PB98-110836

DATA RECONCILIATION BASED TRAFFIC COUNT ANALYSIS SYSTEM

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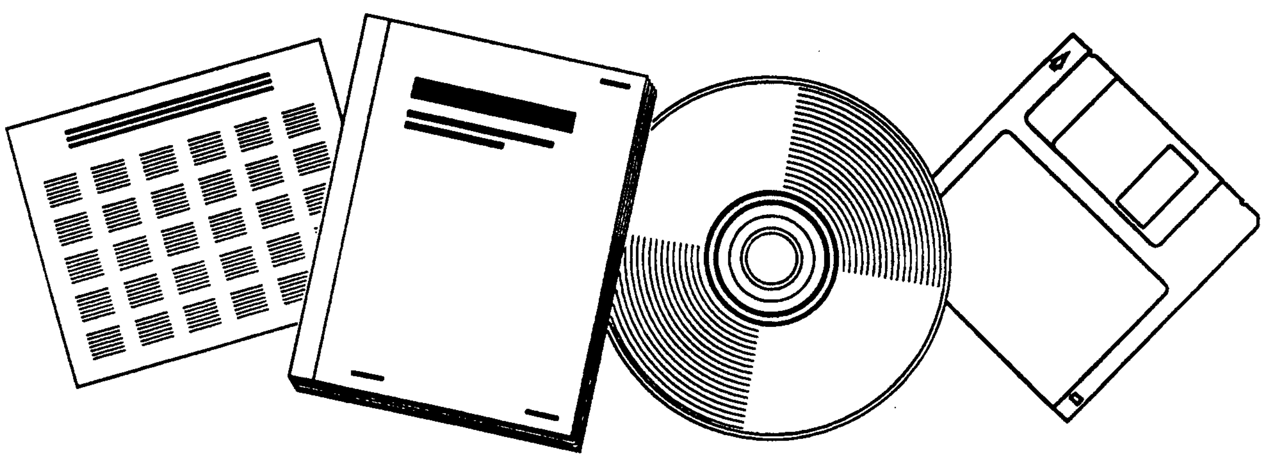

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

CONNECTICUT TRANSPORTATION INSTITUTE

Data Reconciliation Based Traffic Count Analysis System

Ming Zhao
Dr. Norman W. Garrick
Dr. Luke E.K. Achenie

November, 1997

JHR 97-260 Project 95-2

SCHOOL OF ENGINEERING
UNIVERSITY OF CONNECTICUT
STORRS, CONNECTICUT

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This research was sponsored by the Joint Highway Research Advisory Council (JHRAC) of the University of Connecticut and the Connecticut Department of Transportation and was carried out in the Civil and Environmental Department of the University of Connecticut.

Technical Report Documentation Page

1. Report No. JHR 97-260	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Data Reconciliation Based Traffic Count Analysis System		5. Report Date November, 1997
		6. Performing Organization Code
7. Author(s) N.W. Garrick; L.E.K. Achenie; M. Zhao; S.R. Paladugu		8. Performing Organization Report No. Project 95-2
9. Performing Organization Name and Address University of Connecticut Department of Civil and Environmental Engineering 191 Auditorium Road, Box U-37 Storrs, CT 06269		10 Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Connecticut Department of Transportation 280 West Street Rocky Hill, CT 06067-0207		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Traffic volume data, especially Average Annual Daily Traffic (AADT) volumes, are very important in transportation engineering for managing and maintaining existing facilities, and for planning and designing new facilities. This paper addresses the traffic count analysis system developed to produce AADTs for freeway links based on traffic count data. For freeways, traffic counts are usually taken at certain links, and then they are processed to obtain AADTs. This processing is very time-consuming and labor-intensive when performed manually. The objective of developing the TCAS is to reduce the time and labor required in the processing of traffic counts to obtain AADTs. The TCAS was developed based on data coaptation and data reconciliation techniques which are frequently used in the processing of network flow rate data.. The TCAS can be used to calculate AADTs for counted links, to generate AADTs for uncounted links, and to adjust these AADTs to satisfy material balance. It is expected to significantly reduce the time and labor required for processing traffic volume data for freeways.

17. Key Words Traffic Volume Data; Average Annual Daily Traffic; Freeways; Data Reconciliation and Data Coaptation		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 39	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	mililitres	mL
gal	gallons	3.785	Litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
^0F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	^0C

* SI is the symbol for the International System of Measurement

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
^oC	Celcius temperature	1.8C+32	Fahrenheit temperature	^oF

^oF 32 98.6 212 ^oF
-40 0 40 80 120 180 200
-40 -20 0 20 40 60 80 100
^oC 37 ^oC

TABLE OF CONTENTS

	Page
Title Page	i
Technical Documentation Page	ii
Metric Conversion Chart	iii
Table of Contents	iv
List of Figures	vi
List of Tables	vii
I. Introduction	1
II. ConnDOT's Traffic Volume Data System	4
2.1 Traffic Data	4
2.1.1 Traffic Count Data Files	4
2.1.2 Expansion Factor Data Files	6
2.1.3 Station Location Data Files	6
2.1.4 Freeway Strip Maps	6
2.2 Analyzing Freeway Traffic Volume Data	10
2.2.1 Processing Continuous Counting Stations Data	10
2.2.2 Processing Short-term Coverage Counting Station and Loop Monitoring Station Data	10
2.2.3 Generating AADTs for Uncounted Mainline Links	10
III. Data Reconciliation and Data Coaptation	14
3.1 The Incidence Matrix	14
3.2 Data Coaptation and Data Reconciliation	15
3.2.1 Data Coaptation	15
3.2.2 Data Reconciliation	16
3.3 Application to Freeway Traffic Volume Data	17
IV. Implementation of the Traffic Count Analysis System	21

4.1 Organization of the Program 21
4.2 Input Data 21
4.2.1 Calculation Control Parameters 22
4.2.2 Station Location Data Files 23
4.2.3 Additional Data Files 24
4.2 Output Data Files 25

V. Results and Conclusions 27
5.1 Results 27
5.2 Conclusions 30
Reference Cited 32
Appendix A More about the Station Location Data File 33
Appendix B Forming the Incidence Matrix 37
Appendix C Rounding AADT 39

LIST OF FIGURES

Number	Description	Page
2.1	A Section of the Strip Map for I-91	9
2.2	An Example of Freeway Network	12
5.1	The Strip Map of Route 20	28
A.1	Special Situations in the TMS	34

LIST OF TABLES

Number	Description	Page
2.1	A Section of a Traffic Count Data File in the TMS	5
2.2	A Section of an Expansion Factor Data File in the TMS	7
2.3	A Section of a Station Location Data File in the TMS	8
3.1	The Incidence Matrix (corresponding to Figure 2.2)	15
3.2	Data Coaptation and Data Reconciliation Application Results	18
4.1	The Calculation Control Parameter Data File	22
4.2	Typical Records in a Station Location Data File	24
4.3	An Addition Data File	24
4.4	An Example of the Results of the TCAS	25
4.5	An Example of the List of AADTs	26
5.1	Results of the TCAS for Route 20	29
5.2	Lists of the AADTs for Route 20	30
A.1	Special Records in a Station Location Data File	34

I Introduction

Traffic data are very important in transportation engineering for planning and designing new facilities. The Traffic Monitoring System (TMS), developed by the Connecticut Department of Transportation (ConnDOT), collects, processes and distributes traffic data. One important task of the TMS is to assign Average Annual Daily Traffic (AADT) volumes to all links in the state highway system [1].

Theoretically, in order to determine AADTs of all links in the state highway system, the number of vehicles passing each link should be counted for an entire year. This is not feasible in practice because of the huge amount of highway links in the state highway system. In the TMS, traffic volumes on certain links of the highway system are counted for a specified period of time, and then are used to generate estimated AADTs for all other links.

In most cases, one of the following two types of counting stations are used to collect traffic volume data in the TMS:

- Continuous Counting Stations.
- Short-term Coverage Counting Stations.

A total of thirty-seven (37) continuous counting stations are installed on highways throughout the state of Connecticut. These continuous counting stations are used to continuously collect traffic volume data. AADTs calculated from the data collected at these continuous counting stations are considered to be of high reliability and those located on limited access highways are used as control points in the analysis of expressway data. Data from these continuous counting stations are also used to generate expansion factors. An expansion factor is the average ratio of AADT to daily volume for a given day of the week. Daily expansion factors are calculated for each month of the year.

Short-term coverage counting stations constitute the majority of the counting stations in the TMS. They are used to collect traffic volume data for short periods of time (24 hours or 48 hours). The daily traffic volumes calculated from data collected at the short-term coverage counting stations are factored to AADTs using the expansion factors. These AADTs serve as the basis for assigning AADTs to uncounted links in the highway system.

For the freeways in Connecticut, sixteen (16) continuous counting stations are installed on the mainlines, and about 600 short-term coverage counting stations are installed on the ramps each year. The short-term coverage counting stations are installed on freeways in a three-year cycle. Each year about one third of the freeways are monitored in the TMS.

In addition, a number of loop sites are monitored for several weeks each year to supplement mainline counts from the continuous counting stations. Loop monitoring stations are used instead of the normal short-term coverage counting stations because it is difficult to use the standard traffic counting methods (road tubes) on the freeway mainlines.

For each monitored freeway, traffic volumes are counted for all ramps but only for a few mainline links. AADTs for the uncounted mainline links need to be calculated. Material balance at each junction of the freeway is used in the calculation of AADTs for the uncounted mainline links. Material balance for traffic volume data means that traffic entering a freeway junction is equal to traffic leaving the junction. For a freeway, a minimum number of links must be counted in order to be able to use material balance to calculate the traffic volumes of the uncounted links. Any traffic counts beyond the minimum number are used to check the accuracy and consistency of the data.

The calculated AADT from the material balance should be equal to the computed AADT from the traffic count at each link with redundant traffic count. Frequently this is not the case due to sampling errors caused by the reliance on data from short-term coverage counting stations or gross errors caused by faulty or poorly calibrated equipment. Appropriate adjustments of the calculated AADTs are required to eliminate such discrepancies.

Currently, the generation of AADTs for freeways and the adjustments of these AADTs are performed manually at ConnDOT. The Traffic Count Analysis System (TCAS) was developed in this study. The TCAS can be used to (1) calculate AADTs from short-term coverage counts and loop monitoring stations data, (2) generate mainline AADTs, and (3) adjust these AADTs so that they satisfy material balance.

It is expected that the TCAS will significantly reduce the time and labor required for processing the traffic volume data. The TCAS can also serve as an important new research tool for studying traffic pattern because of its ability to quickly process traffic volume data.

II ConnDOT's Traffic Volume Data System

The following sections provide a brief review of the traffic volume data and the procedure used to analyze traffic volume data [1]. The review is focused on freeway traffic volume data, because the Traffic Count Analysis System (TCAS) developed in this project applies only to freeway traffic volume data.

2.1 Traffic Data

Traffic data are stored in a variety of different types of data files. Three types of data files, the traffic count data files, the expansion factor data files and the station location data files, are discussed here because they are the ones used in this project. The traffic count data files contain hourly traffic counts and other related information. The expansion factor data files contain the expansion factors. The station location data files contains information about the locations where the traffic counting stations are installed and other related information.

In addition to the discussion of the data files, freeway strip maps are also introduced in the following sections. The freeway strip maps are used to illustrate the configuration of the freeways.

2.1.1 Traffic Count Data Files

Each year hourly traffic counts collected from all counting stations are stored in a traffic count data file. Table 2.1 (a) shows a section of the traffic count data files for year 1989. A full listing of the content of each column in the traffic count data file is given in Table 2.1 (b).

The traffic count data file consists of records which are primarily hourly traffic counts. In addition, the counting station number, the date related information (month, day, year, day of the week, code for holiday and special situation), and the direction code of the freeway are also provided in each record.

Table 2.1 A Section of a Traffic Count Data File in the TMS

```
034700109128930W000700060001000200090016006501040000000000000000000000000000000000000000000000000000000000000000
034700209118920W000000000000000000000000000001310115008300480057006400620057006700870076006400500031003200140012
034700209128930W000600020004000500050008006101150000000000000000000000000000000000000000000000000000000000000000
034700309118920E000000000000000000000000000000000133004900330072004700390048004300690110007000260028001600200016
034700309128930E000900140006000800000004003501690143000000000000000000000000000000000000000000000000000000000000
034700409118920E000000000000000000000000000000000000007700700066007700730058008601240142008300590038002200150023
034700409128930E001300040005000500010004001900650076000000000000000000000000000000000000000000000000000000000000
034700509128930W000000000000000000000000000003500221014201660165016401450178016802550256020201350127011900690064
034700509138940W003600370023001900490098019803470000000000000000000000000000000000000000000000000000000000000000
034700609128930W000000000000000000000000000010661001040803180270037703880360032003010334022902190158017401040101
034700609138940W004800290019002800430082033811670000000000000000000000000000000000000000000000000000000000000000
034700709128930W000000000000000000000000000008670749013200870102006101310127008500770101006000680060006500310029
034700709138940W001100100006000200060029017909260000000000000000000000000000000000000000000000000000000000000000
```

(a) A Section of the Traffic Count Data File for Year 1989

Column	Description	Column	Description	Column	Description
1 ~ 7	Station Number	17 ~ 20	Midnight to 1:00AM	65 ~ 68	12:00PM to 1:00PM
8 ~ 9	Month	21 ~ 24	1:00AM to 2:00AM	69 ~ 72	1:00PM to 2:00PM
10 ~ 11	Day	25 ~ 28	2:00AM to 3:00AM	73 ~ 76	2:00PM to 3:00PM
12 ~ 13	Year	29 ~ 32	3:00AM to 4:00AM	77 ~ 80	3:00PM to 4:00PM
14	Day of Week Code	33 ~ 36	4:00AM to 5:00AM	81 ~ 84	4:00PM to 5:00PM
15	Code for Holiday	37 ~ 40	5:00AM to 6:00AM	85 ~ 88	5:00PM to 6:00PM
	and Special Situation	41 ~ 44	6:00AM to 7:00AM	89 ~ 92	6:00PM to 7:00PM
16	Direction Code	45 ~ 48	7:00AM to 8:00AM	93 ~ 96	7:00PM to 8:00PM
		49 ~ 52	8:00AM to 9:00AM	97 ~ 100	8:00PM to 9:00PM
		53 ~ 56	9:00AM to 10:00AM	101 ~ 104	9:00PM to 10:00PM
		57 ~ 60	10:00AM to 11:00AM	105 ~ 108	10:00PM to 11:00PM
		61 ~ 64	11:00AM to 12:00PM	109 ~ 112	11:00PM to 12:00PM

(b) A List of the Content of Each Column in Table 2.1 (a)

2.1.2 Expansion Factor Data Files

An expansion factor data file is comprised of Monday through Friday expansion factors for each factor group for each month. An example is shown in Table 2.2. The expansion factor data file contains 72 records which can be divided into 12 sections, each for one month. In each section, there are six records each associated with each function group. In each record, the first number indicates the factor group, followed by five numbers which are the Monday through Friday expansion factors for that group.

2.1.3 Station Location Data Files

Station location data files are used to provide information about the locations where the counting stations are installed. A section of a station location data file is shown in Table 2.2. A typical record in the station location data file contains four items: (1) the station number (seven digits) which is assigned by ConnDOT to each counting station, (2) the route number which indicates the route on which the station is installed, (3) the expansion factor group number, and (4) a brief description of the station location.

2.1.4 Freeway Strip Maps

The strip map of a freeway indicates the configuration of the freeway. It helps in the analyzing of traffic volume data in the TMS. Figure 2.1 shows a section of the strip map for I-91. The strip map is comprised of branches and nodes. Branches represent the links (mainline links and ramp links) on the freeway, and nodes represent the junctions where the mainline links and the ramp link connect. Station numbers, town boundaries, and exit numbers are usually provided on the map.

2.2 Analyzing Freeway Traffic Volume Data

In general, the analyzing of freeway traffic volume data consists of three parts: (1) analyzing the data from the continuous counting stations where applicable, (2) analyzing the data

Table 2.2 A Section of an Expansion Factor Data File in the TMS

```
11.12,1.12,1.12,1.12,0.97,
21.13,1.13,1.13,1.13,1.03,
31.11,1.11,1.11,1.11,0.97,
41.01,1.01,1.01,1.01,0.92,
51.57,1.57,1.57,1.57,1.14,
61.22,1.22,1.22,1.22,1.05/
11.11,1.11,1.11,1.11,0.94,
21.11,1.11,1.11,1.11,1.01,
31.08,1.08,1.08,1.08,0.94,
41.01,1.01,1.01,1.01,0.92,
51.54,1.54,1.54,1.54,1.07,
61.19,1.19,1.19,1.19,1.01/
11.06,1.06,1.06,1.06,0.90,
21.07,1.07,1.07,1.07,0.96,
31.06,1.06,1.06,1.06,0.90,
40.99,0.99,0.99,0.99,0.91,
51.48,1.48,1.48,1.48,1.05,
61.15,1.15,1.15,1.15,0.96/
11.00,1.00,1.00,1.00,0.86,
21.01,1.01,1.01,1.01,0.91,
31.01,1.01,1.01,1.01,0.87,
40.94,0.94,0.94,0.94,0.87,
51.33,1.33,1.33,1.33,1.00,
61.07,1.07,1.07,1.07,0.89/
10.97,0.97,0.97,0.97,0.82,
20.94,0.94,0.94,0.94,0.86,
30.98,0.98,0.98,0.98,0.82,
40.92,0.92,0.92,0.92,0.83,
51.27,1.27,1.27,1.27,0.94,
61.04,1.04,1.04,1.04,0.80/
......
......
10.98,0.98,0.98,0.98,0.82,
20.96,0.96,0.96,0.96,0.86,
30.98,0.98,0.98,0.98,0.83,
40.93,0.93,0.93,0.93,0.85,
51.24,1.24,1.24,1.24,0.79,
61.03,1.03,1.03,1.03,0.85/
11.02,1.02,1.02,1.02,0.87,
21.00,1.00,1.00,1.00,0.90,
31.00,1.00,1.00,1.00,0.86,
40.93,0.93,0.93,0.93,0.84,
51.41,1.41,1.41,1.41,0.90,
61.08,1.08,1.08,1.08,0.93/
11.03,1.03,1.03,1.03,0.89,
20.97,0.97,0.97,0.97,0.91,
30.99,0.99,0.99,0.99,0.88,
40.91,0.91,0.91,0.91,0.85,
51.42,1.42,1.42,1.42,1.14,
61.08,1.08,1.08,1.08,0.93/
```

Table 2.3 A Section of a Station Location Data File in the TMS

0347002	I-84	4	W.B. OFF RAMP TO U.S. 6 & SAWMILL ROAD	000.36
0347003	I-84	4	E.B. OFF RAMP TO U.S. 6 & SAWMILL ROAD	
0347004	I-84	4	E.B. ON RAMP FROM U.S. 6 & SAWMILL ROAD	000.23
0347005	I-84	4	W.B. ON RAMP FROM U.S. 6 & S.R. 824	000.92
0347006	I-84	4	W.B. OFF RAMP TO U.S. 6 & S.R. 824	001.49
0347007	I-84	4	W.B. OFF RAMP TO OLD RIDGEBURY ROAD S.B.	001.49
0347008	I-84	4	E.B. OFF RAMP TO U.S. 7 S.B.	003.38
0347009	I-84	4	W.B. ON RAMP FROM U.S. 7 N.B.	003.37
0347010	I-84	4	E.B. OFF RAMP TO U.S. 6 S.R. 824	000.78
0347011	I-84	4	E.B. ON RAMP FROM OLD RIDGEBURY ROAD	001.60
0347012	I-84	4	W.B. OFF RAMP TO U.S. 7 S.B.	003.70
0347013	I-84	4	E.B. ON RAMP FROM U.S. 7 N.B.	003.69
0347014	I-84	4	W.B. OFF RAMP TO U.S. 6 & 202 (EXIT 4)	004.05
0347015	I-84	4	W.B. ON RAMP FROM U.S. 6 & 202 (EXIT 4)	003.58
0347016	I-84	4	E.B. OFF RAMP TO U.S. 6 & 202 (EXIT 4)	003.82
0347017	I-84	4	E.B. ON RAMP FROM U.S. 6 & 202 (EXIT 4)	004.06
0347018	I-84	4	W.B. ON RAMP FROM ROUTE 39	005.21
0347019	I-84	4	E.B. OFF RAMP TO S.R. 841 (DOWNS STREET)	005.14
0347020	I-84	4	W.B. OFF RAMP TO ROUTE 39	005.39
0347021	I-84	4	E.B. ON RAMP FROM ROUTE 39	005.59
0347022	I-84	4	W.B. OFF RAMP TO ROUTE 37	006.00
0347023	I-84	4	E.B. ON RAMP FROM ROUTE 37	005.97
0347024	I-84	4	W.B. ON RAMP FROM U.S. 7 S.B. & S.R. 805	007.48
0347025	US7	4	S.B. ON RAMP FROM S.R. 805 (FEDERAL ROAD)	025.50
0347026	I-84	4	E.B. OFF RAMP TO U.S. 7 N.B.	007.37
0347027	I-84	4	E.B. OFF RAMP TO U.S. 6 & S.R. 824	000.78
0347028	I-84	4	W.B. OFF RAMP TO U.S. 7 N.B.	007.77
0347029	I-84	4	E.B. ON RAMP FROM U.S. 7 S.B.	007.76
0347030	I-84	4	W.B. ON RAMP FROM U.S. 6 W.B. (EXIT 8)	008.15
0347031	I-84	4	E.B. OFF RAMP TO U.S. 6 E.B. (EXIT 8)	008.16
0347032	I-84	4	E.B. ON RAMP FROM U.S. 6 E.B. (EXIT 8)	008.62
0347042	I-84	4	E.B. ON RAMP FROM U.S. 6 & S.R. 824	001.26
0347043	I-84	4	E.B. ON RAMP FROM OLD RIDGEBURY ROAD	001.60
0347044	I-84	4	E.B. OFF RAMP TO REST AREA	000.78
0347045	I-84	4	E.B. ON RAMP FROM REST AREA	001.60
0347050	I-84	4	W.B. OFF RAMP TO U.S. 6 & S.R. 824	001.49
0347101	US7	4	S.B. ON RAMP FROM MIRY BROOK ROAD	020.10
0347102	US7	4	N.B. OFF RAMP TO WOOSTER HEIGHTS ROAD	020.16
0347103	US7	4	N.B. ON RAMP FROM WOOSTER HEIGHTS ROAD	020.62
0347104	US7	4	S.B. OFF RAMP TO SUGAR HOLLOW ROAD	020.64
0347105	US7	4	N.B. OFF RAMP TO PARK AVENUE	020.79
0347106	US7	4	N.B. ON RAMP FROM BACKUS AVENUE	020.96
0347107	US7	4	S.B. OFF RAMP TO BACKUS AVENUE	020.99
0347700	US7	4	NORTH OF OLD SUGAR HOLLOW ROAD	019.81

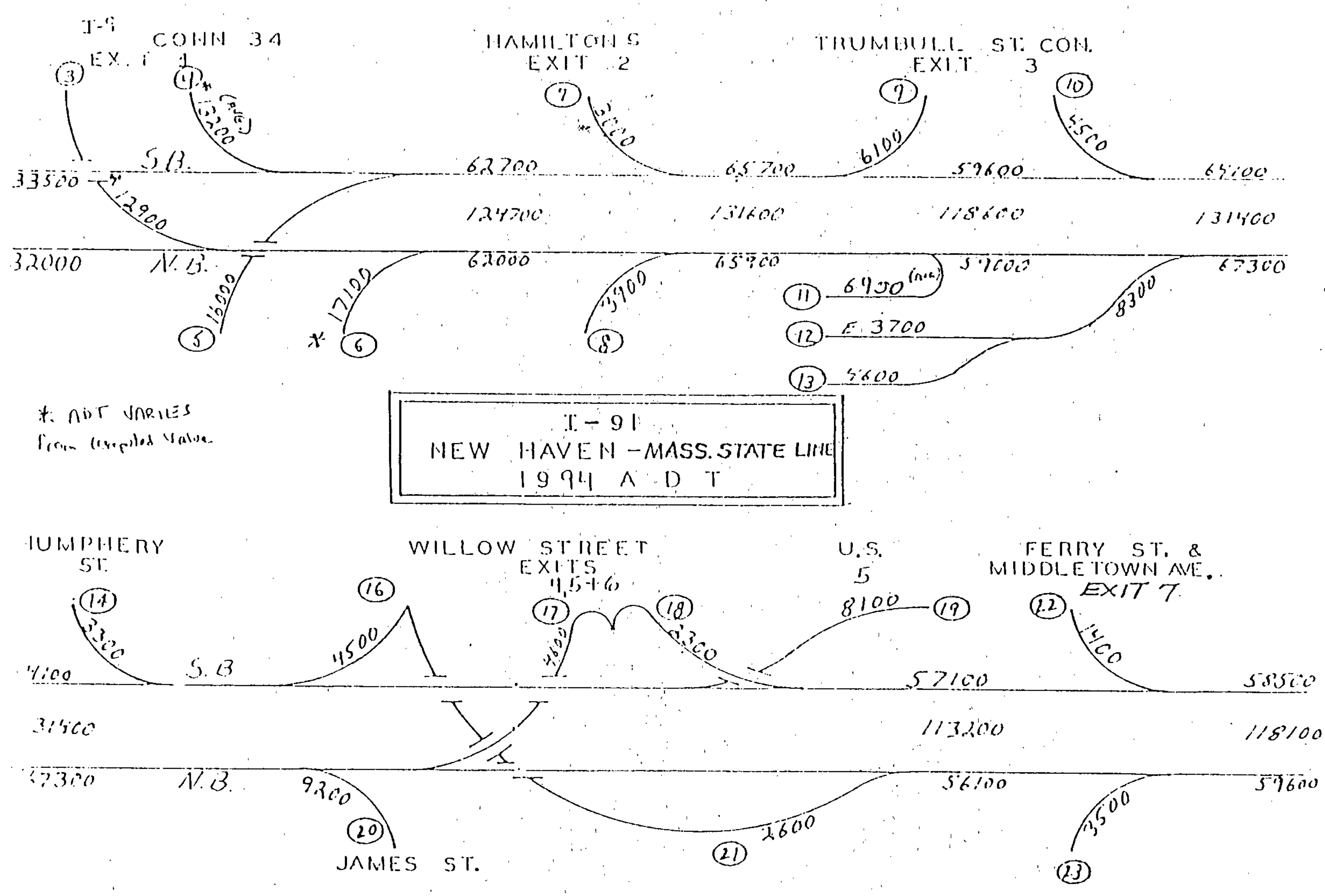

Figure 2.1 A Section of the Strip Map of I-91

from the short-term coverage counting stations and loop monitoring stations, and (3) generating AADTs for uncounted mainline links.

2.2.1 Processing Continuous Counting Station Data

AADTs and expansion factors are obtained using the data from the continuous counting stations. AADT for the link where a continuous counting station is installed is calculated by dividing the total number of vehicles passing the link in the entire year by 365, the number of days in the year.

Expansion factors for a year are produced by first calculating the ratio of the AADT and the daily traffic volume for each day in the year, and then averaging these ratios for each day of the week in each month. For example, the Friday factors are obtained by first determining the ratios of the AADT and the daily volumes for all the Fridays in each month of the year using the data from one continuous counting station. Then all the Friday factors in a given month are averaged to give the Friday factor for that month for that counting station. Finally, for all continuous counting stations in the same factor group, the Friday factors for each month are averaged to give the Friday factor for that month. Expansion factors for other days are determined in the same way.

2.2.2 Processing Short-term Coverage Counting Station Data and Loop Monitoring Station Data

The processing of the data from the short-term coverage counting stations and the processing of the data from the loop monitoring stations are the same. They can be divided into two steps: (1) checking the raw field data for errors, (2) calculating the daily volumes and factoring these daily volumes to AADTs.

2.2.3 Generating AADTs for Uncounted Mainline Links

The strip map of the freeway and the AADTs calculated from the counted data are used to calculate AADTs for the uncounted mainline links for a freeway. First, AADTs from the counted data are put on the strip map of the freeway. Then AADTs for the uncounted mainline links are calculated by adding or subtracting these AADTs in accordance with material balance at each node.

For example, referring to Figure 2.2, seven (7) out of eleven (11) links in a small freeway network are counted. AADTs for the counted links are shown as the numbers within the parentheses in the figure. The calculation of AADTs for the uncounted links starts at Link 1 which has a known AADT and proceeds from there. According to material balance, AADT for Link 3 is equal to AADT for Link 1 plus AADT for Link 2 (12,000 + 1,000 = 13,000). Similarly, AADT for Link 5 is equal to AADT for Link 3 minus AADT for Link 4 (13,000 - 3,000 = 10,000). The AADTs for the uncounted mainline links are shown in Figure 2.2 (number without parentheses).

When a link with redundant AADTs is encountered, for example, Link 11 in Figure 2.2, the counted AADT should equal the calculated AADT. Sometimes they do not match. In this case, link 11 has a counted AADT of 10,000 and a calculated AADT of 9,500. This discrepancy must be eliminated because it violates material balance. Currently, adjustments of these AADTs are based on review of historical data, historical relationships of the data, changes in local dermographics and economics.

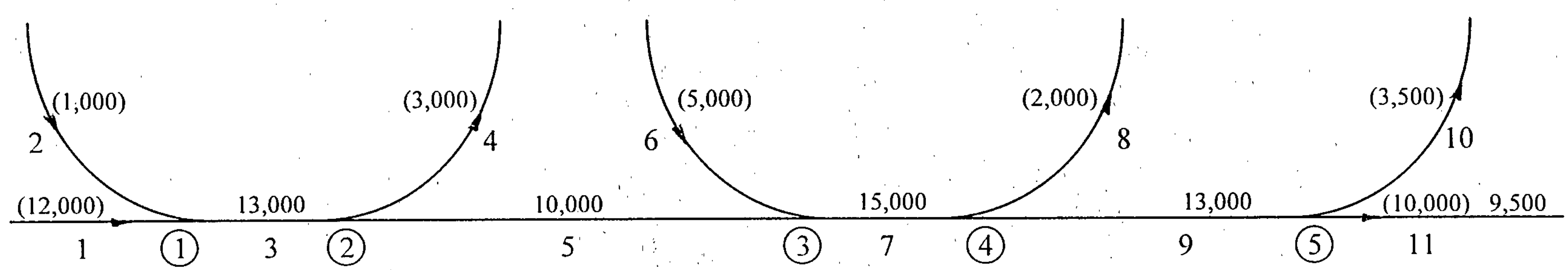

Figure 2.2 An Example of Freeway Network

III Data Coaptation and Data Reconciliation

The Traffic Count Analysis System (TCAS) was developed based on data coaptation and data reconciliation techniques. These two techniques are frequently used in processing flow rate data of a network. Data coaptation involves calculating flow rates for unmeasured links in accordance with material balance. Data reconciliation involves adjusting flow rates for all links to satisfy material balance [2, 3].

The next sections provide an introduction to data coaptation and data reconciliation as well as their application to freeway traffic volume data. The introduction starts with the incidence matrix which is a tool used in this project to represent the freeway configuration.

3.1 The Incidence Matrix

The incidence matrix is a numerical representation of a network which is required when analysis of a network involves complex computations. It consists of a rectangular array of elements with values of 1, -1, or 0. These numbers indicate the relationship between nodes and branches in the network.

Table 3.1 is the incidence matrix corresponding to the network shown in Figure 2.2. It has five (5) rows and eleven (11) columns which correspond to the five (5) nodes and eleven (11) links in Figure 2.2. The element in each row and column indicates the relationship between the corresponding node and branch. For example, the value of one (1) in the second row and third column in Table 3.1 indicates that Branch 3 and Node 2 in Figure 2.2 are connected and the direction of flow on Branch 3 is towards Node 2. The value of negative one (-1) in the second row and fourth column in Table 3.1 indicates that Branch 4 and Node 2 are connected and the direction of flow on Branch 4 is from Node 2. The value of zero (0) in the second row and sixth column in Table 3.1 indicates that Branch 6 and Node 2 are not connected.

Table 3.1 The Incidence Matrix (corresponding to Figure 2.2)

1	1	-1	0	0	0	0	0	0	0	0
0	0	1	-1	-1	0	0	0	0	0	0
0	0	0	0	1	1	-1	0	0	0	0
0	0	0	0	0	0	1	-1	-1	0	0
0	0	0	0	0	0	0	0	1	-1	-1

3.2 Data Coaptation and Data Reconciliation

In this paper, the discussion of data coaptation and data reconciliation is limited to directed network with only one flow parameter. An example of such a network is a freeway in which only traffic volumes are considered. In this case, material balance at each node in the network results in a set of linear equations. It is assumed that the measured flow rate data contains only random errors and that these random errors are normally distributed random variables with zero mean. It is further assumed that each measured flow rate is independent, and thus the covariance matrix of the errors is a diagonal matrix.

A specified number of measured flow rates are required to carry out data coaptation for a network. This number is the difference between the number of the branches and the number of the nodes in the network. Any measured flow rate data beyond this number are redundancies. In this discussion, it is assumed that at least one redundancy is available in the measured flow rate data. One redundancy is the minimum for performing the data reconciliation. Note that redundancies are very important in data reconciliation. The accuracy and the reliability of the final results from data reconciliation depend to a great extent on the number of redundant measurements; in general, the more redundancy is the greater the accuracy.

3.2.1 Data Coaptation

Data coaptation is used to calculate flow rates for the unmeasured links by solving the simultaneous equations resulted from material balance at each node in the network. As pointed out earlier, a specified number of measured flow rates must be available and only this specified number of measured flow rates are required to carry out data coaptation. If redundancies exist in the measured flow rate data, a subset of the measured flow rates containing only the specified number of flow rates must be selected before performing data coaptation.

The material balance equations at all nodes in the network are given by

$$\mathbf{Ay} = \mathbf{0}$$

where, **A** is the incidence matrix for the network, and **y** is the vector of the flow rates. Vector **y** is comprised of the specified number of flow rates (known), the flow rates for the links with redundancy (known but considered unknown here), and the flow rates for the unmeasured links (unknown). By solving these linear simultaneous equations, a vector of the flow rates for the unmeasured links and the links with redundancy are obtained.

3.2.2 Data Reconciliation

By combining the flow rates for the unmeasured links calculated from data coaptation and the flow rates for the measured links, flow rates for all links in the network are obtained. Note that at the links with redundancy, the measured flow rates are used in place of the flow rates from data coaptation. In most cases, flow rates at these links with redundancy do not satisfy material balance; therefore, data reconciliation is required to find the proper adjustments to these flow rates such that the adjusted values of these flow rates satisfy material balance.

Least-square estimation is used in data reconciliation to provide the adjusted flow rates which satisfy material balance and, at the same time, minimize the total overall adjustment that is needed. The objective function, **J**, of the least-square estimation is given by

$$\underset{\hat{\mathbf{x}}}{\mathbf{Min}}\,\mathbf{J} = (\hat{\mathbf{x}} - \hat{\mathbf{y}})^{\mathrm{T}}\,\mathbf{Q}^{-1}(\hat{\mathbf{x}} - \hat{\mathbf{y}})$$

subject to the material balance constraints

$$A\hat{x} = 0$$

where, $\hat{y}$ is the vector of the known flow rates, $\hat{x}$ is the vector of the adjusted flow rates, and, **Q** is the covariance matrix of the flow rates.

In this case, because it is assumed that the measured flow rates are independent of each other, the covariance matrix, **Q**, becomes a diagonal matrix, and each diagonal element is the variance of the flow rate, σ_i^2, which is the square of the standard deviation, σ_i, of the flow rate. The standard deviation of the flow rate is determined by the equipment used in collecting the flow rate data.

Under the statistical assumption presented earlier, this least-square estimation of the flow rates is equivalent to the maximum likelihood and minimum variance unbiased estimation. The solution to this problem is [4]

$$\hat{x}^* = \hat{y} - QA^T(AQA^T)^{-1}A\hat{y}$$

3.3 Application to Freeway Traffic Volume Data

The small freeway network shown in Figure 2.2 is used as an example to illustrate the application of data coaptation and data reconciliation to freeway traffic volume data. Refer to Figure 2.2, seven (7) links (1, 2, 4, 6, 8, 10, 11) are counted and the traffic volumes of these links are shown as the numbers within parentheses in the figure. This data set contains one redundancy which can be the traffic volume of either Link 1, 2, 10, or 11.

Data coaptation must be applied first to obtain the traffic volumes for the uncounted links. Using the traffic volume of Link 11 as redundancy, the material balance equations for all nodes in Figure 2.2 can be written as

$$2,000 + 1,000 - y_3 = 0$$
$$y_3 - 3,000 - y_5 = 0$$
$$y_5 + 5,000 - y_7 = 0$$
$$y_7 - 7,000 - y_9 = 0$$
$$y_9 - 3,500 - y_{11} = 0$$

where y_i are the traffic volumes for the uncounted links (3, 5, 7, 9) and the link with redundancy (11). The traffic volume for Link 11 is assumed to be unknown here in order to carry out data coaptation. The values of y_i can be obtained by solving these simultaneous equations.

The results from solving these equations are shown in Column 3 in Table 3.2. These results are the same as the estimated AADTs for the uncounted mainline links discussed in Section 2.2.3. The procedure used by ConnDOT to generated the AADTs for the uncounted mainline links is in essence data coaptation.

Table 3.2 Data Coaptation and Data Reconciliation Application Results

Link Number	Counted Flow Rate	Coaptation Result	Flow Rates for All Links	Reconciliation Result
1	12,000		12,000	12,000
2	1,000		1,000	1,008
3		13,000	13,000	13,008
4	3,000		3,000	2,926
5		10,000	10,000	10,082
6	5,000		5,000	5,225
7		15,000	15,000	15,307
8	2,000		2,000	1,959
9		13,000	13,000	13,348
10	3,500		3,500	3,348
11	10,000	9,500	10,000	10,000

Combining the traffic volumes calculated from data coaptation for the uncounted links and the traffic volume counted for the counted links, the traffic volumes of all links are obtained as shown in Column 4 in Table 3.2. Note that in this column the traffic volume of Link 11 is the counted traffic volume, not the traffic volume from data coaptation. These traffic volumes of all links do not satisfy material balance at Node 5 (refer to Figure 2.2), because the counted traffic volume, instead of the traffic volume from data coaptation, for Link 11 are used. Therefore, data reconciliation is required to adjust these traffic volume to satisfy material balance.

The objective function discussed in Section 3.2.2 can be written in another form as

$$J = \sum_i \frac{(\hat{x}_i - \hat{y}_i)^2}{\sigma_i^2}$$

where, $\hat{y}_i$ are the known traffic volumes, $\hat{x}_i$ are the adjusted traffic volumes, and σ_i is the standard deviation of $\hat{y}_i$. For this example, this equation become

$$J = \frac{(\hat{x}_1 - 12{,}000)^2}{(0.0 \times 12{,}000)^2} + \frac{(\hat{x}_2 - 1{,}000)^2}{(0.025 \times 1{,}000)^2} + \ldots + \frac{(\hat{x}_{10} - 3{,}500)^2}{(0.025 \times 3{,}500)^2} + \frac{(\hat{x}_{11} - 10{,}000)^2}{(0.0 \times 10{,}000)^2}$$

where the standard deviations, σ_i, are assumed to be 2.5% of the traffic volume $\hat{y}_i$ for all links except for Link 1 and Link 11, for which the standard deviations are assumed to be zero. A zero standard deviation of a flow rate means that the flow rate is consider to be the actual flow rate, and in turn, it should not be changed in data reconciliation.

The purpose of assuming two zero standard deviations for the links at the beginning and the end of the network here is to simulate the actual situation in the TMS. In the TMS, the processing of the freeway traffic volume data usually starts and ends at the control points where the AADTs are considered of very high reliability. The traffic volumes for these control points should not be changed in the adjustment process.

Minimization of this equation subject to the constraints

$$\hat{x}_1 + \hat{x}_2 - \hat{x}_3 = 0$$
$$\hat{x}_3 - \hat{x}_4 - \hat{x}_5 = 0$$
$$\ldots\ldots$$
$$\hat{x}_9 - \hat{x}_{10} - \hat{x}_{11} = 0$$

gives the optimal estimates, $\hat{x}^*_i$, of the adjusted traffic volumes shown in Column 5 in Table 3.2. These values of $\hat{x}^*_i$ are calculated using the TCAS. They satisfy material balance at each node in the network, and meanwhile, minimize the total adjustments to the traffic volumes. This result can be considered to be the best estimates of the actual traffic volumes (unknown) given the available information.

IV Implementation of the Traffic Count Analysis System

The Traffic Count Analysis System (TCAS) is a software package comprising of a computer program and data files. It can be used to process input data to obtain AADTs, to perform data coaptation and data reconciliation of these AADTs, and to present the final results from these analysis. In the following sections, the organization of the program and the data files (input and output) of the TCAS are discussed.

4.1 Organization of the Program

The TCAS program includes a number of subroutines written in the FORTRAN computer programming language. It can be roughly divided into four categories: input, data coaptation, data reconciliation, and output.

The input section starts with reading the calculation control parameters discussed in Section 4.2.1. Then the TCAS reads and processes the input data. The processing of input data involves four steps: (1) form the incidence matrix, (2) calculate the daily traffic volumes, (3) factor these daily traffic volumes into AADTs, and (4) read AADTs for the continuous counting stations and those ramp counting stations for which hourly traffic count data are not available from the traffic count data file.

In the data coaptation and the data reconciliation sections, data coaptation and data reconciliation are performed on the AADTs from the input data processing. Details of the data coaptation and reconciliation procedures were discussed in Section 3.2.

In the output section, the final results of the TCAS is presented. Two output data files are used to store the final results.

4.2 Input Data

The input data of the TCAS include the calculation control parameters and four types of input data files which are: (1) traffic count data files, (2) expansion factor data files, (3) station location data files, and (4) additional data files. The calculation control parameters define the range of the study and the diagonal covariance matrix of the traffic flow rates. A traffic count data file contains the hourly traffic count data and other pertinent information. An expansion factor data file stores the expansion factors. A station location data file provides the information on the location of the counting stations. An additional data file gives the AADTs for certain links on the freeway.

The traffic count data files and the expansion factor data files of ConnDOT's mainframe computer (discussed in Sections 2.1.1 and 2.1.2) are directly used as the traffic count data files and the expansion factor data files for the TCAS. Examples of these two types of data files were given in those two sections. In the following sections, the calculation control parameters, the station location data files and the additional data files for the TCAS are discussed.

4.2.1 Calculation Control Parameters

In the TCAS, the calculation control parameters can be read in by either the interactive mode through the input device (monitor and keyboard), or the non-interactive mode through a data file, named the calculation control parameter data file. The calculation control parameters are discussed here through an example of the calculation control parameter data file (Table 4.1).

Table 4.1 The Calculation Control Parameter Data File

```
'1994', '91', 'N', 1489055, 0337071, 1, 0.0025, 1
'1991'
1489055, 0.00
```

The parameters in Table 4.1 can be divided into three sections. The first section is the control section which contains the study year, the route, the route direction, the starting station number, the ending station number, the number of the years for which AADTs are desired to be calculated, the coefficient for the covariance matrix, and the number of the links that have specified coefficient for the covariance matrix. These parameters are provided in the first record in Table 4.1.

The second section is a list of the years for which AADTs are desired to be calculated. AADTs for these years can be used for studying trends of traffic flow rates. The number of years listed in this section must be equal to the number of years specified in the first section. This list of the years are provided in the second record in Table 4.1.

The third section provides the coefficient for the covariance matrix for certain links on the study freeway. It includes the station number and the specified coefficient for each of the links. This section may contain more than one record. The number of the records in this section must be equal to the number of the links specified in the first section. An example of this section is shown in the third record in Table 4.1.

4.2.2 Station Location Data Files

A station location data file is developed for each freeway to provide information required for generating the incidence matrix and for calculating daily traffic volumes and AADTs. It contains a subset of the ConnDOT's mainframe station location data file and some other information. The discussion here addresses typical records in a station location data file. Other records related to some special cases are discussed in Appendix A.

Typical records in a station location data file include the records for short-term coverage counting stations, continuous counting stations and loop monitoring stations. A typical record contains seven items: (1) the link number, (2) the station number, (3) the route number, (4) the expansion factor group number, (5) the route direction code, (6) the traffic flow direction code, and (7) a brief description of the station. The link number (first item) is the number that is assigned sequentially to each links on the freeway. The other items are the same as those in the record of the ConnDOT's mainframe station location data file discussed in Section 2.1.3. Table 4.2 gives examples of typical records in a station location data file.

Table 4.2 Typical Records in a Station Location Data File

```
 78 0337080 I-91 4 S.B. OFF RAMP TO CONN. 9
 76 0337081 I-91 4 S.B. OFF RAMP TO CONN. 9 N.B.
 74 0337082 I-91 4 S.B. ON RAMP FROM CONN. 9
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
153 0469053 I-91 0 N.B. IN CONTINUOUS COUNT STATION 53
167 0469053 I-91 0 S.B. OUT CONTINUOUS COUNT STATION 53
168 0487190 I-91 4 S.B. ON RAMP FROM U.S. 5 (EXIT 46)
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
123 0631022 I-91 1 S.B. OUT BETWEEN EXIT 33 AND EXIT 34
111 0631022 I-91 1 N.B. IN BETWEEN EXIT 33 ADN EXIT 34
    0631122 I-91 1 (HOV LANE) BETWEEN EXIT 33 AND EXIT 34
```

4.2.3 Additional Data Files

The additional data file for a freeway is used to explicitly provide AADTs for certain links, including mainline links on which the continuous counting stations are installed and ramp links for which the hourly traffic volume data are not available from the traffic count data file. Table 4.3 shows the additional data file for I-91 northbound for year 1994. For each record in Table 4.3, the first item is the link number, the second item is the station number, and last item is the AADT value associated with the link.

Table 4.3 An Additional Data File

10	0920000	8300
24	1007030	9500
45	1489055	30500
56	0797064	3200
86	1598102	3400
106	0638104	1700
134	1648102	1500
153	0469953	41000

4.3 Output Data Files

In the TCAS, two output data files are developed to present the final results for each direction of a freeway. One file contains the primary results of the TCAS which are the estimated AADTs for all links in the study range. The other provides the lists of AADTs for ramp links in the study range for the study year and specified preceding year(s). The latter file is produced only when the list of the preceding years is provided in the calculation control parameters. Table 4.4 and Table 4.5 are examples of these two types of output data files.

Table 4.4 An Example of the Results of the TCAS

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION
BUREAU OF POLICY AND PLANNING
PLANNING INVENTORY AND DATA

DAILY COUNTS, AADTS AND RECONCILIATION RESULTS

ROUTE 91 DIRECTION N YEAR 1994

LINK NUMBER	STATION NUMBER	DAILY VOLUME	AADT	RECON. RESULT
045	1489055	30500	30500	30500
046	1487052	5915	5500	5500
047				25000
048	1487053	5414	5035	5000
049				30000
050	0797055	2882	2680	2700
051				27300
052	0797058	10947	10180	10200
053				17100
054	0797059	15130	14070	14200
055				31300
056	0797064	3200	3200	3200
057				28100
058	0000999	9692	8839	8900
059				37000
060	0797068	1139	1070	1100
061				38100
062	0827075	3244	3049	3000
063				35100
064	0827076	1330	1250	1300
065	0821021	40462	38507	36400
066	0337071	3379	3176	3200
067				33200

END OF FILE

Table 4.5 An Example of the Lists of AADTs

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION
BUREAU OF POLICY AND PLANNING
PLANNING INVENTORY AND DATA

LIST OF AADTS FOR DESIRED CYCLES

ROUTE 91 DIRECTION N CURRENT YEAR 1994

LINK	STATION	1994-AADT	1991-AADT
046	1487052	5500	4941
048	1487053	5035	4161
050	0797055	2680	2631
052	0797058	10180	9134
054	0797059	14070	12195
056	0797064	3200	3010
060	0797068	1070	1031
062	0827075	3049	2986
064	0827076	1250	1286
065	0821021	38507	35131
066	0337071	3176	3277

END OF FILE

In Table 4.4, there are five columns below the title section. These columns contain the link numbers, the station numbers, the daily traffic volumes, AADTs factored from the daily traffic volumes, and the reconciliation results for the links in the study range.

Table 4.5 shows AADTs for the links in the study range for the preceding year given in the calculation control parameters, in this case, year 1991 only. The four columns in Table 4.4 are the link numbers, the station numbers, AADTs for the study year (1994) and AADT for the preceding year (1991).

V Results

This chapter presents the results from the application of the TCAS to freeways using data collected for Route 20 (Windsor Lock, Connecticut) westbound in 1994. The configuration of Route 20 is shown by a strip map in Figure 5.1. There are nine (9) nodes and nineteen (19) links in each direction of this freeway. Twelve (12) of the nineteen (19) links in each direction were measured in 1994.

The results of the TCAS for Route 20 westbound in 1994 are shown in Table 5.1. The link numbers of all links on Route 20 westbound are given in the first column in the table. The second column provides the station number corresponding to each link on which a counting station is installed. The daily traffic volume and the AADT (factored from the daily traffic volume) for each counting station are provided in the third and fourth columns. The last column contains the reconciliation results (adjusted AADTs) for each link. These adjusted AADTs satisfy material balance at all nodes on this freeway and minimize the total adjustments of the factored AADTs (column 4 in Table 5.1). They are the best estimates of the actual AADTs under the information available.

In Table 5.1, the reconciliation results (Column 5) are rounded in accordance with the protocol used by ConnDOT (discussed in Appendix C). Except for this rounding, the reconciliation results (in Column 5) for Stations, 0397702 and 1657701, are the same as the original AADTs (in Column 4) for these two counting stations. In this example, these two counting stations are considered control points.

AADTs calculated from the traffic count data collected in 1994, 1993 and 1990 on Route 20 westbound in Windsor Lock are listed in Table 5.2. These AADTs can be used to study the trends of traffic volume data. Trends of the historical traffic volume data are of great values in the adjustments of the AADTs and in the detection of the gross errors. Gross errors caused by equipment failures or poor calibrated equipment sometimes exist in traffic count data. They

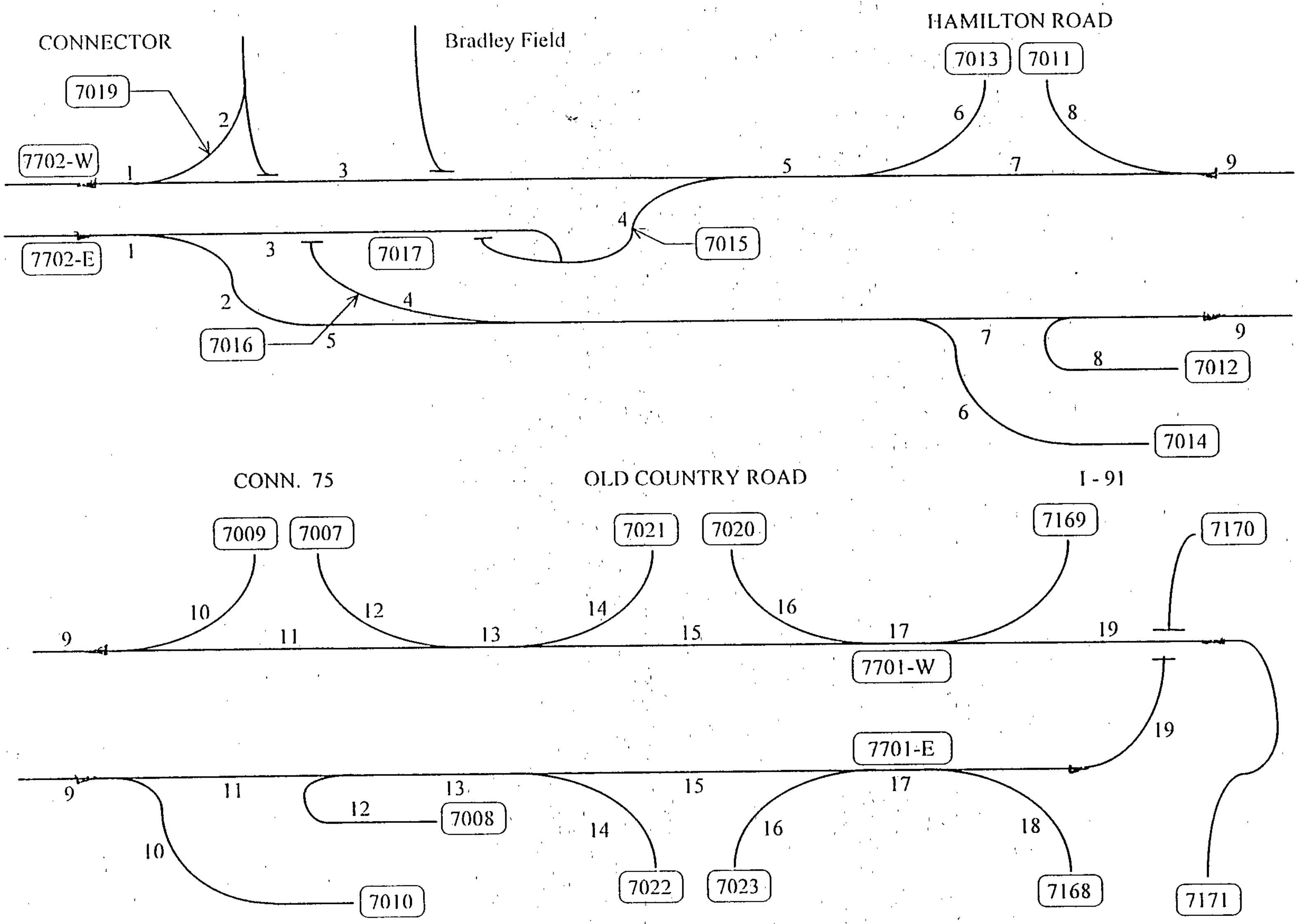

Figure 5.1 The Strip Map of Route 20

should be identified and deleted from the traffic count data before the TCAS is used, because these gross errors would significantly degrade the overall results from the TCAS.

Table 5.1 Results of the TCAS for Route 20 Westbound

LINK NUMBER	STATION NUMBER	DAILY VOLUME	AADT	ADJUSTED RESULT
001	0397702	13515	12704	12700
002	0397019	3117	2929	3000
003				9700
004	1657015	6060	5696	5500
005				15200
006	1657013	703	660	600
007				14600
008	1657011	2922	2746	2700
009				17300
010	1657009	1835	1724	1800
011				15500
012	1657007	7163	6733	6300
013				21800
014	1657021	1339	1258	1300
015				20500
016	1657020	3196	3004	2900
017	1657701	24878	23385	23400
018	1647169	11331	10651	10300
019	1647171	14447	13580	13100

Table 5.2 Lists of the AADTs for Route 20

LINK NUMBER	STATION NUMBER	AADT (1994)	AADT (1993)	AADT (1990)
001	0397702	12704	10830	11397
002	0397019	2929	3212	3327
004	1657015	5696	4373	4894
006	1657013	660	699	1057
008	1657011	2746	2519	3799
010	1657009	1724	1709	2071
012	1657007	6733	7222	7333
014	1657021	1258	1147	-[a]
016	1657020	3004	3213	-
017	1657701	23385	20690	19846
018	1647169	10651	-	-
019	1647171	13580	-	-

[a]Data for the link are not available in the year

VI Summary and Conclusions

The TCAS was developed to analyze traffic count data for freeways using the FORTRAN computer programming language. It can be used to (1) calculate AADTs for freeway ramps and certain mainline links using the collected traffic count data, (2) estimate AADTs for uncounted mainline links, and (3) adjust these AADTs so that they are balanced at all freeway junctions.

Data coaptation and data reconciliation techniques are used in the development of the TCAS. These two techniques have been used successfully in the processing of network flow rate data. Data coaptation is used to calculate AADTs for the uncounted links based on AADTs for the counted links. Data reconciliation is used to determine the smallest overall adjustments of the AADTs such that the adjusted AADTs all satisfy material balance.

Incidence matrices are used to represent the configuration of freeways in the TCAS. Normally, node numbers, link numbers, and the flow directions for all links on a network are required to define the incidence matrix of a network. In the TCAS, only a part of this data set is needed to form the incidence matrix for a freeway when three simple constraints are placed on the assignment of link numbers. The data needed include the link numbers and the traffic flow directions for all links. This information is stored in the station location data file for each freeway in the TCAS. The advantage of using this simplified system for forming the incidence matrix is that the time and effort required to prepare data for the incidence matrix are significantly reduced.

The station location data file for each freeway in the state of Connecticut, including I-84, I-91 and I-95, was built based on the station location data file in the TMS. The overall system was tested using data in the traffic count data files and the expansion factor data files for the years 1989 to 1995. The station location data file for a freeway can be used for consecutive years if no changes occur to the freeway. If changes occur to the freeway, the station location data file must be changed accordingly. A subprogram was developed in the TCAS to modify the station location data file.

The TCAS was designed to use to the greatest possible extent possible existing traffic volume data from the TMS. The traffic count data files and the expansion factor data files in the TMS are directly used as input data files to the TCAS. For a freeway, after the station location data file is built, the only data file that might be required to be built is the additional data file. The additional data file contains records for only those links for which traffic counts are not available in the traffic count data file. Generally, the additional data file is very small and is easy to build if needed.

The TCAS was applied to all freeways in Connecticut. For each freeway, the results from the analysis, AADTs for all links, are similar to the results for Route 20 given in the preceding chapter. All these results satisfy material balance, and at the same time, minimize the total overall adjustment.

The results of the TCAS are comparable to those from the procedure currently used in the TMS. The TCAS is also very easy to used; therefore, it is a very useful tool in the analysis of freeway traffic count data. It is expected that the TCAS will greatly reduce the time and effort required to process traffic counts for freeways in the TMS.

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Appendix A More about Station Location Data File

As pointed out earlier, the station location data file for a freeway is required to form the incidence matrix and to calculate daily traffic volumes and AADTs. Three records in the station location data file for a freeway have been discussed in Section 4.2.1. These records are associated with a short-term coverage counting station, a continuous counting station and a loop monitoring station. This appendix discusses some special records in the station location data file which are designed to handle special situations existing in the TMS.

A.1 Records for Pseudo-Stations

In the TCAS, a record in the station location data file is used to indicate a counting station, as well as a link on which the counting station is installed. To form the incidence matrix for a freeway, all ramp links must be included in the station location data file for the freeway. In other words, for each ramp link for a freeway, there must be a record associated with it in the station location data file for the freeway.

In the TMS, no counting stations are designated to a handful of ramps. An example is shown in Figure A.1 (a). No counting station is assigned to the off-ramp from I-91 northbound to I-91 northbound HOV lane. This means that there is no record associated with a counting station located at this ramp in the ConnDOT's station location data file. In this case, a record must be added to the station location data file for the freeway to indicate the ramp in the TCAS. This record is associated with a non-existing counting station, which is referred as to a pseudo-station.

The record for the example shown in Figure A.1 (a) is given in Record (1) in Table A.1. This record has the same six items as the record for a short-term coverage counting station. While running the TCAS, this record is used to form the incidence matrix of the freeway. Note that AADT for this ramp must be provided in the additional data file for the freeway.

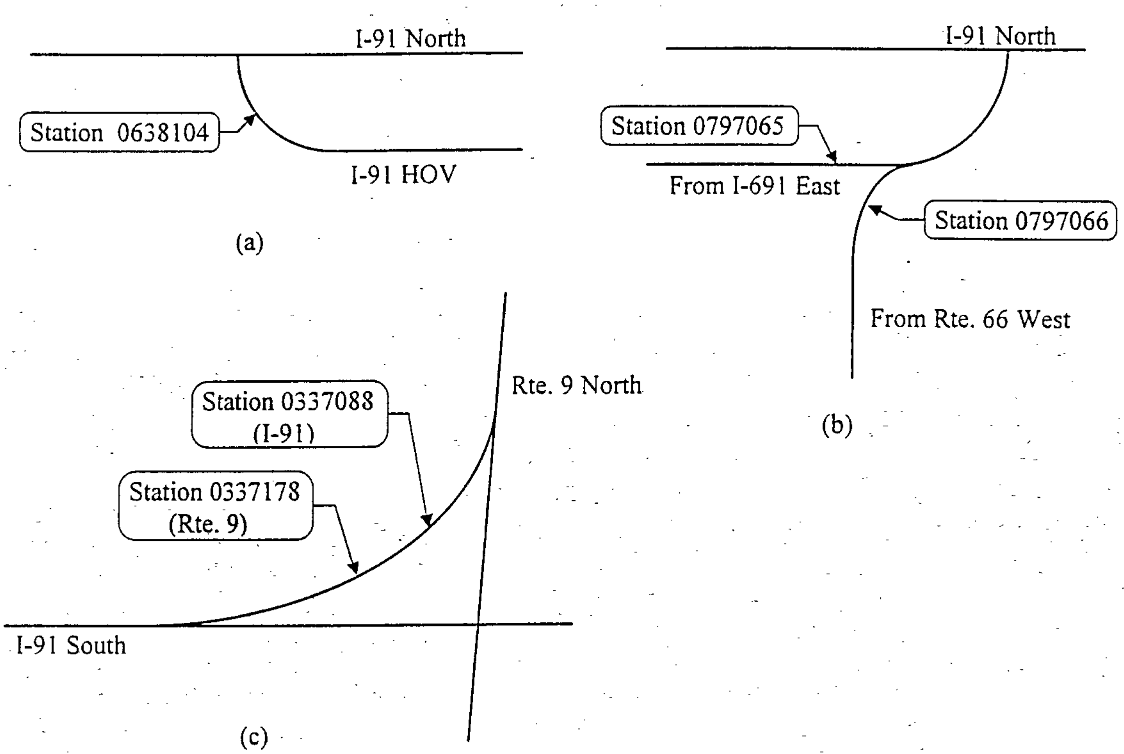

Figure A.1 Special Situation in the TMS/H

Table A.1 Special Records in a Station Location Data File

```
 74 0337083 I-91 4 N.B. ON RAMP FROM CONN. 9
 72 0337088 I-91 4 S.B. ON RAMP FROM ROUTE 9 S.B.  ................(4)
 74 0337177      9N4 S.B. ON RAMP FROM CONN. 9
 74 0337178      9N4 N.B. ON (OFF RAMP TO I-91 N.B.)
 78 0337179      9S4 S.B. OFF RAMP TO CONN. 9
 72 0337181      9S4 S.B. ON RAMP FROM ROUTE 9 S.B.  .................(5)
 76 0337182      9N4 S.B. OFF RAMP TO CONN. 9 N.B.
.............................................
120 0638104 I-91 4 S.B. ON RAMP FROM I-91 HOV  ..................  (1)
106 0638104 I-91 4 N.B. OFF RAMP TO I-91 HOV.
...............................................
 58 0797065 I-91 1 N.B. ON RAMP FROM I-691 E.B.  ..................  (2)
 58 0797066 I-91 4 N.B. ON RAMP FROM CONN. 66 W.B.  ................  (3)
 62 0797067 I-91 4 S.B. OFF RAMP TO BALDWIN AVENUE
```

A.2 Records for 'Y' Situation

For certain types of ramps in the TMS, there are no counting stations designated to these ramps, but there are counting stations designated to the links directly connected to these ramps. This is referred to as a 'Y' situation. An example of this situation is shown in Figure A.1 (b). Traffic from I-691 eastbound and Route 66 westbound merge at the ramp of I-91. Counting stations are installed on the links of I-691 and Route 66, but not on the ramp of I-91 North.

In the TCAS, for this situation, the records for the counting stations assigned to the links connected to the ramp are used to indicate the ramp. For example, records for the above example are given in Records (2) and (3) in Table A.1. These two records have the same link number which is the link number of the ramp. While running the TCAS, the incidence matrix is formed based on either of the records. AADTs for the ramp are obtained by adding the AADTs for the two links connected to the ramp.

A.3 Record for Counting Stations Designated for other Freeways

At the interchange of two freeways, two counting stations are usually installed on the ramp shared by the freeways, one for each of the freeways. An example of this situation is shown in Figure A.1 (c). At the interchange of Route 9 and I-91, the off-ramp from I-91 South is also the on-ramp to Route 9 North. On this ramp, two counting stations, 0337088 (I-91) and 0337181 (Route 9), were installed in 1994.

In this case, it is sometimes helpful to use the data collected from both counting stations while analyzing the traffic count data for one freeway. To use the data from the counting station designated for the other freeway, a new record is required to be added to the station location data file for the freeway. For example, the new record added to the station location data file for I-91 for the above mentioned example is given in Record (4) in Table A.1. In addition to the six items for a short-term coverage counting station, this new record contains a new item which is the route direction code for Route 9. This new item is required to calculated the AADT for this counting station. This new record has the same link number at the record for the counting station located at the same ramp (shown in Record (5)).

While running the TCAS, AADTs from both counting stations are calculated and then the following prompts are displayed:

```
************** MULTIPLE STATIONS ******************

 ADT at station  337088 on route I-91 is    4293 in 1994
 ADT at station  337181 on route    9 is    4462 in 1994

 How do you want to use them?
   1 - Average
   2 - Use the first one
   3 - Use the last one
   4 - Specify

My choice is (1->4):
```

The user of the TCAS must chose how to use these calculated AADTs. The AADT for the ramp can be either (1) an averaged value of the calculated AADTs, (2) the AADT from the first counting station, (3) the AADT from the last counting station, or (4) a specific AADT value.

Appendix B Forming the Incidence Matrix

In the TCAS, the incidence matrix of the freeway section in the study is formed using the link numbers and the traffic flow directions for all ramp links and the beginning mainline link in the study range. Link numbers and traffic flow directions for other mainline links, as well as node numbers are not required to form the incidence matrix, because they can be determined by the given information if the link numbers are assigned in a specified manner. The next sections discuss the criteria of the assignment of link numbers and the procedure for forming the incidence matrix in the TCAS.

B.1 Criteria for Assigning Link Numbers

In the TCAS, a link number is assigned to each link on a freeway in accordance with the following criteria:

1. Link numbers are assigned to only the mainline links and the ramp links directly connected to the mainline.
2. Link numbers are assigned sequentially for each direction of the freeway.
3. All ramp links are assigned even numbers.

B.2 Procedure for Forming the Incidence Matrix

From the discussion in Section 3.2, node numbers, link numbers and link directions for a network are normally required to determine the incidence matrix of the network. For a freeway, only the link numbers and the link directions for all ramp links and the beginning mainline link are required to form the incidence matrix for the freeway section. Other information can be determined by these data.

The node number for each node can be determined by the link number for the link connected to the node. The mainline link number can be determined by the link number for the links adjacent to it. The traffic flow direction of a mainline link is the same as the first mainline link. For example, refer to Figure 2.2, each node number is equal to half the link number of the link connected to the node. Each mainline link number is equal to the link number of the link behind it minus one, and each mainline link traffic flow direction is the same as the mainline link traffic flow direction of the beginning mainline link.

In the TCAS, the link numbers and the traffic flow directions are included in the station location data file. The link number is given in the first item of each record in the station location data file. The link traffic flow direction is indicated by the traffic flow direction code in the record. Records for the mainline counting stations (Continuous Counting Station and Loop Monitoring Station) can be used as the beginning point for forming the incidence matrix.

Appendix III Rounding the Results of the TCAS

In the TCAS, the final estimated AADTs are rounded in accordance with the protocol used by ConnDOT for rounding AADTs. The purpose of coding the protocol in the TMS into the TCAS is to make the final estimated AADTs from the TCAS consistent with the AADTs from ConnDOT.

The protocol used in the TMS to round the final AADTs are as follows:

- If AADT is less than 100, it is rounded to the nearest 10.
- If AADT is greater than 99 and less than 1000, it is rounded to the nearest 50.
- If AADT is greater than 999, it is rounded to the nearest 100.

Mathematical formulas for the protocol were derived in order to code the protocol into the TCAS. Denoting the given AADT by A and the rounded AADT by B, the protocol can be expressed mathematically using the following formulas:

$$\text{If } A < 100 \qquad B = \text{int}\left(\frac{A + 5.0}{10.0}\right) \times 10.0$$

$$\text{If } 00 \leq A < 1000 \qquad B = \text{int}\left(\frac{A + 25.0}{50.0}\right) \times 50.0$$

$$\text{If } A \geq 1000 \qquad B = \text{int}\left(\frac{A + 50.0}{100.0}\right) \times 100.0$$

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