DEVELOPMENT AND PRELIMINARY TESTING OF AN AUTOMATIC TURNING MOVEMENTS IDENTIFICATION SYSTEM

Final Report

Submitted to

Ohio Transportation Consortium

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February, 2010

Executive Summary

It is important for many applications, such as intersection delay estimation and adaptive signal control, to obtain vehicle turning movement information at signalized intersections. However, vehicle turning movement information is very time consuming to obtain and usually the data can only be counted manually. Previous efforts were focused on solving the problem using an O-D matrix but the result is not accurate and reliable. Limitations with the existing methods to handle shared-lane situations have prevented them from being used for many intersections. Motivated by the need to identify vehicle turning movements for many real time applications without being constrained by the intersection configuration, the University of Akron's transportation research group has developed an Automatic Turning Movement Identification System (ATMIS) and tested it through lab and field evaluation. The results from those experiments are very encouraging with small errors compared with the ground truth. This project has demonstrated the great potential of ATMIS to be used for other applications after further testing and enhancement.

ACKNOWLEDGEMENTS

Funding for this research is provided by the Ohio Transportation Consortium, a Tier II University Transportation Center sponsored by the US Department of Transportation. Special thanks go to Mr. David Gasper and the Signal Shop of the City of Akron for supporting this research.

TABLE OF CONTENTS

Page

LIST OF TABLES 6

LIST OF FIGURES 7

1. PROBLEM DESCRIPTION 8

2. BACKGROUND 10

2.1 Mathematical Approach 10

2.2 Direct Detector Data Approach 12

3. METHODOLOGY 13

3.1 ATMIS Algorithm 14

3.1.1 Input Detection Recording Module 18

3.1.2 Output Detection Matching Module 18

3.1.3 Input Detection Cleanup Module 21

4. ATMIS EXPERIMENTS AND RESULTS 21

4.1 Laboratory Experiments 21

System Architecture 21

4.1.1 Experimental Results 24

4.2 Field Test 28

5. CONCLUSION AND FUTURE WORK 30

REFERENCES...32

APPENDIX LIST OF ABBREVIATIONS 33

LIST OF TABLES

Table Page

3.1 Corresponding Turning Movement for Detector Pairing..................................... 16

4.1 Volume and Error Percentage of Laboratory Experiments.................................. 28

LIST OF FIGURES

Figure Page

2.1 Basic Intersection Model 11

3.1 Detector Configuration for a Four-Leg One-Lane Intersection 15

3.2 Flow Chart of ATMIS Algorithm 17

3.3 Example of Multiple Matches from Input Detections 20

4.1 ATMIS Architecture 22

4.2 Prerecorded Video for Laboratory Experiment 22

4.3 NEMA Standard Traffic Controller Emulator 23

4.4 Turning Movement Identification Program 24

4.5 Geometry Layout of Three Intersections in Laboratory Experiments 26

4.6 Laboratory Experiment Results on Fifth Avenue at South Arlington Street 26

4.7 Laboratory Experiment Results on East
Wilbeth Road at South Arlington Street 27

4.8 Laboratory Experiment Results on Wedgewood Avenue at Canton Road 27

4.9 ATMIS System Architecture for Field Test 29

4.10 Field Test Result on Fifth Avenue and South Arlington Street 30

1. PROBLEM DESCRIPTION

Turning Movements Information (TMI) for vehicles at signalized intersection is important for many applications including but not limited to intersection design, signal control, dynamic traffic assignment and traffic demand estimation. Traditionally, TMI is collected manually using handheld devices in the field which is usually very labor intensive and time consuming (1). The desire for real-time TMI for applications such as adaptive signal control gives rise to the effort to explore vehicle turning movements automatically. Previous efforts on this problem mainly focused on a mathematical method by solving an O-D matrix in which the turning movements represent distributions of the arriving flow from each intersection approach. However, such a matrix cannot be mathematically solved without using supplementary volume data from the local detectors; previous studies showed the results from the O-D method are not accurate.

Identifying turning vehicles directly from detector information is another method to obtain TMI. Limited studies using this method have been reported for intersections without shared lanes. Since many intersections in the field allow lane sharing, this method is not practical without further improvement. Driven by the need to identify vehicle turning movement automatically regardless of the geometric and operational conditions of the intersection, this research endeavored to develop and test an Automatic Turning Movement Identification System (ATMIS).

The development of ATMIS supports other related research such as vehicle delay estimation. Average vehicle delay for traffic coming from each direction is considered as one of the most important Measures of Effectiveness (MOE) for assessing the performance of intersection operation. Field delay measurements are valuable but can be very costly, because to collect such data requires extensive use of a large number of labors as data collectors to work in the field for long periods of time. On the contrary, use of ATMIS holds great potential for saving cost and increasing data efficiency.

2. BACKGROUND

2.1 Mathematical Approach

The origin-destination (O-D) matrix method for TMI was first introduced in 1981 by Cremer and Keller (2). Consider a signalized intersection as presented in Figure 1.1, where detectors are placed on each lane to detect both arriving and leaving vehicles. Suppose the traffic volume flow into/out of the intersection on each approach is known for given time period t, with the assumption that no vehicle exists in the system before and after the time period t, we can set up the following equations:

$$\begin{pmatrix} 0 & b_{21} & \cdots & b_{N1} \\ b_{12} & 0 & & b_{N2} \\ \vdots & & \ddots & \vdots \\ b_{1N} & b_{2N} & \cdots & 0 \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{pmatrix} = \begin{pmatrix} O_1 \\ O_2 \\ \vdots \\ O_N \end{pmatrix} \qquad 1.1$$

Where,

N	the number of approaches for the studied intersection
I_i	traffic volume going into the intersection at approach i (i = 1 to N)
O_j	traffic volume going out of the intersection at approach j (j = 1 to N)
b_{ij}	probability for a vehicle entering the intersection from approach i will leave at approach j (i = 1 to N and j = 1 to N)

According to the definitions, we can have the following constraints in addition:

$$\begin{cases} b_{ij} \geq 0 \text{ when } i \neq j \\ b_{ij} = 0 \text{ when } i = j \end{cases} \quad \text{where} \quad i, j = 1 \text{ to } N \qquad 1.2$$

With the assumption that no U-Turn is allowed, we can get

$$\sum_{j=1}^{N} b_{ij} = 1 \text{ where } i = 1 \text{ to } N \qquad 1.3$$

Once the O-D matrix composed by b_{ij} has been solved, the volume of vehicle turning movements can be calculated by multiplying the probability b_{ij} with corresponding volume q_i.

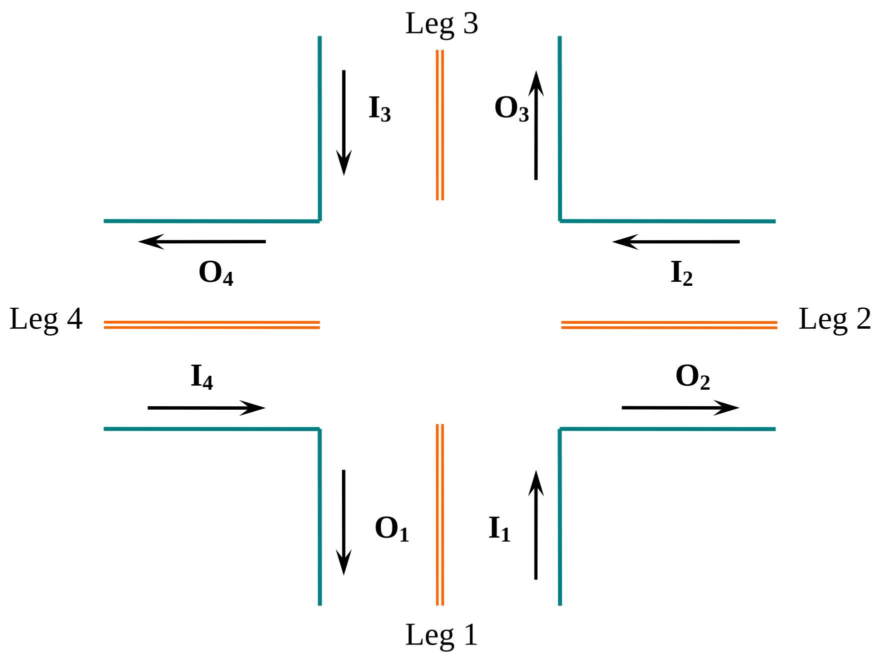


Figure 1.1 Basic Intersection Configuration

However, this seemingly simple mathematical problem cannot be easily solved. It has been found that when the number of approaches is more than 3, the matrix has multiple solutions due to more variables than equations. In addition, the mathematical formulation requires that there be no errors in the traffic volume data at each approach; otherwise, it may become an unsolvable matrix. To address these problems, plausible assumptions need to be applied or additional constraints must be provided. This limits the potential of this model for field applications. Nihan and Davis (3) developed a Kalman filtering algorithm to solve the O-D matrix. This algorithm is an extension to stochastic gradient algorithm in dynamic identification of flow distributions at complex intersection. However, this method is not reliable to use, as the Root Mean Square (RMS) error is from 29.2% to 49.4%. Later Cremer and Keller (4) proposed an application of maximum likelihood algorithm for intersection O-D matrix estimation. Similarly, the RMS error of their model is from 6.1% to 24.7%.

The mathematical methods including the above models also require as input accurate volume information. In practice, however, errors from human operators and field facilities commonly exist and cannot be easily identified and eliminated. To compensate the errors in traffic volume, Jiao et al. (5) in 2005 developed a method using Genetic Algorithm as an improvement. Based on their simulation, it was found that such errors can be reduced to about 5%. The errors are expected to grow much higher in field applications.

Finally, the O-D matrix based methods use data covering a long time period (more than 15 minutes) in order to minimize the impact of traffic flow fluctuation on the calculations. This condition may further limit the method from being used to model certain intersections with dynamic traffic demand and signal controls.

2.2 Direct Detector Data Approach

Another approach to obtain TMI is to make use of the detector data directly. In 1998, Time And Place System (TAPS) was first developed by Virkler and Kumar (6) at University of Missouri-Columbia and five more field tests were conducted in 2004 (7). In TAPS, signal timing and detection information was utilized to identify vehicle turning movements at signalized intersection in real-time. In the field tests, the average errors of turning movement identification under no lane-sharing scenario are from 8% to 16% while it increased to 13% to 36% when shared lanes were involved. In particular, for the shared left-turn movements, the errors were as high as 71% compared with 10% in the shared right-turn situation in the same test (due to the use of a special detector placed at the corner of the intersection to detect right turn vehicles).

Another effort to identify TMI is by Sunkari, Charara and Urbanik of Texas Transportation Institute (8). The authors introduced a similar method to TAPS to estimate vehicle turning movements at a signalized diamond interchange. Their method also requires special right turn detectors without shared left turning lanes during the test. According to their limited test result (only one scenario), the turning movement identification error is about 10% on average.

From the above discussion of successes and problems in TMI identification, it is clear that additional work is needed to improve the methodology for applications in more general situations involving shared turning lanes. In such cases, the accuracy of TMI is affected by the position of the shared lanes, local traffic conditions, and interactions by the turning movements in the opposite direction or the cross street.

3. METHODOLOGY

Identifying vehicle turning movement automatically at intersections with shared lanes is always a challenge to transportation engineers. Driven by the need to develop an automatic system to identify vehicle turning movements in various geometric layouts, we developed an Automatic Turning Movement Identification System (ATMIS) in the Transportation Laboratory of The University of Akron. This system is designed to be independent of the geometric layout of the intersection, including shared lanes and irregular intersection configurations (more than four legs or odd shape), and it is calibrated to tolerate a certain level of detection errors. For convenience of placing detectors and watching the traffic condition for ground truth verification, we used the video detection system in support of the development and testing of ATMIS.

2.1 ATMIS Algorithm

The algorithm used in ATMIS is developed using information from the detection system and the signal system. By tracking each detector's status and traffic signal operation second by second, vehicle turning movements are calculated in real-time. To illustrate the algorithm, we use a four-leg intersection as an example. The detector configuration for a typical four-leg one-lane intersection is shown in Figure 2.1, where the white detectors are placed close to the stop bar at each flowing-in lane to detect vehicle arrivals at the intersection, and the gray detectors are placed at each flowing-out lane to detect vehicles leaving the intersection. Whenever a vehicle passes the intersection, a pair of detectors from the arrival detectors (white) and departure detectors (gray) will be matched. For different pairs of detectors, we have identified different corresponding turning movements as shown in Table 2.1. The algorithm in ATMIS will use this table along with the detection information and signal status to identify vehicle turning movements.

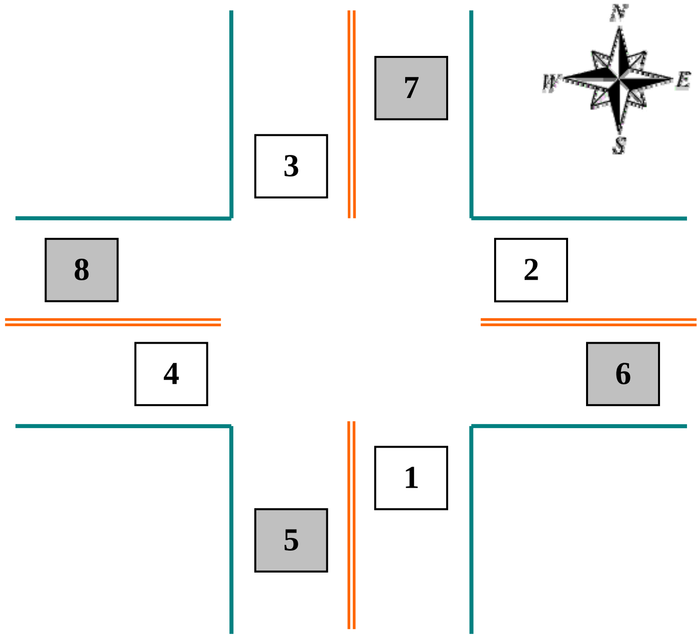


Figure 2.1 Detector Configuration for a Four-Leg One-Lane Intersection

At a signalized intersection, only some of the vehicles at or approaching the intersection can be given the right of way at any moment. The signal information can help narrow the possible candidate movements. However, the process to identify turning movements from the detector pair can still be very complicated when there are multiple choices caused by shared lane situations. For instance, in Figure 3.1 detection from detector 6 can be paired with detection from detector 1 as a northbound right turn, or it may be from a southbound left turn when combined with detection from detector 3. The purpose of our algorithm is to identify the turning movement under such circumstances independent from the geometry of the intersection. There are three modules in the algorithm, Input Detection

Recording Module, Output Detection Matching Module and Input Detection Cleanup Module. As shown in Figure 2.2, the detail procedures of these three modules are introduced below.

Table 2.1 Corresponding Turning Movement for Detector Pairing

Arrival Detector	**Leave Detector**	**Turning Movement**	**Abbreviation**
1	7	Northbound Through	NBT
1	6	Northbound Right Turn	NBR
1	8	Northbound Left Turn	NBL
2	8	Westbound Through	WBT
2	7	Westbound Right Turn	WBR
2	5	Westbound Left Turn	WBL
3	5	Southbound Through	SBT
3	8	Southbound Right Turn	SBR
3	6	Southbound Left Turn	SBL
4	6	Eastbound Through	EBT
4	5	Eastbound Right Turn	EBR
4	7	Eastbound Left Turn	EBL

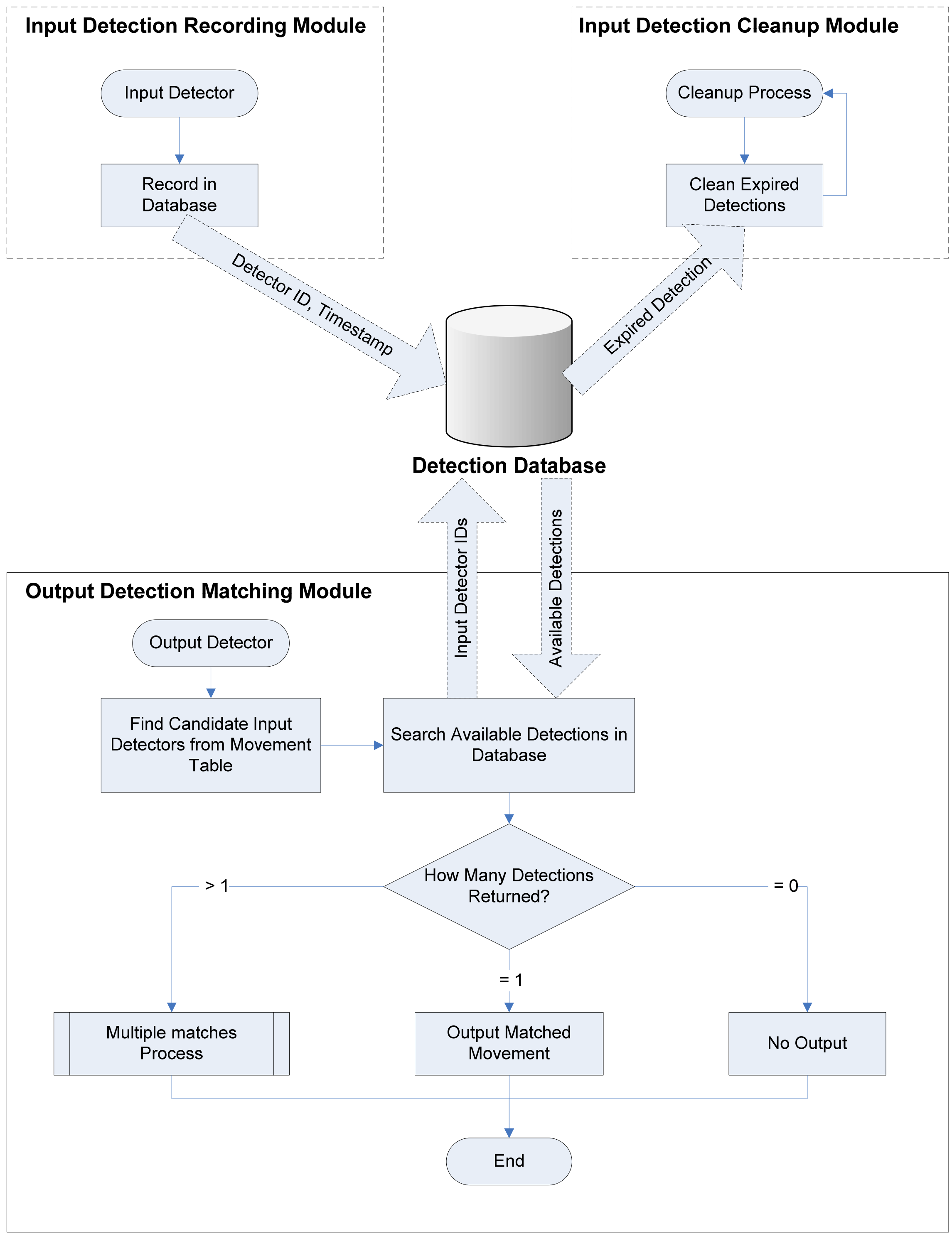


Figure 2.2 Flow Chart of ATMIS Algorithm

2.1.1 Input Detection Recording Module

This module is triggered by the detection from input detectors. Once the status of an input detector changes from activation to deactivation, which means the vehicle occupying the detector has left; the detector's ID and the deactivation timestamp will be recorded and sent to the database. The timestamp will be used in two places, the first is to match the sequence in detector pair and the second is to time-out unmatched detections. These input detections will be used later in the other two modules.

2.1.2 Output Detection Matching Module

This module is triggered by the detection from output detectors. An output detection means a vehicle has left the intersection and there should be one and only one input detection to match with it. However, in practice, more than one matched input detection is often returned from the database. As shown in Figure 2.2, three possible cases can happen as described below:

Case I: No matched detection is found in the database.

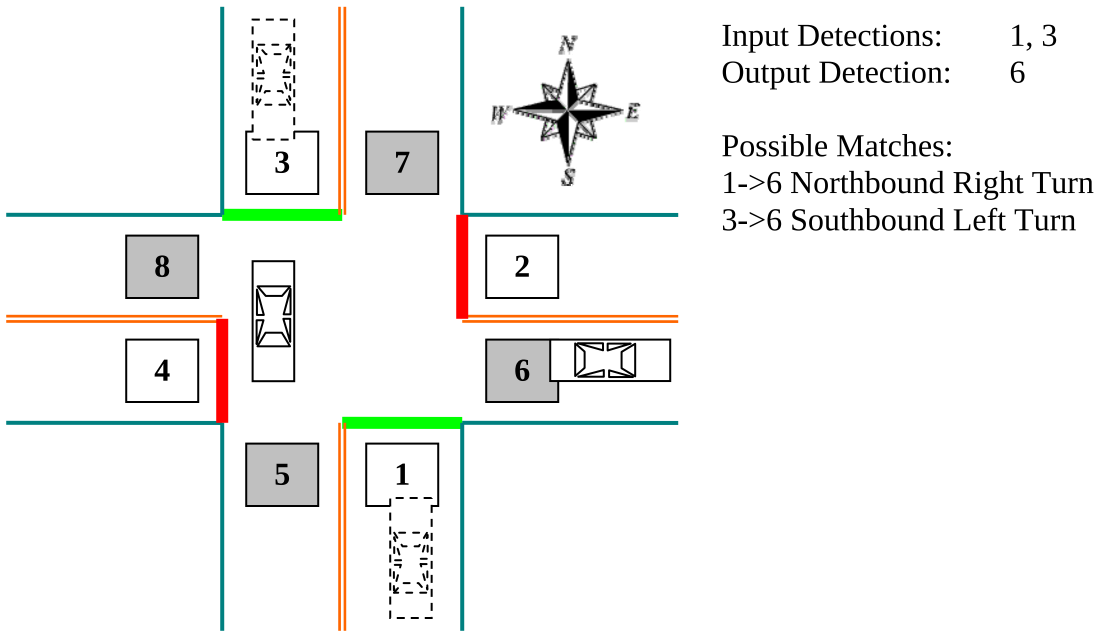
No matched detection can be caused by either miss detection on input detectors or false detection from output detectors. Since any detection in the future will not be helpful to solve this problem, we will just ignore the output detection and output the error.

Case II: Only one matched detection is found in the database.

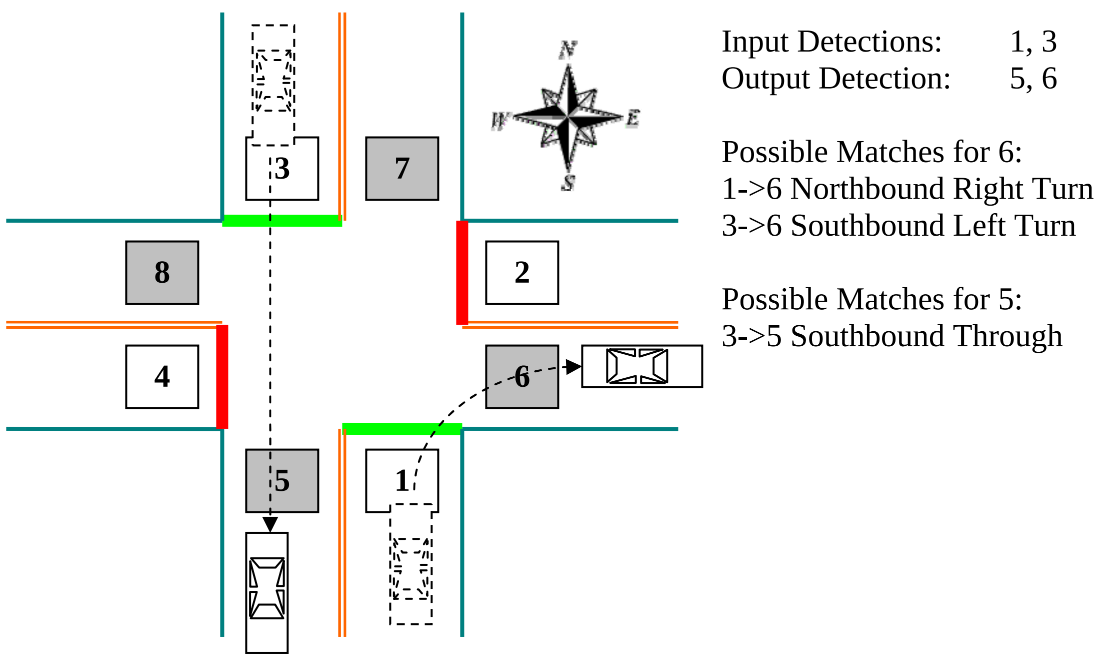
This is the best condition for detection match. We will simply search the turning movement table and find the corresponding movement for the detection pair from the turning movement table. The corresponding output and the input detection will be removed from the database.

Case III: More than one matched detection is found in the database.

This is the most complicated situation we must deal with in the algorithm, and it can be caused by many things, such as false detections, vehicles not cleared in the intersection, etc. The process to solve this problem is very complicated involving multiple trial-and-error steps. We will use a very simple example to explain how it works. Think about a four-leg intersection with one lane on each direction as shown in Figure 2.3. A vehicle moves from south to east (northbound right turn) and another vehicle moves from north to south (southbound through). At one moment, the vehicles' position is shown in Figure 2.3(a), with two input detections saved in database from detector 1 and detector 3. When the vehicle leaves detector 6, one output detection will be sent to the system. The algorithm will pull out the possible input detections from the database, but in this case it is hard to tell which one is correct. The multi-matching sequence will be changed if the southbound vehicle is assumed to leave the intersection and triggered detector 5. As shown in Figure 2.3 (b), since detection 5 can only be matched with detection 3, the algorithm will output the movement southbound through and remove the input detection 3 from the database. Consequently, the algorithm will output northbound right turn and remove the input detection 1 from the database. Thus, all the output detections have been matched and the turning movements are counted.



(a) Unsolvable Situation Caused by Vehicle



(b) Solvable Situation When Vehicle Cleared the Intersection

Figure 2.3 Example of Multiple Matches from Input Detections

2.1.3 Input Detection Cleanup Module

This module is an independent process which cleans up the unmatched input detections. These non-matched detections may be caused by false detection from input detector or misdetection on output detector. Input detections which have no matched output detection for a given time are removed from the database and the cleanup process is performed at every time step.

4. ATMIS EXPERIMENTS AND RESULTS

This section discusses the testing and evaluation of ATMIS in both a laboratory environment and in the field.

4.1 Laboratory Experiments

After the algorithm had been developed, ATMIS was tested in the laboratory first with prerecorded video from the field. The system architecture and test results are discussed below.

System Architecture

ATMIS is built based on NEMA standard system and consists of two parts, hardware and software. The hardware used in laboratory experiments includes a DVD player, RCA cables, video amplifier, video detection unit (Autoscope® 2020), R485 Cable, interface card and a personal computer as shown in Figure 3.1. The DVD player simulates the cameras to provide continuous video for detection system. The videos played in DVD player are prerecorded in the field with 4-in-1 to maintain synchronization of four cameras as shown in

Figure 3.2. Since one DVD player needs to supply four video detection units (simulate four cameras at one time), a video amplifier is necessary to compensate the signal loss due to splitting. The detectors are configured in the video detection unit according to the video provided by DVD player.

This unit is connected to a personal computer equipped with an interface card through R485 cable. The software of ATMIS is installed in this computer.

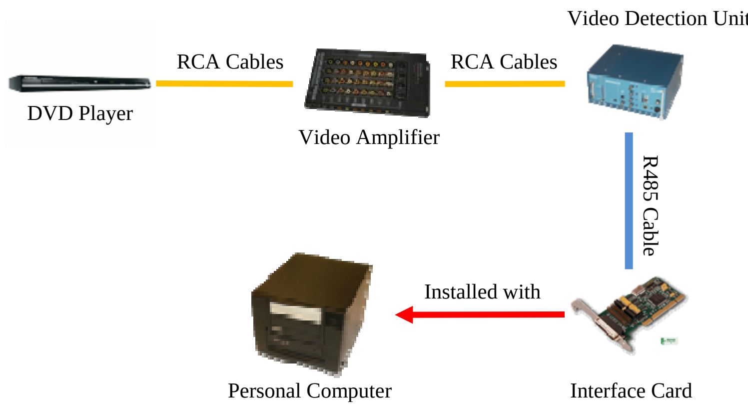


Figure 3.1 ATMIS Architecture

Figure 3.2 Prerecorded Video for Laboratory Experiment

The software part of ATMIS includes a NEMA standard traffic controller emulator and vehicle turning movement identification program. The controller emulator simulates a NEMA standard traffic controller to send out messages (frames) to detection unit and receive detection information (frames). The interface of emulator is shown in Figure 3.3.

Figure 3.3 NEMA Standard Traffic Controller Emulator

Once the detection information is collected in controller emulator, it will be forwarded to vehicle turning movement identification program along with the signal status. The interface of identification program is shown in Figure 3.4. Vehicle turning movements are identified with the built algorithm based on the detections and signal status. The results can be exported to Microsoft Excel ® for further study.

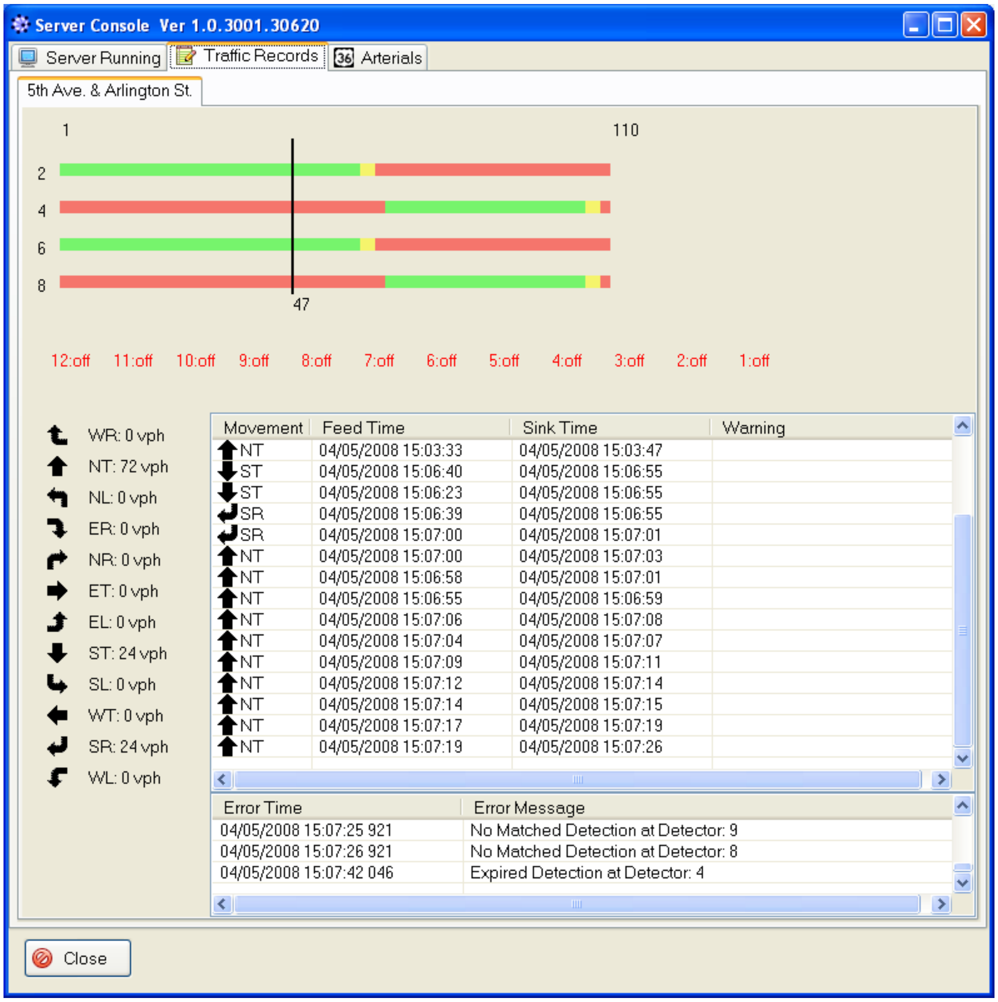


Figure 3.4 Turning Movement Identification Program

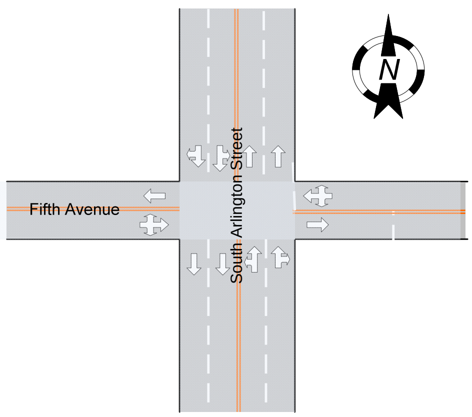
3.1.1 Experimental Results

Three intersections were tested in the laboratory environment, including intersection of Fifth Avenue at South Arlington Street, East Wilbeth Road at South Arlington Street, and Wedgewood Avenue at Canton Road; all locations are in the City of Akron, Ohio. These three intersections are all video camera equipped and their geometries are different. As shown in

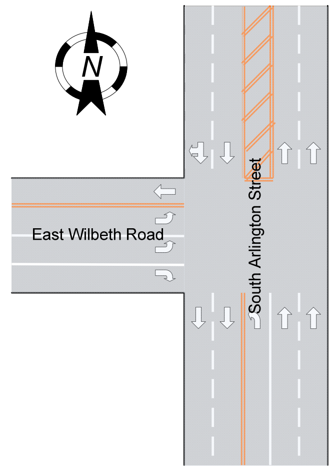
Figure 3.5a, the intersection of Fifth Ave. and S. Arlington St. is a regular four-leg intersection with shared lanes. The intersection of E. Wilbeth Rd. and S. Arlington St. is a T-intersection with only one lane shared by right turn and through traffic, and most other lanes in this intersection are exclusive lanes as shown in

Figure 3.5b. The third intersection, Wedgewood Ave. at Canton Rd., is an irregular intersection. From

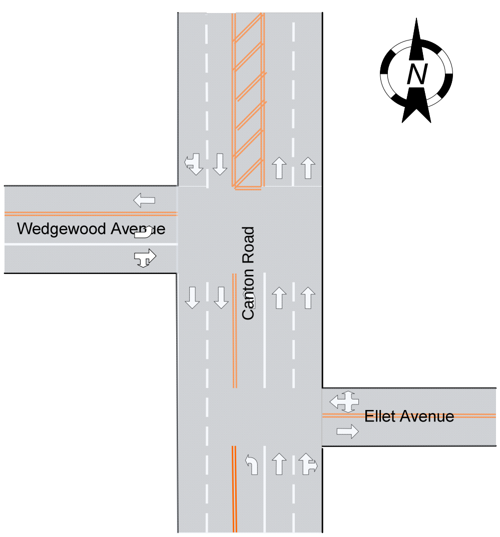
Figure 3.5c we can find that the two side streets, Wedgewood Ave. and Ellet Ave. are shifted making it an interesting case to study. The differences among these intersections challenge the ability of ATMIS to handle various intersection configurations.



(a) Fifth Ave. and S. Arlington St.



(b) E. Wilbeth Rd. and S. Arlington



(c) Wedgewood Ave. and Canton Rd.

Figure 3.5 Geometry Layout of Three Intersections in Laboratory Experiments

For each intersection, a video tape is recorded during the day time. The duration of the video varies from 60 minutes to 100 minutes. The ground truth of the turning movements is collected by watching the video (with repetitions) and the results of the experiments at 20-minute intervals are shown in Figure 3.6, **Error! Reference source not found.** and Figure 3.7.

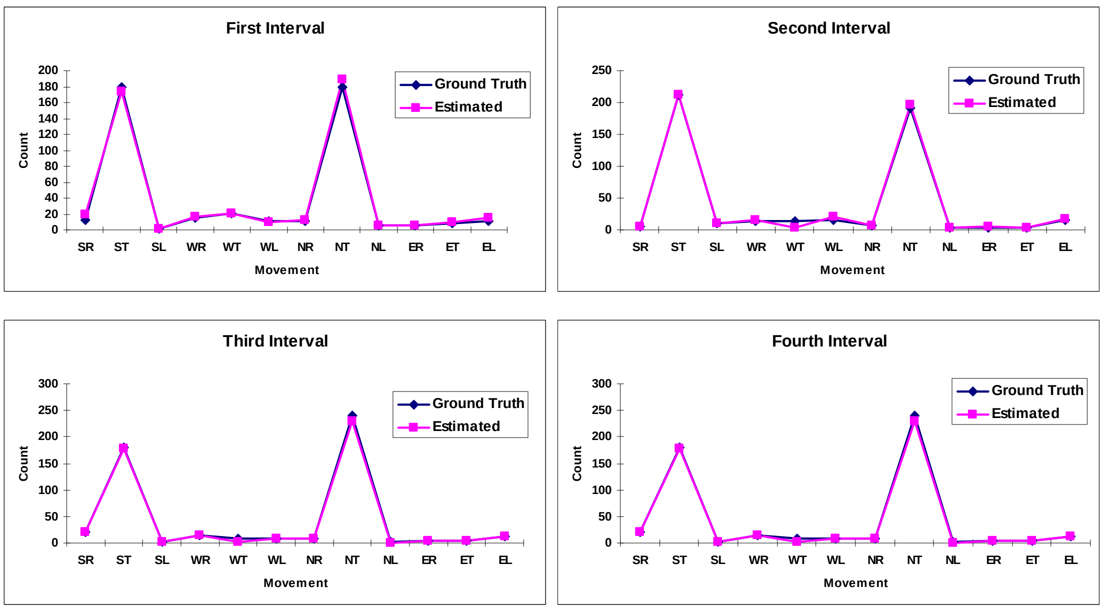


Figure 3.6 Lab Results on Fifth Avenue at South Arlington Street

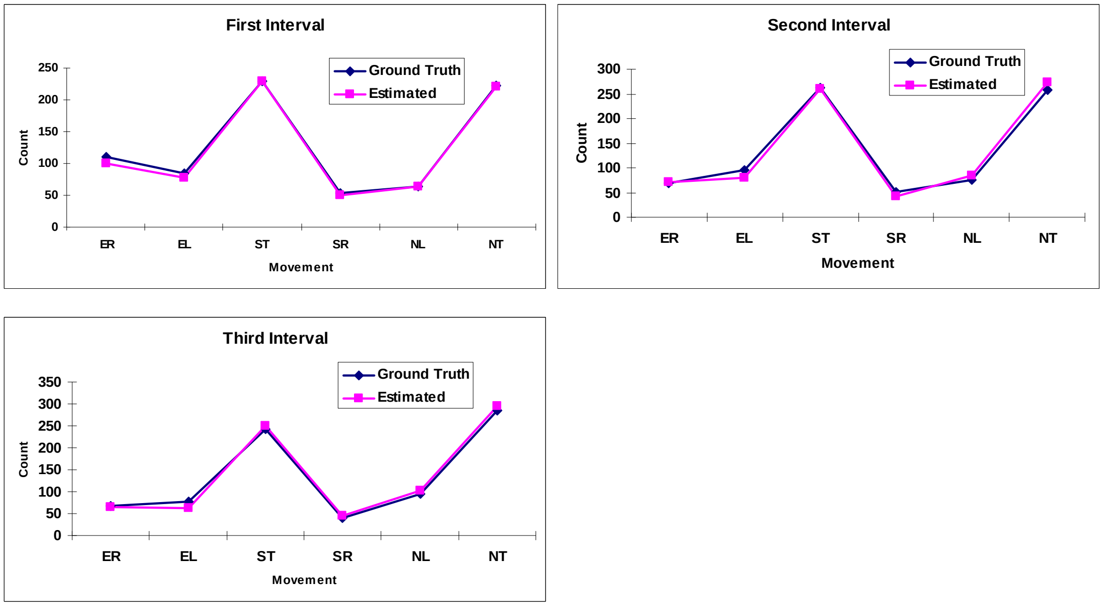


Figure 4.7 Lab Results on East Wilbeth Road at South Arlington Street

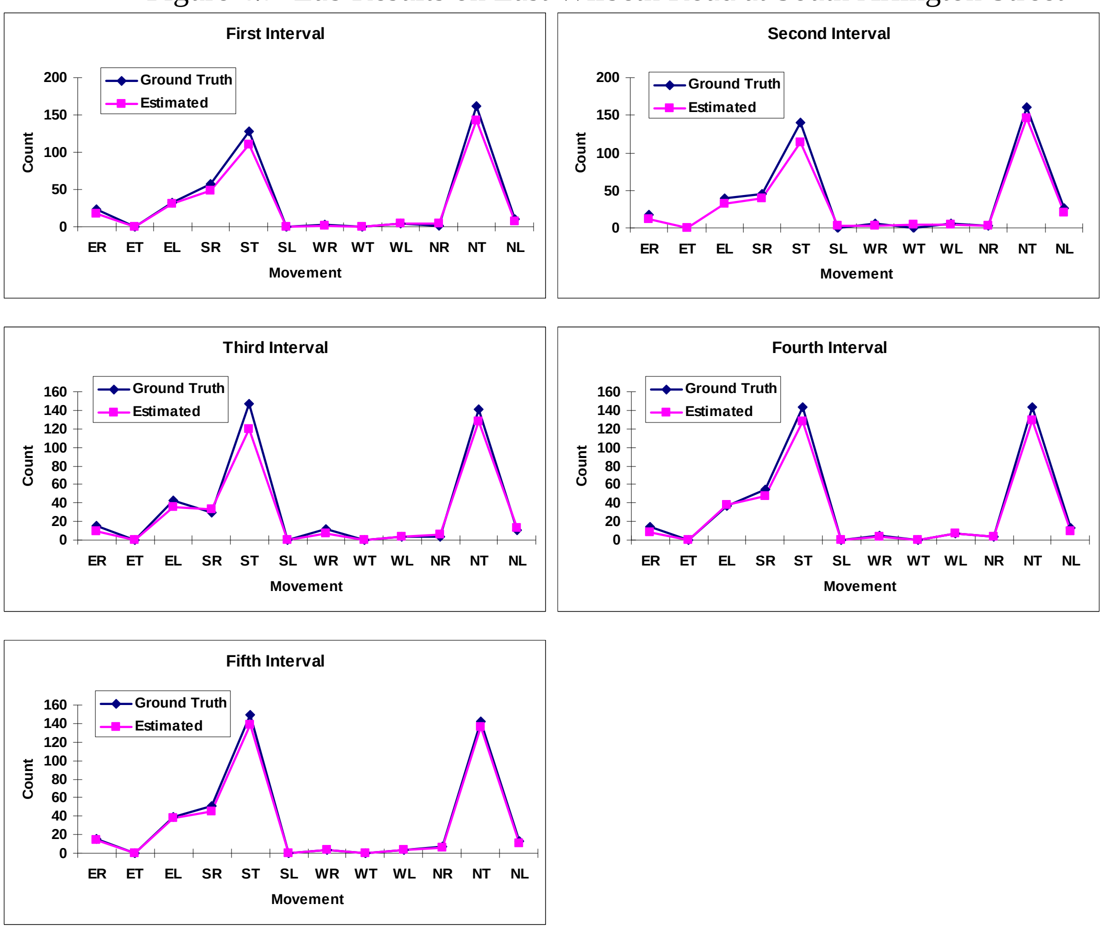


Figure 3.7 Lab Results on Wedgewood Avenue at Canton Road

From the above figures, it is clear that the estimated vehicle turning movements from ATMIS match with the ground truth very well. The volume and the estimation error of each intersection are listed in Table 3.1, where we can find the overall error percentages at each intersection. ATMIS performed better for the regular intersections than for the irregular intersections. The difference between the error percentages of two regular intersections is very small (4.94% vs. 5.30%) which indicate ATMIS works well in the shared-lane conditions. The average error percentage for the irregular intersection is 13%, which shows room for further improvement. The possible causes for worse performance of ATMIS on irregular intersection may be the longer and more complicated vehicle movements inside the odd-shaped intersection. Thus, a special algorithm may need to be developed accordingly.

Table 3.1 Volume and Error Percentage of Laboratory Experiments

Time Interval	**Fifth & Arlington**		**Wilbeth & Arlington**		**Wedgewood & Canton**	
	Volume	**Error %**	**Volume**	**Error %**	**Volume**	**Error %**
1	461	6.49%	764	3.14%	422	14.22%
2	496	5.44%	811	6.66%	443	17.16%
3	505	4.75%	804	5.97%	407	16.46%
4	518	3.28%			421	12.11%
5					423	6.38%
Average	495	4.94%	793	5.30%	423.2	13.28%

3.2 Field Test

Even though the results of the laboratory experiments are very encouraging, we further tested ATMIS in the field to examine its performance in a real world environment. During the field test, the first priority is not to disturb the normal traffic. The design of the system architecture for ATMIS in the field test is shown in Figure 3.8. The analog video signals from cameras are split into two outputs. One output will go to the video detection unit in the cabinet to keep the detection for normal signal operation, and the other will feed an extra video detection unit to collect the detection for vehicle turning movement identification. A SDLC special data sniffer is developed and used to capture the detections and signal status transferred on the SDLC bus in NEMA standard system. Under this architecture, everything in the cabinet remains the intact and ATMIS is “invisible” to the system in the cabinet.

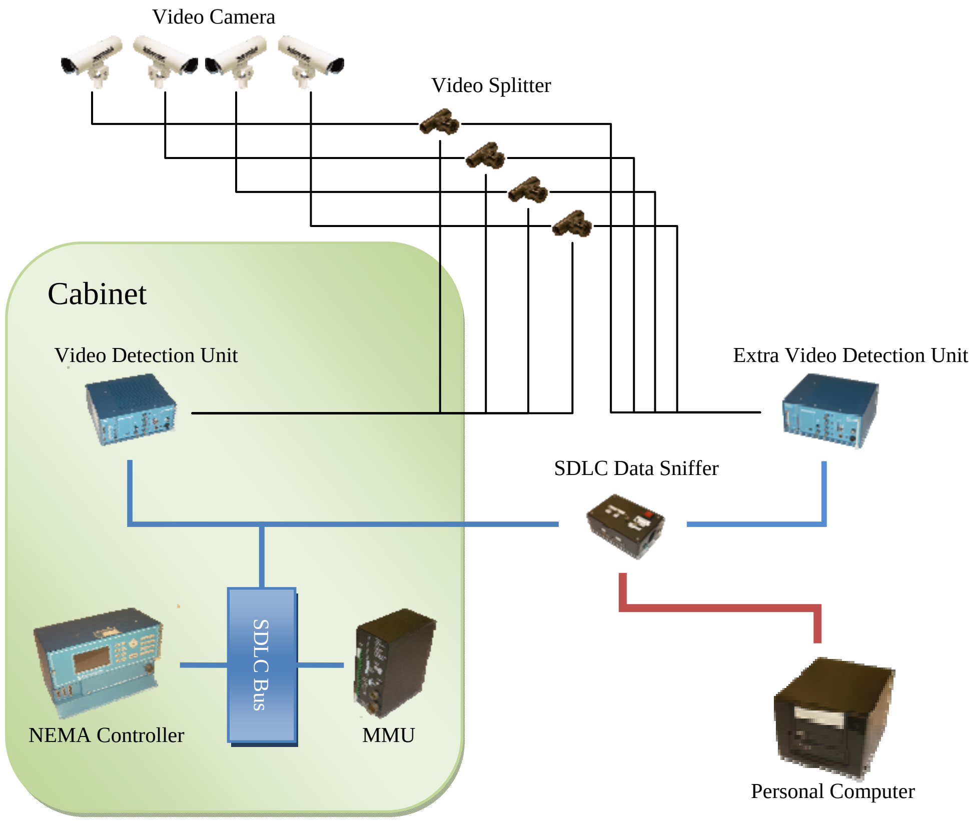


Figure 3.8 ATMIS System Architecture for Field Test

A field test was performed at the intersection of Fifth Avenue at South Arlington Road on the morning of March 17th 2008. The test result is shown in Figure 3.9. From this additional but very important test we can see that ATMIS produced very good results after they were compared with the ground truth; the average error after the test was found to be 7.89%. The possible reason for a larger error than the lab test may be the lack of detector calibration. In the laboratory experiments, we have plenty of time to adjust the position of the detectors and calibrate them, while in the field test the calibration time is much shorter. Nevertheless, the results in both the lab and field tests have been very encouraging.

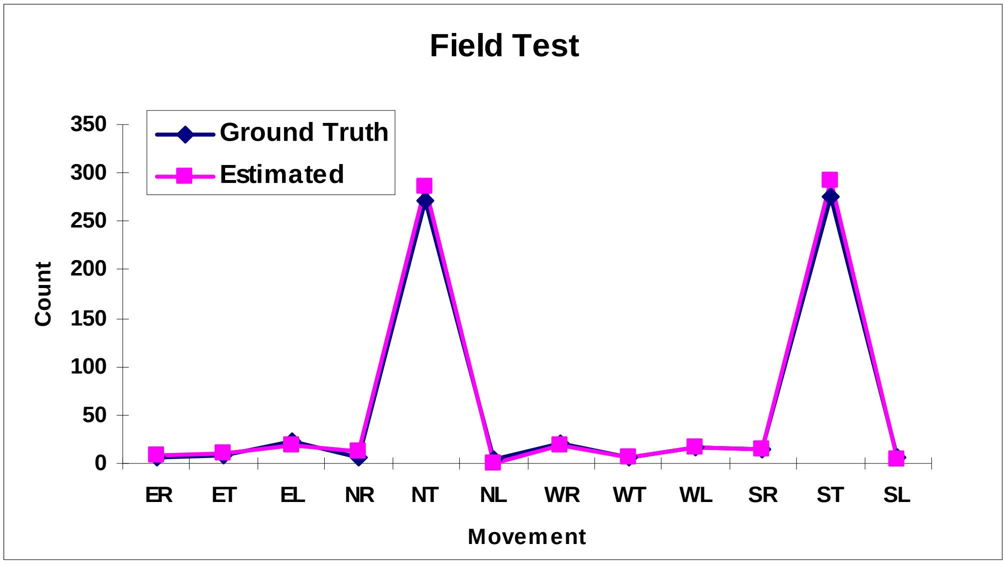


Figure 3.9 Field Test Results on Fifth Avenue and South Arlington Street

5. CONCLUSION AND FUTURE WORK

An effective method for intersection turning movement estimation has been developed and tested in this research project. This project effort primarily includes two parts, algorithm development and software development/system integration. Based on the lab and field test results, the developed Automatic Turning Movement Identification System (ATMIS) has demonstrated its strength to identify vehicle turning movements with 5% errors in a lab environment and 8% errors in limited field test. The ability of ATMIS to handle shared lanes in different intersection layouts is very promising as compared with other existing methods developed for the same purpose.

Improvements on ATMIS will be needed and additional tests, especially field tests, should be conducted. For intersections with irregular configuration, a special algorithm may be developed to increase the accuracy level. Future work on ATMIS also should be linked to the applications of the system, for example, on travel time estimation. With improved algorithm for data filtering, the vehicle turning movement information (TMI) can be used to calculate intersection delay more reliably from better turning movement counts in real time.

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APPENDIX

LIST OF ABBREVIATIONS

EB: Eastbound

ET: Estimated Travel Time

ITT: Intersection Travel Time

GT: Ground truth

MT: Modified Travel Time

SB: Southbound

SBR: Southbound Right Turn

SBL: Southbound Left Turn

SBT: Southbound Through

TM: Turing Movements

NB: Northbound

WB: Westbound

MOE: Measure of Effectiveness

OD: Original Destination

ATMIS: Automatic Turning Movements Identification System

TMI: Turning Movements Identification