the problem is to quantify the benefit derived from each scenario in order to allow a rational evaluation of costs and benefits. None of the variables outlined above are addressed by the catchment-area model; however, the Quality of Service Index of the TRAM model could provide an objective, quantitative indication of which alternative would be most favourably perceived by transit users.

XIII. Conclusions

This research aimed to contribute to the understanding of disaggregate choice behaviour modelling by investigating its application in a practical transit planning context. Three research objectives were set out and have been accomplished:

- A multinomial logit model has been calibrated to describe the transit route choice behaviour of morning downtown commuters in Edmonton. The model, known as the Transit Route Analysis Model (TRAM), appears to be reasonable in terms of the signs and magnitudes of its utility function coefficients.
- The TRAM computer program embodies the calibrated multinomial logit model and accomodates its convenient application to transit planning problems. The program was tested extensively as an integral part of this research and functions well in the research environment.
- The output of the TRAM model has been validated against the observed behaviour of transit users at two "levels". The results show that TRAM has considerable merit at both the microscopic and macroscopic level.

The remainder of this chapter outlines the main conclusions of the research, several other findings arising from it, and suggestions for the direction of future research.

Main Conclusions

The results of the macro-level testing indicate that TRAM is an acceptable method of determining stop-by-stop transit demand which could be used in the production of transit route profiles. TRAM was found to be a relatively complex model, but not such that it was impractical to use. However, the test cases in this study demonstrated that the relatively simple catchment area model can produce results which are quite similar to those of the TRAM model.

The route proportion comparisons and some of the stop-by-stop boarding results indicated that the TRAM model is potentially superior to the catchment area model. This is attributed to the fact that, in more complex applications, TRAM better accomodates trade-offs between the various attributes of a transit trip. In fact, of the many factors associated with transit choice behaviour, only walking distance is addressed by the catchment area model. However, because of the remarkable similarity between the results of the TRAM and catchment area models themselves, if in a particular instance only a basic solution is required and the level of detail is routine, the catchment area model would be more appropriate. In another situation where the level of detail, the complexity of the problem, and the consequences of the resulting decision are great, the additional effort required for the use of the TRAM model would be justified.

The thesis demonstrated the production of a measure of composite utility labelled the Quality of Service Index. It suggested that the Quality of Service Index provides a useful and valid method of measuring and understanding the perceptions of transit users regarding transit service. Although the Index is very difficult to validate with certainty, the favourable results of the micro-level testing indicate that TRAM provides a good representation of transit user perceptions and behaviour. This is especially true in light of the absence of alternative approaches.

Other Findings

This research focused on the transit travel behaviour of morning downtown commuters. However, the validation survey revealed that this particular market segment contributes only a fraction of the total passenger load in the morning peak period. This finding combined with the problems encountered in the use of the Regional Travel Model transit trip generation rate indicates that care must be exercised when using the results of the macro-level predictions.

The hypothesis that different transit trip generation rates should be used to reflect differences in population density was not supported by the research. Testing showed that increases of up to twenty per cent in the trip generation rate for higher-density portions of a neighborhood did not result in a significant improvement in the performance of either TRAM or the catchment area model.

A lack of useful statistical techniques for quantifying the goodness of fit of discrete distributions was identified. Several common techniques were evaluated as candidates and rejected. A measure called the average absolute difference ($\bar{\Delta}$) was developed, and appears to be logical and conceptually attractive. Although it relies on the use of a second model to provide a basis of comparison for the TRAM model, it was used successfully as a comparitive tool.

As a means of enhancing evaluation of the macro-level results, the use of moving averages to smooth the results did not provide additional meaningful insight which would not have been evident from the raw results. Compounded with the conceptual difficulty associated with the averaging of survey observations, the moving average technique was not considered beneficial.

The research found that aggregation units of postcode size were convenient and appropriate for use with the TRAM program. However, it is noted that much manual data collection was required and made the TRAM program relatively time-consuming in application. Advances in computerized geographic information systems should be applied as available to eliminate much of the manual work and render the TRAM program considerably more convenient and practical.

It is concluded that the decision to test the TRAM results at both the microscopic and macroscopic levels was sound. Each aspect contributed to the investigation of the technique, and neither level of testing would have provided in isolation an equivalent insight.

The survey method selected to gather the data for the two levels of testing was considered successful. Although there were some minor mishaps in the data collection, the were caused primarily by human error rather than a deficiency in the survey design.

With the benefit of hindsight, some tasks would be approached differently. Initially it had been assumed that only insignificant numbers of passengers would choose the routes classified as secondary. Since the numbers of boardings assigned by TRAM to these routes were not negligible, it would have been beneficial to include in the validation survey the monitoring of the so-called secondary transit routes in the study areas.

A concern was noted with the size of the sample used to calibrate the TRAM model. In order to remove a measure of uncertainty about the calibration, it would have been better to have included a larger sample in the calibration process.

Future Research

In terms of continued research in this area, it is concluded that the TRAM procedure shows promise as a useful transit planning tool. In order to become more certain of its usefulness, it must be evaluated in a more complex situation to prove or disprove its potential superiority to the catchment area model.

Some potential alterations to the TRAM utility function are worth consideration. Among these are addition of a dummy variable specific to transit centres and addition of other more detailed variables such as whether a stop has a shelter, a concrete pad, or a bench. However, it is concluded that it would be beneficial to first apply TRAM in a more complex application, since the existing utility function may perform acceptably and a more complicated utility function may simply increase the margin of effort required to model using TRAM as compared to catchment areas.

It would also be useful to test the TRAM modelling technique in other market segments. For example, it would be good to test the performance of TRAM in modelling destinations other than the central business district, such as the University or an industrial park. Likewise, it would be illustrative to attempt to model different trip purposes and times of travel, such as mid-day shopping trips and school trips.

The matrix of equivalencies arising from the TRAM utility function provides useful insight into transit user perceptions of the various components of a transit trip. This insight contributes to considerations of transit network density and transfer policies.

It was concluded the in numerous instances the results of the comparison of stop-by-stop boardings and predictions had better visual similarity than indicated by the statistical measures of goodness of fit. The use of perpendicular envelopes as an alternative means of assessing goodness of fit was shown to be potentially beneficial, but requires further development.

The possibility was identified of relationships between the micro-level performance of the TRAM model and various demographic variables such as study area size and population. Although this aspect was beyond the scope of the current research, it may warrant further investigation.

It would be worth investigating the idea of validating the composite utility value referred to herein as the Quality of Service Index. This might be accomplished by long term use of census questions regarding satisfaction with transit service in different areas. Time series analysis of attitudes versus transit service could then be compared to predictions of composite utilities to determine their validity.

Also worthwhile would be further investigation of the role of the composite utility value as a linkage among components in the hierarchical modelling process. This is one of the most powerful aspects of the multinomial logit formulation, and it has potential applications including hierarchical models of mode split.

The key recommendation to guide future research in this area is to ensure that the pace of theoretical advancement is matched by practical, in-field validation of the predictions of the developing modelling techniques. Without such validation, it is impossible to know if or when the theories will find their way to benefit the transportation planning process.

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Appendix A

TRAM Program

Input Data File Format Descriptions

TRAM PROGRAM

Input Data File Format Descriptions

TRAM program input consists of two groups of data: (a) a network scenario description and (b) an aggregation unit description. The network scenario description provides information on the routes composing the particular transit network scenario which is to be analyzed; the aggregation unit description provides information on the alternatives available to each aggregation unit in the analysis area.

The two groups of TRAM data are contained in separate input datafiles, each consisting of a descriptive title line and a series of program data lines. The data lines are categorized into line types to accomodate organization and data checking.

The descriptive Title Line can be any combination of alphanumeric characters, and is used to identify the contents of the datafile and/or the particular program run. The numerical program data are entered as whole numberps without decimal points, right justified, in 5-column fields. The Line Type number always occupies the first 5-column field.

The following pages specify the exact contents of each Line Type.

NETWORK SCENARIO DESCRIPTION DATA
(I/O Unit 1)

Title Line

The first line in the data group must be the Title Line, which is a literal description of the network scenario being analyzed. Up to 60 alphanumeric characters may be used. Only one Title Line is permitted.

Columns Used	Entry
1-60	Identifier

Line Type 11

For each route in the network scenario, this line identifies the route, the number of stops on the route, and the nominal frequency of sevice on the route. One Line Type 11 is required for each route. The maximum number of routes is 20, though in practice this limit will seldom be approached.

Columns Used	Entry
1-5	11
6-10	Route number
11-15	Number of stops on route (maximum of 100)
16-20	Nominal frequency of service on route (minutes of headway)

Note:

(a) Line Type 11 is the first line in the description of each route in the routing scheme. It must be followed be one Line Type 12 for each stop on the route.

Line Type 12

One Line Type 12 is required to describe each stop on the route of the previous Line Type 11. The number of Lines Type 12 required is specified on Line Type 11, Columns 11-15. The maximum number of stops on each route is 100, though in practice this limit will seldom be approached.

Columns Used	Entry
1-5	12
6-10	Stop number
11-30	Literal description of address of stop
31-35	Scheduled arrival time, using the 24-hour clock (hhmm)

Note:

(a) The stop address (Columns 11-30) can be any combination of alphanumeric characters, but is recommended to be consistent with the City of Edmonton Transportation Department stop-description convention.

AGGREGATION UNIT DESCRIPTION DATA
(I/O Unit 2)

Title Line

The first line in the data group must be the Title Line, which is a literal description of the analysis area location and/or the particulars of the program run. Up to 60 alphanumeric characters may be used. Only one Title Line is permitted.

Columns Used	Entry
1-60	Identifier

Line Type 21

This line contains the average automobile travel time from the analysis area to the downtown. (This value is used to calculate the utility of an automobile-equivalent transit service which is used for comparitive purposes in the program output.) A Line Type 21 must follow the Title Line and precedes Lines Type 22 and 23.

Columns Used	Entry
1-5	21
6-10	Automobile travel time (minutes)

Note:

(a) The automobile travel time from Line Type 21 is used in program calculations for all aggregation units which follow sequentially in the datafile. It can be changed by entering another Line Type 21 immediately preceding any Line Type 22. This may be desirable if the analysis area is so large that travel times differ significantly over the area.

Line Type 22

This line describes the characteristics of an aggregation unit. One Line Type 22 is required for each aggregation unit. The maximum number of aggregation units is 1000, though in practice this limit will seldom be approached.

Columns Used	Entry
1-5	22
6-10	Label of aggregation unit
11-15	Population of aggregation unit
16-20	Transit trip generation rate (percent)
21-25	Number of transit alternatives available to aggregation unit (maximum of 9)

Note:

(a) Line Type 22 is the first line in the description of each aggregation unit in the analysis area. It must be followed by one Line Type 23 for each transit alternative available to the aggregation unit.

(b) The aggregation unit population (Columns 11-15) and transit trip generation rate (Columns 16-20) are used to determine the number of people in the aggregation unit who use transit for a morning work trip to the downtown. There is more than one way to input this to TRAM:

- o If the actual population is used, a realistic transit generation rate for the specified type of trip must be used.

- o If the user can estimate the number of morning downtown commuters directly, the estimate can be entered as the "population" of the aggregation unit and the "transit trip generation rate" entered as 100 percent.

Line Type 23

One Line Type 23 is required to describe the attributes of each transit alternative available to the aggregation unit of the previous Line Type 22. The number of Lines Type 23 required is specified on Line Type 22 Columns 21-25. The maximum number of transit alternatives is 9.

Columns Used	Entry
1-5	23
6-10	Route number of transit alternative (consistent with and corresponding to a route on Line Type 11, Columns 6-10)
11-15	Stop number of transit alternative (consistent with and corresponding to a stop on Line Type 12, Columns 6-10)
16-20	Walking distance from centroid of aggregation unit to the transit stop (metres)
21-25	Number of transfers required to reach the downtown
26-30	Effective frequency of service, which overrides the nominal frequency of Line Type 11, Columns 16-20 (see note "a")

Note:

(a) If Line Type 23, Columns 21-25 is non-zero, an effective frequency must be specified, even if it is the same as the nominal frequency; if the contents of the columns are zero, the effective frequency must also be zero.

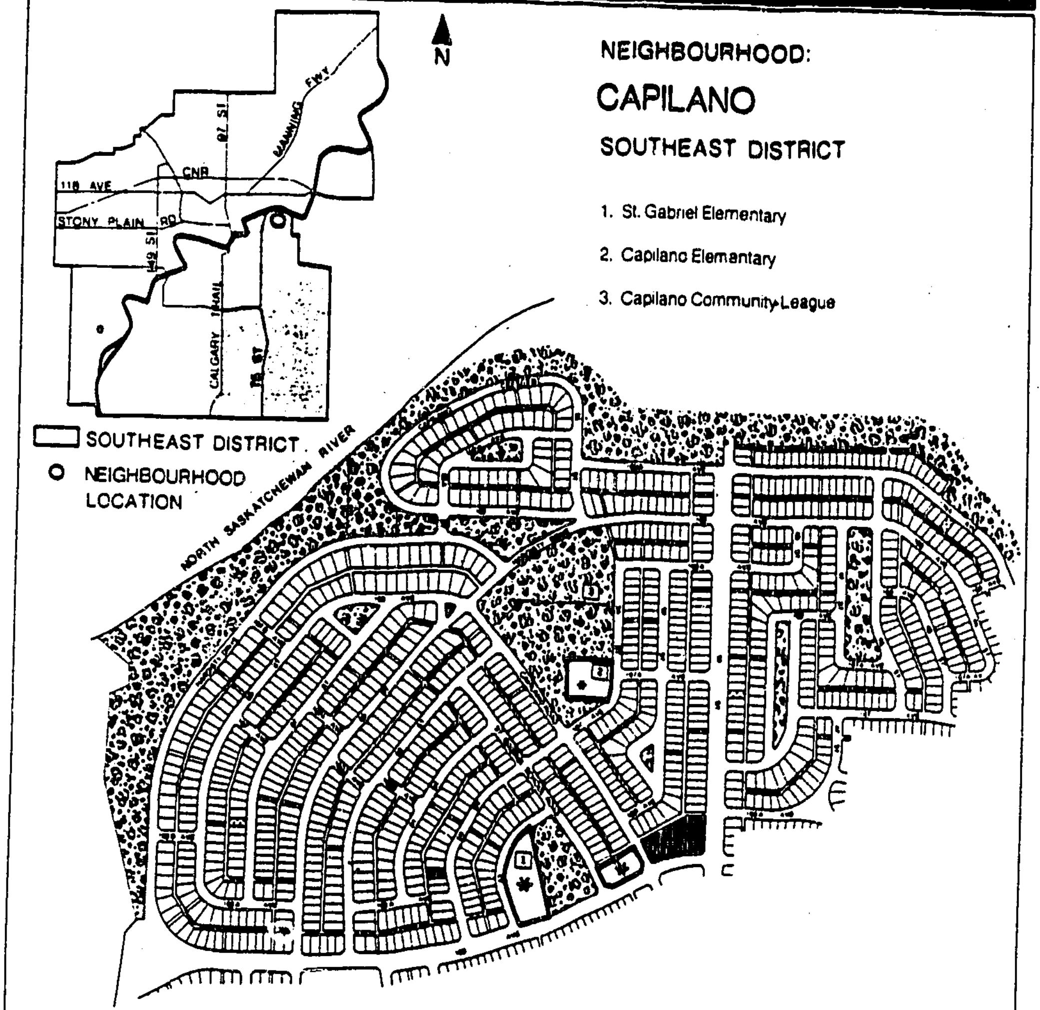
Appendix B

Neighborhood Fact Sheets

Source: City of Edmonton Planning Department

Index:

NEIGHBOURHOOD FACT SHEET



LAND USE

- Single Dwelling
- Two Unit Dwellings
- Multiple Family Dwellings
- Apartments
- Recreation, Open Space
- Commercial
- Industrial, Public Utilities
- Institutional
- Transportation
- Vacant, Undeveloped
- Vacant, Residential
- Vacant, Institutional
- Vacant, Commercial

CAPILANO: BASIC FACTS

Housing Types	No. of Units
Single Detached	1077
Duplex/Semi-Detached	6
Row/Townhousing	0
Apartments	0
TOTAL	1083

Length of residence in neighbourhood: at same address	%
5 or more years	79
3 to 4 years	10
1 to 2 years	7
less than 1 year	4

Tenure	%
Homeowners	92
Renters	7
Vacant	1
Under Construction	0

WHAT PEOPLE ARE:

	Pre-Sch.	Kind.-Gr. 6	Gr. 7-Gr. 9	Gr. 10-Gr. 11	Post Sec.	Home Maker	Emp. Full Time	Emp. Part Time	Not Emp.	Retired	Other
Male	84	114	66	107	106	0	872	40	81	193	9
Female	72	88	65	78	82	498	428	192	19	33	13
TOTAL	156	202	131	185	188	498	1300	232	100	226	22

Total Population- 3,244

Age Groups	No.	%	Comparison With Nearby Neighbourhoods: Forest Heights %	Fulton Place %	Gold Bar %	City of Edmonton %
0-4	123	3.7	4.6	3.0	4.8	7
5-14	332	10.1	6.3	8.4	13.1	13
15-19	315	9.7	6.6	8.1	10.4	7
20-39	909	27.5	39.4	29.2	27.1	43
40-59	1037	31.7	22.1	28.0	27.2	19
Over 60	528	17.3	21.0	23.3	17.4	11

Source: 1983 Civic Census

Schools

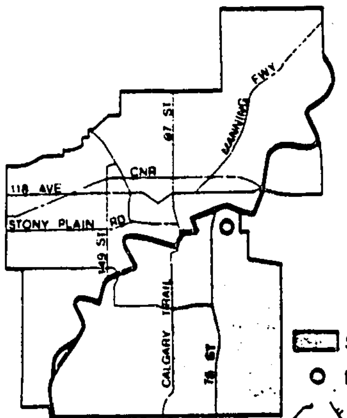
	Enrollment 1972	Enrollment 1982	% Change	Capacity	% Capacity Occupied
Capilano Elementary	390	173	-55	400	43
St. Gabriel Elementary & Junior High	490	244	-50	425	57

December, 1983

For information on Planning services, contact the **Southeast District Planning** team at 421-7080. For information on other Civic services, contact the **Citizen Action Centre** 428-2600.

The City of Edmonton PLANNING

NEIGHBOURHOOD FACT SHEET

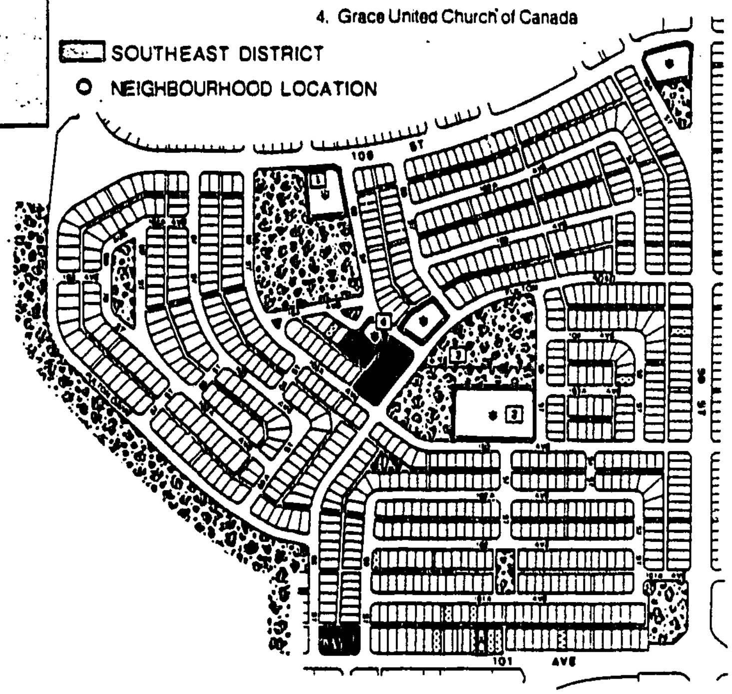


NEIGHBOURHOOD:

FULTON PLACE

SOUTHEAST DISTRICT

1. Hardisty Junior High
2. Fulton Place Elementary
3. Fulton Place Community League
4. Grace United Church of Canada



LAND USE

Single Dwelling	Recreation, Open Space	Transportation
Two Unit Dwellings	Commercial	Vacant, Undeveloped
Multiple Family Dwellings	Industrial, Public Utilities	Vacant, Residential
Apartments	Institutional	Vacant, Institutional
		Vacant, Commercial

FULTON PLACE: BASIC FACTS

Housing Types	No. of Units	Length of residence in neighbourhood at same address	%	Tenure	%
Single Detached	796	5 or more years	72.4	Homeowners	81.1
Duplex/Semi-Detached	26	3 to 4 years	10.9	Renters	16.9
Row/Townhousing	108	1 to 2 years	9.5	Vacant	2.0
Apartments	71	less than 1 year	7.2	Under Construction	0
TOTAL	1001				

WHAT PEOPLE ARE:

	Pre-Sch.	Kind.-Gr. 6	Gr. 7-Gr. 9	Gr. 10-Gr. 11	Post Sec.	Home Maker	Emp. Full Time	Emp. Part Time	Not Emp.	Retired	Other
Male	68	83	43	84	73	1	648	30	102	204	2
Female	50	64	39	52	49	407	371	96	30	142	5
TOTAL	116	147	82	136	122	408	1019	126	132	346	7

Total Population- 2,639

Comparison With Nearby Neighbourhoods

Age Groups	No.	%	Capilano %	Goldbar %	Terrace Heights %	City of Edmonton %
0-4	82	3.0	3.7	4.8	4.1	7
5-14	228	8.4	10.1	13.1	7.8	13
15-19	216	8.1	9.7	10.4	6.9	7
20-39	776	29.2	27.5	27.1	39.2	43
40-59	749	28.0	31.7	27.2	25.4	19
Over 60	588	23.3	17.3	17.4	16.6	11

Source: 1983 Civic Census

Schools

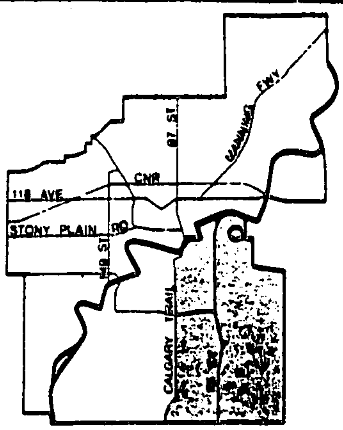
	Enrollment 1972	Enrollment 1982	% Change	Capacity	% Capacity Occupied
Fulton Place Elementary	603	239	-60	600	39
Hardisty Junior High	936	389	-58	955	40

December, 1983

The City of Edmonton PLANNING

For information on Planning services, contact the **Southeast District Planning** team at 421-7080. For information on other Civic services, contact the **Citizen Action Centre 428-2600.**

NEIGHBOURHOOD FACT SHEET



▭ SOUTHEAST DISTRICT

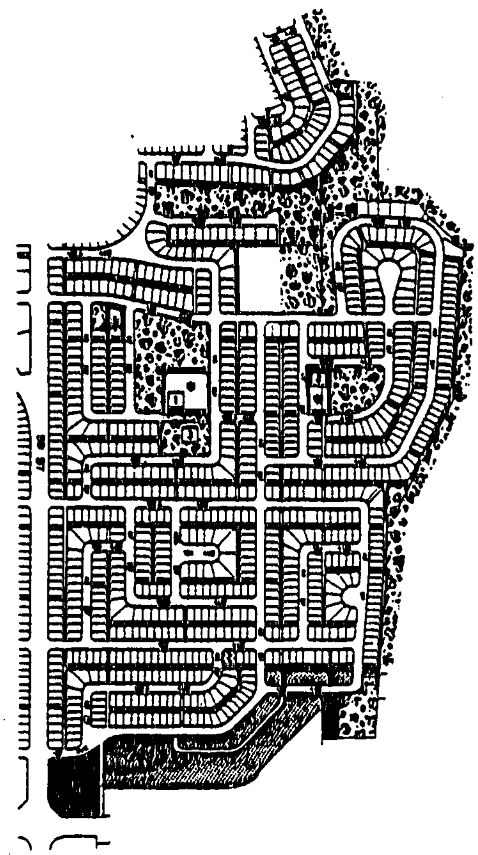
O NEIGHBOURHOOD LOCATION

1. Gold Bar Elementary
2. St. Bede Elementary
3. Gold Bar Community League

NEIGHBOURHOOD:

GOLD BAR

SOUTHEAST DISTRICT



LAND USE

Single Dwelling	Recreation, Open Space	Transportation
Two Unit Dwellings	Commercial	Vacant, Undeveloped
Multiple Family Dwellings	Industrial, Public Utilities	Vacant, Residential
Apartments	Institutional	Vacant, Institutional
		Vacant, Commercial

GOLD BAR : BASIC FACTS

Housing Types	No. of Units	Length of residence in neighbourhood at same address	%	Tenure	%
Single Detached	874	5 or more years	69.5	Homeowners	69.9
Duplex/Semi-Detached	6	3 to 4 years	11.2	Renters	29.1
Row/Townhousing	102	1 to 2 years	10.2	Vacant	1.0
Apartments	36	less than 1 year	9.1	Under Construction	0
TOTAL	1018				

WHAT PEOPLE ARE

	Pre-Sch.	Kind.-Gr. 6	Gr. 7-Gr. 9	Gr. 10-Gr. 11	Post Sec.	Home Maker	Emp. Full Time	Emp. Part Time	Not Emp.	Retired	Other
Male	118	159	99	102	89	0	845	58	167	114	13
Female	110	143	96	102	67	407	481	197	59	105	4
TOTAL	218	302	195	204	156	407	1326	255	226	219	17

Total Population- 3,520

Comparison With Nearby Neighbourhoods

Age Groups	No.	%	Capilano %	Fulton Place %	Ottewell %	City of Edmonton %
0-4	171	4.8	3.7	3.0	2.7	7
5-14	472	13.1	10.1	8.4	9.7	13
15-19	369	10.4	9.7	8.1	11.3	7
20-39	1143	27.1	27.5	29.2	29.9	43
40-59	973	27.2	31.7	28.0	31.9	19
Over 60	392	17.4	17.3	23.3	14.5	11

Source: 1983 Civic Census

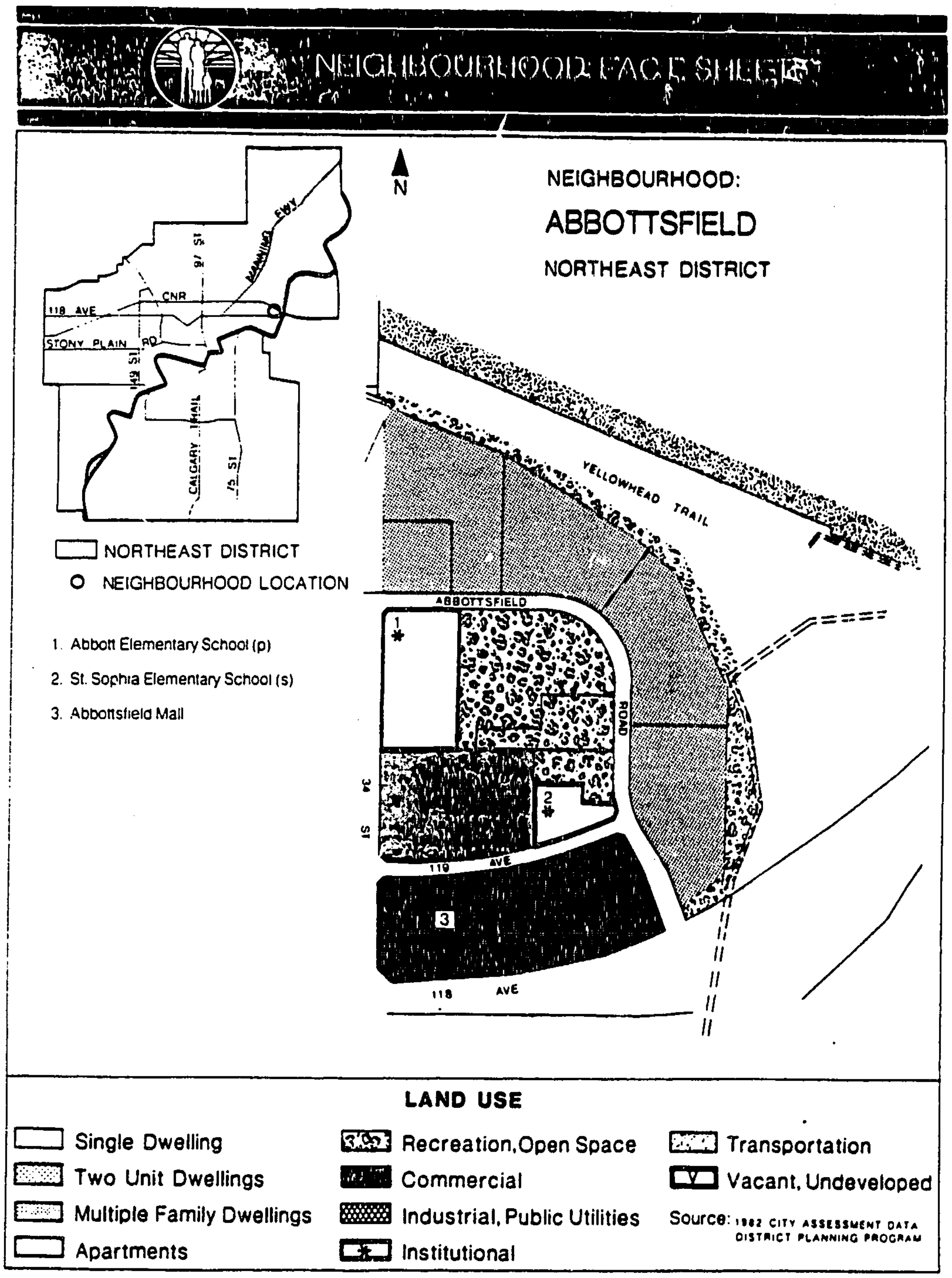
Schools

	Enrollment 1972	Enrollment 1982	% Change	Capacity	% Capacity Occupied
St. Bede Elementary	296	106	-64	250	42
Gold Bar Elementary	464	169	-63	450	37

December, 1983

For information on Planning services, contact the Southeast District Planning team at 421-7080. For information on other Civic services, contact the Citizen Action Centre 428-2600.

The City of Edmonton PLANNING


NEIGHBOURHOOD FACT SHEET
N
NEIGHBOURHOOD:
ABBOTTSFIELD
NORTHEAST DISTRICT
118 AVE
STONY PLAIN RD
CNR
149 ST
CALGARY TRAIL
YELLOWHEAD TRAIL
ABBOTTSFIELD ROAD
34 ST
119 AVE
118 AVE
NORTHEAST DISTRICT
NEIGHBOURHOOD LOCATION
1. Abbott Elementary School (p)
2. St. Sophia Elementary School (s)
3. Abbottsfield Mall
LAND USE
Single Dwelling
Two Unit Dwellings
Multiple Family Dwellings
Apartments
Recreation, Open Space
Commercial
Industrial, Public Utilities
Institutional
Transportation
Vacant, Undeveloped
Source: 1982 CITY ASSESSMENT DATA
DISTRICT PLANNING PROGRAM

ABBOTTSFIELD

Neighbourhood Character

Density: 40.4 people/hectare (gross)

Housing	No. of Units	
Single Family Dwellings	-	-%
Semi/Duplex Dwellings	-	-%
Multi Family Dwellings	478	65.5%
Apartments (1-4 storeys)	252	34.5%
Apartments (5+storeys)	-	-%
	730 units	

Land Area	51.9ha.	
Residential	13.9ha.	26.8%
Institutional	2.5ha.	4.8%
Recreation/Open Space	3.4ha.	6.6%
Commercial	5.2ha.	10.0%
Other	26.9ha.	51.8%

Length of Residence
Lived at the same address:

5 or more years	17.3%
1 to 4 years	52.7%
less than 1 year	30.0%

Tenure

Homeowners	22.5%
Renters	77.5%

Population

Age Groups	1983 No.	1983 %	1983 City of Edmonton %
0-4	285	13.6	7.6
5-19	628	30.0	21.0
20-39	908	43.3	42.4
40-59	221	10.5	18.7
60-64	18	.9	3.3
65+	38	1.7	7.0
	2,098		

Sources: 1983 - City of Edmonton Civic Census

Schools

	Enrollment 1972	Enrollment 1982	Capacity
Abbott Elementary (Public)	201	310	525
St. Sophia Elementary (Separate)	N/A	130	250

Recreation Facilities

Abbott Elementary - ball diamonds, soccer fields, playground
Abbotsfield Road - playground, tot lot
District Facilities nearby:
- Rundle Park A.C.T. Centre, pool - 118 Avenue/Victoria Trail
- Santa Rosa Arena - 120 Avenue/68 Street

Community Services

Edmonton Social Services - Beverly Centre - 5005 112 Avenue - 474-8221
Beacon Heights Community League

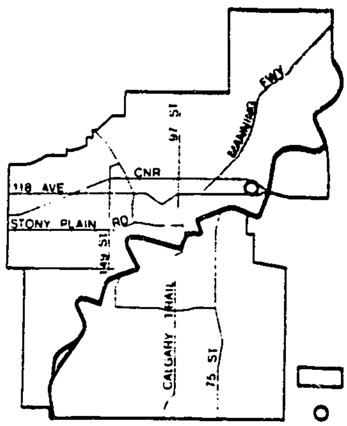
APRIL 1984

THE CITY OF Edmonton PLANNING

For information on Planning services, contact the **Northeast District Planning Team** at 428-8565.

For information on other Civic services, contact the Citizen Action Centre at 428-2600.

NEIGHBOURHOOD FACT SHEET



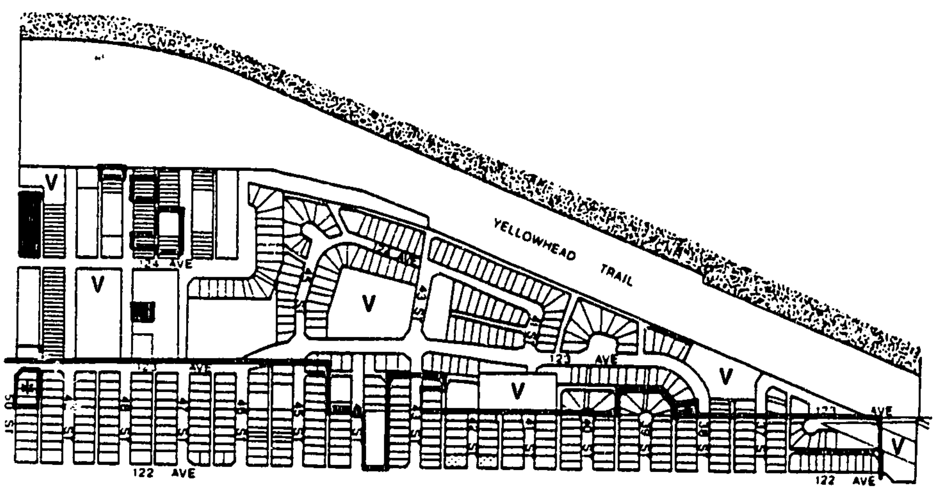
NEIGHBOURHOOD:

BERGMAN

NORTHEAST DISTRICT

NORTHEAST DISTRICT

O NEIGHBOURHOOD LOCATION



LAND USE

Single Dwelling	Recreation, Open Space	Transportation
Two Unit Dwellings	Commercial	Vacant, Undeveloped
Multiple Family Dwellings	Industrial, Public Utilities	
Apartments	Institutional	

Source: 1982 CITY ASSESSMENT DATA, DISTRICT PLANNING PROGRAM

BERGMAN

Neighbourhood Character

Density: 12.5 people/hectare (gross)

Housing	No. of Units		Land Area	88.6ha.	
Single Family Dwellings	214	95.5%	Residential	14.0ha.	15.8%
Semi/Duplex Dwellings	10	4.5%	Institutional	.3ha.	.3%
Multi Family Dwellings	-	-%	Commercial	.1ha.	.1%
Apartments (1-4 storeys)	-	-%	Other	74.2ha.	83.7%
Apartments (5+storeys)	-	-%			
	224 units				

Length of Residence
Lived at the same address:

5 or more years	65.8%
1 to 4 years	20.4%
less than 1 year	13.8%

Tenure

Homeowners	71.7%
Renters	28.9%

Population

Age Groups	1971 No.	1971 %	1983 No.	1983 %	1983 City of Edmonton %
0-4	106	9.8	61	5.1	7.6
5-19	421	38.8	329	27.4	21.0
20-39	290	26.8	373	31.0	42.4
40-59	208	19.2	296	24.6	18.7
60-64	18	1.7	53	4.4	3.3
65+	41	3.7	90	7.5	7.0
	1,084		1,202		

Sources: 1983 - City of Edmonton Civic Census
1971 - Census of Canada

Recreation Facilities

District Facilities nearby:
- Rundle Park, A.C.T. Centre, Pool - 118 Avenue/Victoria Trail
- Santa Rosa Arena - 120 Avenue/ 68 Street

Community Services

Edmonton Social Services - Beverly Centre - 5005 112 Avenue - 474-8221
Beacon Heights Community League

APRIL 1984

The City of Edmonton PLANNING

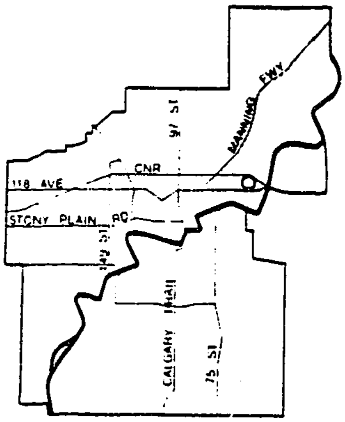
For information on Planning services, contact the **Northeast District Planning Team** at 428-8565.

For information on other Civic services, contact the Citizen Action Centre at 428-2600.

NEIGHBOURHOOD:

BEACON HEIGHTS

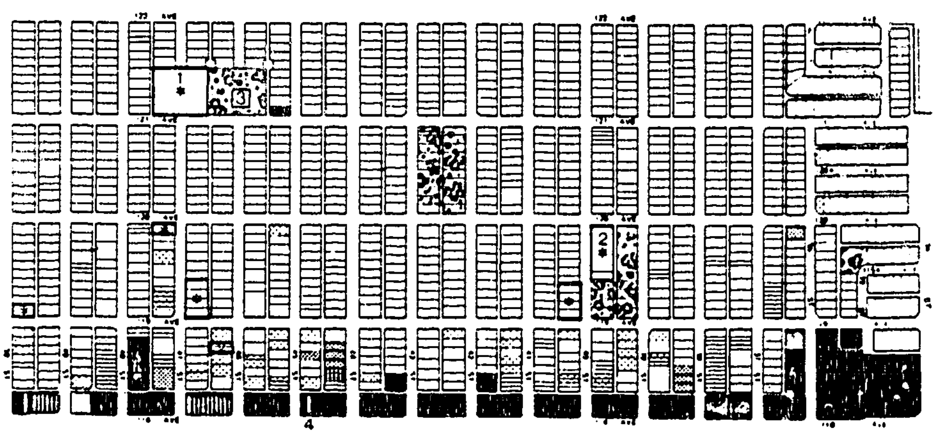
NORTHEAST DISTRICT



NORTHEAST DISTRICT

NEIGHBOURHOOD LOCATION

1. Beacon Heights Elementary (p)
2. St. Bernadette Elementary (s)
3. Beverly Jubilee Park/Beacon Heights Community League
4. Beacon Heights Community League Hall



LAND USE

- Single Dwelling
- Two Unit Dwellings
- Multiple Family Dwellings
- Apartments
- Recreation, Open Space
- Commercial
- Industrial, Public Utilities
- Institutional
- Transportation
- Vacant, Undeveloped

Source: 1987 FIELD SURVEY DISTRICT PLANNING PROGRAM

BEACON HEIGHTS

Neighbourhood Character

Density: 28.6 people/hectare (gross)

Housing	No. of Units	
Single Family Dwellings	1,224	81.9%
Semi/Duplex Dwellings	50	3.3%
Multi Family Dwellings	77	5.2%
Apartments (1-4 storeys)	143	9.6%
Apartments (5+storeys)	-	-%
	1,494 units	

Land Area	119.0ha.	
Residential	64.6ha.	54.3%
Institutional	1.8ha.	1.5%
Recreation/Open Space	3.2ha.	2.7%
Commercial	6.9ha.	5.8%
Other	42.5ha.	35.7%

Length of Residence
Lived at the same address:

5 or more years	64.1%
1 to 4 years	19.4%
less than 1 year	16.5%

Tenure

Homeowners	65.9%
Renters	34.1%

Population

Age Groups	1971 No.	1971 %	1983 No.	1983 %	1983 City of Edmonton %
0-4	474	9.9	162	4.8	7.6
5-19	1,754	36.7	740	21.9	21.0
20-39	1,360	28.4	1,148	34.0	42.4
40-59	832	17.4	887	26.3	18.7
60-64	154	3.2	154	4.6	3.3
65+	209	4.4	284	8.4	7.0
	4,783		3,375		

Sources: 1983 - City of Edmonton Civic Census
1971 - Census of Canada

Schools	Enrollment 1972	Enrollment 1982	Capacity
St. Bernadette Elementary (Separate)	296	158	250
Beacon Heights Elementary (Public)	316	116	275

Recreation Facilities

Beacon Heights Elementary - ball diamond, soccer fields
St. Bernadette Elementary - ball diamonds, soccer fields
Playgrounds - 120 Avenue/35 Street
- 120 Avenue/43 Street
Beacon Heights Community League - halls, playground
District Facilities nearby:
- Rundle Park, A.C.T. Centre, pool - 118 Avenue/Victoria Trail
- Santa Rosa Arena - 120 Avenue/68 Street

Community Services

Edmonton Social Services - Beverly Centre - 5005 112 Avenue - 474-8221
Beacon Heights Community League

SEPTEMBER 1983.

The City of Edmonton PLANNING

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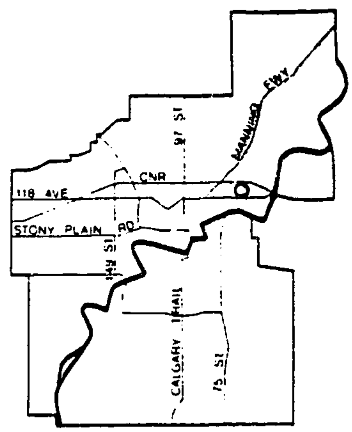
NEIGHBOURHOOD FACT SHEET



NORTHEAST DISTRICT

O NEIGHBOURHOOD LOCATION

1 Newton Elementary School (p)

2 St. Leo Elementary/Jr. High School (s)

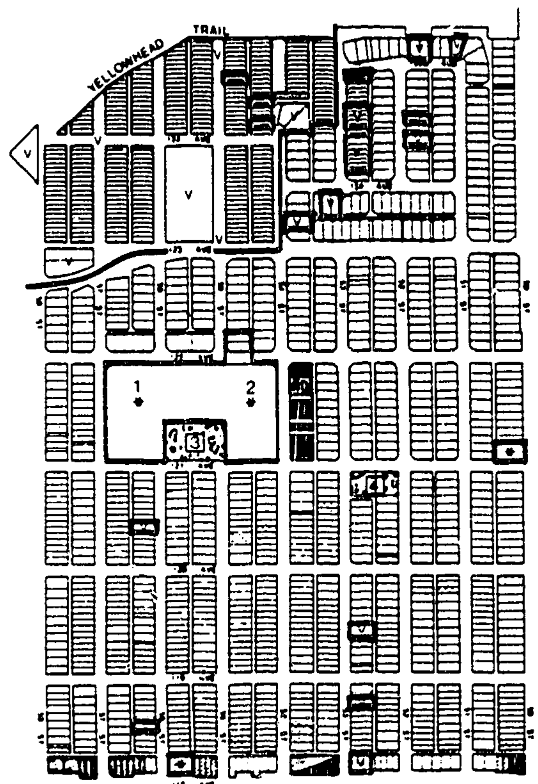
3 Newton Community League

4 Jacob Prins Park

NEIGHBOURHOOD:

NEWTON

NORTHEAST DISTRICT



LAND USE

Single Dwelling

Two Unit Dwellings

Multiple Family Dwellings

Apartments

Recreation, Open Space

Commercial

Industrial, Public Utilities

Institutional

Transportation

Vacant, Undeveloped

Source: 1982 FIELD SURVEY DISTRICT PLANNING PROGRAM

NEWTON

Neighbourhood Character

Density: 27.7 people/hectare (gross)

Housing	No. of Units	
Single Family Dwellings	887	84.1%
Semi/Duplex Dwellings	40	3.8%
Multi Family Dwellings	14	1.3%
Apartments (1-4 storeys)	114	10.8%
Apartments (5+storeys)	-	-%
	1055 units	

Land Area	106.9 ha.	
Residential	48.9 ha.	45.7%
Institutional	4.4 ha.	4.2%
Recreation/Open Space	.9 ha.	.8%
Commercial	.6 ha.	.6%
Other	52.1 ha.	48.7%

Length of Residence
Lived at the same address:

5 or more years	57.4%
1 to 4 years	29.8%
less than 1 year	12.8%

Tenure

Homeowners	67.6%
Renters	32.4%

Population

Age Groups	1971 No.	1971 %	1983 No.	1983 %	1983 City of Edmonton %
0-4	267	9.0	122	4.2	7.6
5-19	982	33.1	610	20.9	21.0
20-39	826	27.8	992	33.9	42.4
40-59	651	22.0	693	23.7	18.7
60-64	79	2.6	172	5.9	3.3
65+	166	5.5	333	11.4	7.0
	2971		2922		

Sources: 1983 - City of Edmonton Civic Census
1971 - Census of Canada

Schools	Enrollment 1972	Enrollment 1982	Capacity
Newton Elementary (Public)	281	179	425
St. Leo Elementary/Jr. High (Separate)	252	176	325

Recreation Facilities

Newton Elementary - ball diamonds, soccer fields, playgrounds
St. Leo Elementary/Jr. high - ball diamonds, soccer fields
Newton Community League Hall
District Facilities nearby:

- Borden Park - 112 Avenue/75 Street
- Eastglen Pool - 114 Avenue/68 Street
- Floden Park - 109 Avenue/40 Street
- Rundle Park, A.C.T. Centre, Pool - 118 Avenue/Victoria Trail
- Santa Rosa Arena - 120 Avenue/68 Street

Community Services

Edmonton Social Services - Beverly Centre - 5005 112 Avenue - 474-0221
Newton Community League

SEPTEMBER 1983.

The City of Edmonton PLANNING

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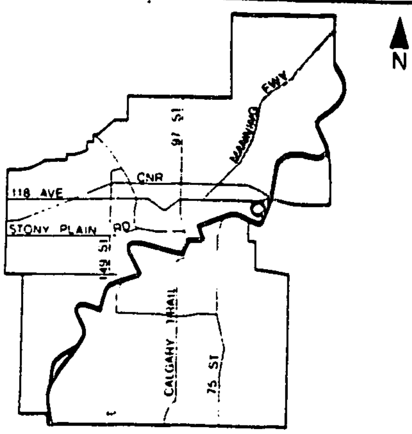
NEIGHBOURHOOD FACT SHEET



NORTHEAST DISTRICT

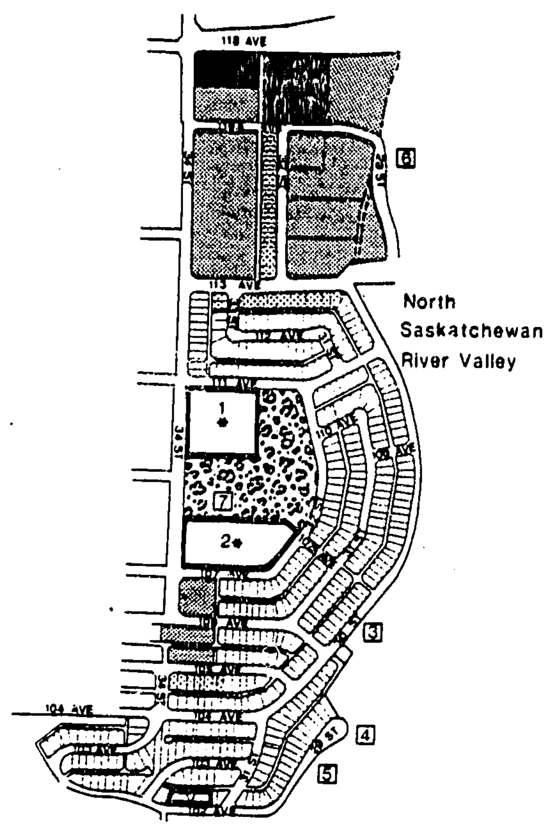
O NEIGHBOURHOOD LOCATION

1. Rundle Elementary School (p)
2. St. Jerome Elementary/Jr. High School (s)
3. Rundle Park
4. A. C. T. Centre
5. Family Recreation Centre
6. Rundle Park Golf Course
7. Rundle Heights Playground

NEIGHBOURHOOD:

RUNDLE HEIGHTS

NORTHEAST DISTRICT



LAND USE

Single Dwelling	Recreation, Open Space	Transportation
Two Unit Dwellings	Commercial	Vacant, Undeveloped
Multiple Family Dwellings	Industrial, Public Utilities	Source: 1982 CITY ASSESSMENT DATA DISTRICT PLANNING PROGRAM
Apartments	Institutional	

RUNDLE HEIGHTS

Neighbourhood Character

Density: 46.8 people/hectare (gross)

Housing	No. of Units	
Single Family Dwellings	369	30.3%
Semi/Duplex Dwellings	40	3.3%
Multi Family Dwellings	605	49.7%
Apartments (1-4 storeys)	203	16.7%
Apartments (5+storeys)	-	-%
	1,217 units	

Land Area	75.7ha.	
Residential	40.7ha.	53.8%
Institutional	4.6ha.	6.1%
Recreation/Open Space	5.1ha.	6.7%
Commercial	.9ha.	1.2%
Other	24.4ha.	32.2%

Length of Residence
Lived at the same address:

5 or more years	41.3%
1 to 4 years	33.0%
less than 1 year	25.7%

Tenure

Homeowners	37.7%
Renters	62.3%

Population

Age Groups	1971 No.	1971 %	1983 No.	1983 %	1983 City of Edmonton %
0-4	298	17.6	307	8.6	7.6
5-19	505	30.0	1,177	33.0	21.0
20-39	691	40.9	1,298	36.4	42.4
40-59	151	8.8	665	18.6	18.7
60-64	12	.7	60	1.7	3.3
65+	34	2.0	62	1.7	7.0
	1,691		3,569		

Sources: 1983 - City of Edmonton Civic Census
1971 - Census of Canada

Schools	Enrollment 1972	Enrollment 1982	Capacity
Rundle Elementary (Public)	501	427	500
St. Jerome Elementary/Junior High (Separate)	161	127	200

Recreation Facilities

Rundle Elementary - ball diamonds, soccer fields, playgrounds
St. Jerome Elementary/Junior High - ball diamonds, soccer fields, playgrounds
Rundle Park, A.C.T. Centre, Pool - 118 Avenue/Victoria Trail

Community Services

Edmonton Social Services - Beverly Centre - 5005 112 Avenue - 474-8221
Beverly Heights Community League

APRIL 1984

The City of Edmonton PLANNING

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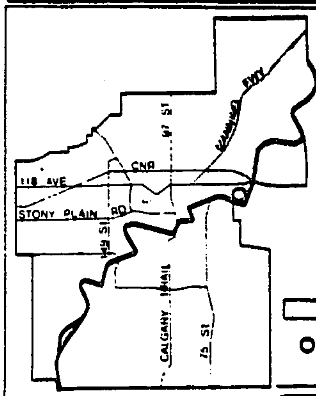
NEIGHBOURHOOD FACT SHEET

NEIGHBOURHOOD:

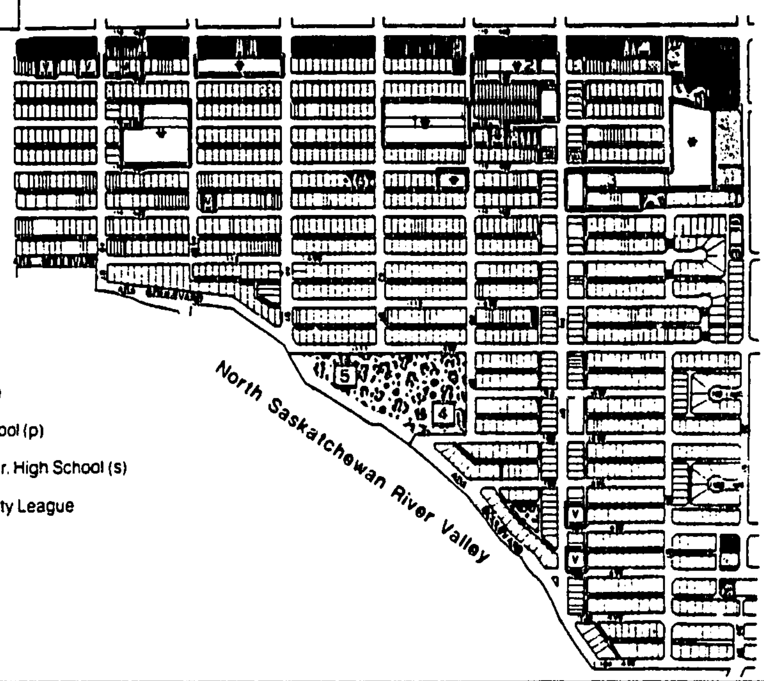
BEVERLY HEIGHTS

NORTHEAST DISTRICT



NORTHEAST DISTRICT

O NEIGHBOURHOOD LOCATION



1. Lawton Jr. High School (p)
2. R.J. Scott Elementary School (p)
3. St. Nicholas Elementary/Jr. High School (s)
4. Beverly Heights Community League
5. Floden Park
6. Beverly Lion's Playground

LAND USE

- Single Dwelling
- Two Unit Dwellings
- Multiple Family Dwellings
- Apartments
- Recreation, Open Space
- Commercial
- Industrial, Public Utilities
- Institutional
- Transportation
- Vacant, Undeveloped

Source: 1982 FIELD SURVEY DISTRICT PLANNING PROGRAM

BEVERLY HEIGHTS

Neighbourhood Character

Density: 29.2 people/hectare (gross)

Housing	No. of Units	
Single Family Dwellings	1,280	81.9%
Semi/Duplex Dwellings	18	1.2%
Multi Family Dwellings	9	.6%
Apartments (1-4 storeys)	256	16.3%
Apartments (5+storeys)	-	-%
	1,563 units	

Land Area	155.5hs.	
Residential	78.4hs.	50.4%
Institutional	10.4hs.	6.7%
Recreation/Open Space	5.8hs.	3.7%
Commercial	53.4hs.	34.4%
Other	7.5hs.	4.8%

Length of Residence
Lived at the same address:

5 or more years	65.2%
1 to 4 years	20.4%
less than 1 year	14.4%

Tenure

Homeowners	65.4%
Renters	34.6%

Population

Age Groups	1971 No.	1971 %	1983 No.	1983 %	1983 City of Edmonton %
0-4	614	10.3	168	3.7	7.6
5-19	2,108	35.3	921	20.4	21.0
20-39	1,706	20.5	1520	33.6	42.4
40-59	1,172	19.6	1,233	27.3	18.7
60-64	150	2.5	249	5.5	3.3
65+	227	3.8	428	9.5	7.0
	5,977		4,519		

Sources: 1983 - City of Edmonton Civic Census
1971 - Census of Canada

Schools

	Enrollment 1972	Enrollment 1982	Capacity
R.J. Scott Elementary (Public)	223	138	225
St. Nicholas Elementary/Junior High (Separate)	397	255	315
Lawton Junior High (Public)	674	322	690

Recreation Facilities

Lawton Junior High - ball diamonds, soccer fields
R.J. Scott Elementary - ball diamonds, soccer fields
St. Nicholas Elementary - ball diamonds, soccer fields
Beverly Heights Community League - hall, rink
Floden Park - playground
Playgrounds - 115 Avenue/42 Street
- 117 Avenue/36 Street
- 108 Avenue/38 Street
District Facilities nearby:
- Rundle Park, A.C.T. Centre, Pool - 118 Avenue/Victoria Trail
- Eastglen Pool - 114 Avenue/68 Street
- Santa Rosa Arena - 120 Avenue/68 Street

Community Services

Beverly Heights Community League
Beverly Lodge - 117 Avenue/44 Street
Porta Place - 4436 117 Avenue
Beverly Ukranian Apartments - 116 Avenue/37 Street
Catholic Social Service Group Homes - 3807 116 Avenue; 4026 - 115 Avenue
Edmonton Social Services - Beverly Centre - 5005 112 Avenue - 474-8221

APRIL 1984

The City of Edmonton PLANNING

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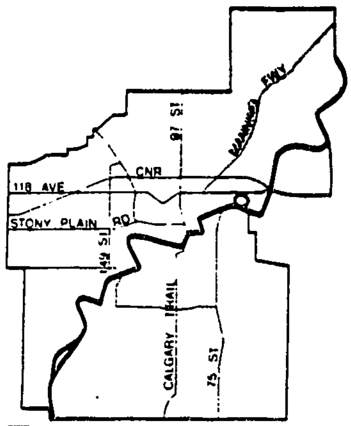
NEIGHBOURHOOD FACT SHEET



NORTHEAST DISTRICT

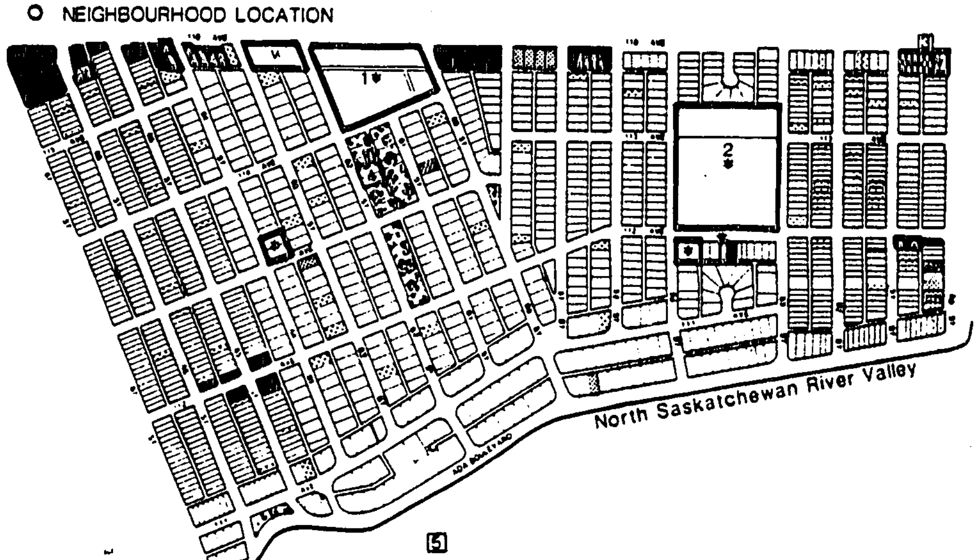
NEIGHBOURHOOD LOCATION

NEIGHBOURHOOD:

HIGHLANDS

NORTHEAST DISTRICT

1. Highlands Jr. High School (p)
2. Mt. Royal Elementary School (p)
3. Fire Station # 7
4. Highlands Community League
5. Highlands Golf and Country Club



LAND USE

Single Dwelling	Recreation, Open Space	Transportation
Two Unit Dwellings	Commercial	Vacant, Undeveloped
Multiple Family Dwellings	Industrial, Public Utilities	Source: 1982 FIELD SURVEY DISTRICT PLANNING PROGRAM
Apartments	Institutional	

HIGHLANDS

Neighbourhood Character

Density: 26.2 people/hectare (gross)

Housing	No. of Units	
Single Family Dwellings	1,023	81.5%
Semi/Duplex Dwellings	146	11.6%
Multi Family Dwellings	29	2.3%
Apartments (1-4 storeys)	57	4.6%
Apartments (5+storeys)	-	-%
	1,255 units	

Land Area	118.1hs.	
Residential	63.3hs.	53.6%
Institutional	6.8hs.	5.8%
Recreation/Open Space	2.2hs.	1.9%
Commercial	2.2hs.	1.9%
Other	43.6hs.	36.9%

Length of Residence
Lived at the same address:

5 or more years	65.7%
1 to 4 years	21.5%
less than 1 year	12.8%

Tenure

Homeowners	74.3%
Renters	25.7%

Population

Age Groups	1971 No.	1971 %	1983 No.	1983 %	1983 City of Edmonton %
0-4	289	7.7	170	5.4	7.6
5-19	959	25.6	527	17.0	21.0
20-39	929	24.8	1,029	33.2	42.4
40-59	913	24.3	563	18.2	18.7
60-64	239	6.4	217	7.0	3.3
65+	424	11.2	592	19.2	7.0
	3,753		3,098		

Sources: 1983 - Planning Department - PRISM
1983 - City of Edmonton Civic Census
1971 - Census of Canada

Schools	Enrollment 1972	Enrollment 1982	Capacity
Mount Royal Elementary (Public)	163	127	275
Highlands Junior High (Public)	579	468	655

Recreation Facilities

Highlands Junior High - ball diamonds, soccer fields
Mount Royal Elementary - ball diamonds, soccer fields
Highlands Community League Hall, playground, tennis, lawn bowling
Playgrounds - 112 Avenue/53 Street; 112 Avenue/62 Street
District Facilities nearby:

- Bordon Park - 112 Avenue/75 Street
- Santa Rosa Arena - 120 Avenue/68 Street
- Rundle Park, A.C.T. Centre, Pool - 118 Avenue/Victoria Trail

Community Services

Edmonton Social Services - Beverly Centre - 5005 112 Avenue - 474-8221
Highlands Community League

SEPTEMBER 1983.

THE CITY OF Edmonton PLANNING

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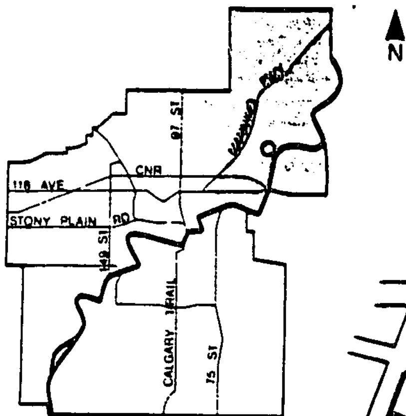
NEIGHBOURHOOD FACT SHEET



NEIGHBOURHOOD:

FRASER

NORTHEAST DISTRICT

LAND USE

- Single Dwelling
- Two Unit Dwellings
- Multiple Family Dwellings
- Apartments
- Recreation, Open Space
- Commercial
- Industrial, Public Utilities
- Institutional
- Transportation
- Vacant, Undeveloped

Source: 1982 CITY ASSESSMENT DATA
DISTRICT PLANNING PROGRAM

FRASER

Neighbourhood Character

Density: 25.1 people/hectare (gross)

Housing	No. of Units	
Single Family Dwellings	492	58.5%
Semi/Duplex Dwellings	166	19.7%
Multi Family Dwellings	183	21.8%
Apartments (1-4 storeys)	-	-%
Apartments (5+storeys)	-	-%
	841 units	

Land Area	77.5ha.	
Residential	30.6ha.	39.5%
Other	46.9ha.	60.5%

Length of Residence
Lived at the same address:

5 or more years	.2%
1 to 4 years	73.4%
less than 1 year	26.4%

Tenure

Homeowners	66.7%
Renters	33.3%

Population

Age Groups	1983 No.	1983 %	1983 City of Edmonton %
0-4	262	13.5	7.6
5-19	364	18.7	21.0
20-39	1,163	60.0	42.4
40-59	120	6.2	18.7
60-64	10	.5	3.3
65+	23	1.1	7.0
	1,942		

Sources: 1983 - City of Edmonton Civic Census

Recreation Facilities

District Facilities nearby:

- Hermitage Park - Hermitage Road/Hooke Road
- Rundle Park, A.C.T. Centre, Pool - 118 Avenue/Victoria Trail
- Londonderry Pool, Arena - 144 Avenue/66 Street

Community Services

Peter Pan Day Care - 14527 29 Street
Edmonton Social Services - Beverly Centre - 5005 112 Avenue - 474-8221
Fraser Community League

SEPTEMBER 1983.

The City of Edmonton PLANNING

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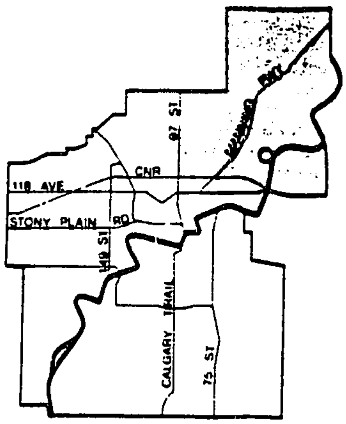
NEIGHBOURHOOD FACT SHEET



N

NEIGHBOURHOOD:

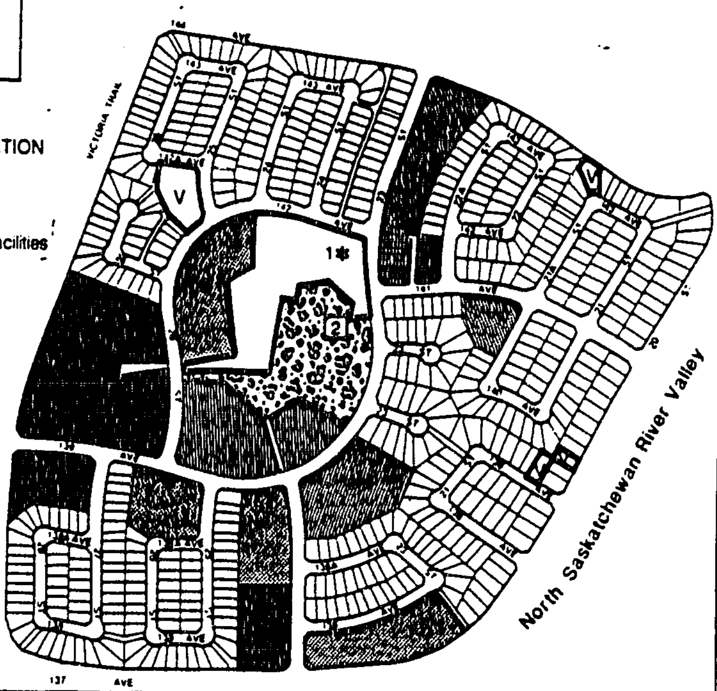
BANNERMAN

NORTHEAST DISTRICT

NORTHEAST DISTRICT

O NEIGHBOURHOOD LOCATION

1. Bannerman Elementary School (p)
2. Bannerman Community League Facilities



LAND USE

- Single Dwelling
- Two Unit Dwellings
- Multiple Family Dwellings
- Apartments
- Recreation, Open Space
- Commercial
- Industrial, Public Utilities
- Institutional
- Transportation
- Vacant, Undeveloped

Source: 1982 CITY ASSESSMENT DATA DISTRICT PLANNING PROGRAM

BANNERMAN

Neighbourhood Character

Density: 46.9 people/hectare (gross)

Housing	No. of Units	
Single Family Dwellings	533	44.2%
Semi/Duplex Dwellings	-	-%
Multi Family Dwellings	447	37.1%
Apartments (1-4 storeys)	225	18.7%
Apartments (5+storeys)	-	-%
	1,205 units	

Land Area	74.1hs.	
Residential	45.1hs.	60.9%
Institutional	2.6hs.	3.5%
Recreation/Open Space	2.7hs.	3.6%
Commercial	2.6hs.	3.5%
Other	21.1hs.	28.5%

Length of Residence
Lived at the same address:

5 or more years	7.1%
1 to 4 years	75.9%
less than 1 year	17.0%

Tenure

Homeowners	74.9%
Renters	25.1%

Population

Age Groups	1983 No.	1983 %	1983 City of Edmonton %
0-4	469	13.6	7.6
5-19	821	23.8	21.0
20-39	1,827	52.9	42.4
40-59	291	8.4	18.7
60-64	23	.6	3.3
65+	25	.7	7.0
	3,456		

Sources: 1983 - City of Edmonton Civic Census

Schools	Enrollment 1982	Capacity
Bannerman Elementary (Public)	418	500

Recreation Facilities

Bannerman Elementary - ball diamonds, soccer fields
Bannerman Community League - rink, playground
District Facilities nearby:

- Hermitage Park - Hermitage Road/Hooke Road
- Rundle Park, A.C.T. Centre, pool - 118 Avenue/Victoria Trail
- Londonderry Pool, arena - 144 Avenue/66 Street

Community Services

Thumpers #2 Day Care - 14063 Victoria Trail - 478-2755 (Clareview Shopping Village)
Edmonton Social Services - Beverly Centre - 5005 112 Avenue - 474-8221
Bannerman Community League

SEPTEMBER 1983.

The City of Edmonton PLANNING

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