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The Minnesota Bicycle and Pedestrian Counting Initiative: Implementation Study

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Research Project
Final Report 2015-34

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16. Abstract (Limit: 250 words)

The Minnesota Bicycle and Pedestrian Counting Initiative: Implementation Study reports results from the second in a series of three MnDOT projects to foster non-motorized traffic monitoring. The objectives were to install and validate permanent automated sensors, use portable sensors for short duration counts, develop models for extrapolating counts, and integrate continuous counts into MnDOT traffic monitoring databases. Commercially available sensors, including inductive loops, integrated inductive loops and passive infrared, pneumatic tubes, and radio beams, were installed both as permanent monitor sites and used for short-duration counts at a variety of locations in cities, suburbs, and small towns across Minnesota. All sensors tested in the study produced reasonably accurate measures of bicycle and pedestrian traffic. Most sensors undercounted because of their inability to distinguish and count bicyclists or pedestrians passing simultaneously. Accuracy varied with technology, care and configuration of deployment, maintenance, and analytic methods. Bicycle and pedestrian traffic volumes varied greatly across locations, with highest volumes being on multiuse trails in urban areas. FHWA protocols were used to estimate annual average daily traffic and miles traveled on an 80-mile multiuse trail network in Minneapolis. Project findings were incorporated in a new MnDOT guidance document, "DRAFT Bicycle and Pedestrian Data Collection Manual" used in statewide training workshops. A major challenge in implementing bicycle and pedestrian traffic monitoring is data management. Years will be required to institutionalize bicycle and pedestrian traffic successfully.

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The Minnesota Bicycle and Pedestrian Counting Initiative: Implementation Study

Final Report

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EXECUTIVE SUMMARY

The Minnesota Department of Transportation (MnDOT) launched the Minnesota Bicycle and Pedestrian Counting Initiative (the Initiative) in 2011. The Initiative is a collaborative, statewide effort to encourage and support non-motorized traffic monitoring by local, regional, and state governments and nonprofit organizations. MnDOT has funded three projects to support the Initiative:

1. Methodologies for Counting Bicyclists and Pedestrians in Minnesota (2011-13)
2. Implementing Bicycle and Pedestrian Traffic Counts and Data Collection (2013-15)
3. Institutionalizing the Use of State and Local Pedestrian and Bicycle Traffic Counts (2014-16)

This report summarizes the results of the second project, the Implementation study. The general goal of this project was to demonstrate the feasibility of using automated sensors to collect bicycle and pedestrian traffic data in Minnesota. The main objectives were to work with local units of government to:

- Acquire and install sensors for automated counting of bicyclists and pedestrians
- Calibrate and validate the sensors
- Use portable sensors for short duration counts
- Develop models for extrapolation of short duration counts
- Integrate continuous count data into MnDOT traffic monitoring databases

Key findings from this study include:

- Automated sensors for monitoring bicycle and pedestrian traffic are available commercially at reasonable cost and can be deployed at both permanent and short-duration monitoring sites. The sensors deployed in Minnesota included inductive loop sensors for permanent monitoring of bicycle traffic on roads (Duluth, Eagan, Minneapolis); integrated passive infrared and inductive loop sensors for permanent monitoring of bicycle and pedestrian traffic on trails (Duluth, Rochester); pneumatic tube sensors for short-duration monitoring of bicycle traffic on roads or trails (Bemidji, Grand Marais, Hennepin County) and radio beam sensors for short-duration monitoring bicycle and pedestrian traffic on trails (Bemidji, Grand Marais, Rochester). Sensors varied in costs from $1,200 to $7,500, plus costs for installation. Installation costs were in the vicinity of $5,000 for inductive loops embedded in the road surface or trail service. Each of the permanent sensors installed during the project operated successfully year-round, although some experienced problems and required maintenance in the field. Vendors provided a range of support services, ranging from troubleshooting to automated analyses of data. Sensors that transmit data remotely offer potential to reduce labor costs for data collection and analysis but require payment of annual service fees.

- Bicycle and pedestrian traffic volumes varied greatly across locations, with highest volumes observed on multiuse trails in urban areas (e.g., traffic volumes as high as several thousand individuals per day in Minneapolis and Duluth). Much lower volumes were observed on residential streets and county roads in smaller communities (e.g., fewer than 10 bicyclists per day at locations in Bemidji and Grand Marais). In Hennepin County, mean daily bicycle volumes at short-duration monitoring sites on roads ranged from less than 10 to more than 1,000, with weekend daily volumes at one location exceeding 1,600.

- All sensors tested in the study produced reasonably accurate measures of bicycle and pedestrian traffic, although accuracy varied with the specific technology, care taken in deployment, maintenance following deployment, analytic methods used in analysis, and specifics of the configuration, including traffic volumes. Most technologies tended to undercount. Occlusion, or multiple users passing a sensor simultaneously, was a principal source of error. Correction equations and adjustment factors were developed to correct counts for systematic error, but the need for correction depends on the application, the need for accuracy, and the costs for additional data management.

- Portable sensors were deployed efficiently and provided useful measures of bicycle and pedestrian traffic. Because of hourly and day-of-week variations in bicycle and pedestrian traffic, short-duration monitoring results are most useful if they include a minimum of seven complete days (i.e., the weekdays and weekend days). However, if the goal of monitoring is simply to obtain an indicator of the general order of magnitude of bicycle or pedestrian traffic, shorter monitoring periods may suffice.

- The FHWA's *Traffic Monitoring Guide* (2013) outlines an approach to estimating annual average daily traffic that involves use of factors derived from permanent monitoring locations to extrapolate short-duration counts. To demonstrate the applicability of this approach to non-motorized traffic monitoring, the study team used data from permanent and short-duration monitoring on an 80-mile multiuse trail network in Minneapolis to estimate Average Annual Daily Traffic (AADT) for each trail segment. These estimates then were used to estimate miles traveled by bicyclists and pedestrians on the network. The study team showed that AADT on trail segments ranged from about 40 to more than 3,700 and that summertime trail Annual Daily Traffic (ADT) was approximately double AADT. The study team estimated that users of the Minneapolis trail network traveled more than 28 million miles on the trails in 2013. The study team identified four traffic patterns on trails: commuter, commuter-mixed, multipurpose, and multipurpose-mixed. These patterns potentially can be used to establish factor groups for use in other applications.

- A major challenge in implementing bicycle and pedestrian traffic monitoring is data management, specifically the challenge of formatting data from different sensors and integrating data into motorized traffic monitoring data management systems. The goal of integrating data collected during the Implementation study into MnDOT's traffic data management was not achieved because the vendor that was supporting implementation of the new data management system ceased operations.

In addition to these findings, an additional outcome from this project is a new MnDOT guidance document, "DRAFT Bicycle and Pedestrian Data Collection Manual." Team members used this manual in training workshops in spring 2015. The DRAFT Manual includes a set of case studies that summarize how local officials have and are using bicycle and pedestrian accounts to inform transportation planning, engineering, and policy-making. These case studies illustrate the demand for better data that exists in Minnesota.

Years will be required to implement and institutionalize bicycle and pedestrian traffic successfully. One strategy that may be useful as staff work to institutionalize monitoring is to complete case studies that illustrate how officials have used data to make decisions on projects that increase the efficiency and safety of transportation systems.

CHAPTER 1: INTRODUCTION

The Minnesota Department of Transportation (MnDOT) has many policies, plans, and programs to encourage and support bicycling and walking, including Minnesota GO, the agency's 50-year vision plan; Complete Streets; and Toward Zero Deaths. MnDOT needs information about bicycle and pedestrian traffic volumes to evaluate these programs, develop performance measures, evaluate the effectiveness of safety-related counter-measures, and assess progress towards goals. In 2011, MnDOT staff launched the Minnesota Bicycle and Pedestrian Counting Initiative (i.e., the Initiative), a collaborative, statewide effort to encourage and support non-motorized traffic monitoring by local, regional, and state organizations. To support the Initiative and provide agencies the tools they need for monitoring bicycle and pedestrian traffic, MnDOT has funded three research and implementation projects:

1. Methodologies for Counting Bicyclists and Pedestrians in Minnesota (2011-13);
2. Implementing Bicycle and Pedestrian Traffic Counts and Data Collection (2013-15); and
3. Institutionalizing the Use of State and Local Pedestrian and Bicycle Traffic Counts (2014-16).

The results of the first project are summarized in the report, "The Minnesota Bicycle and Pedestrian Counting Initiative: Methodologies for Non-motorized Traffic Monitoring" (Lindsey et al. 2013). The research focused on development of consistent procedures for manual traffic counts, coordination of statewide manual counts, and illustration of ways in which data from automated traffic monitors can be used to inform engineering and planning related to bicycling and walking. The Technical Advisory Panel to this project made five recommendations:

1. MnDOT should continue and institutionalize coordination of annual statewide manual bicycle and pedestrian counts;
2. MnDOT should improve methods for reporting results of field counts and explore web-based programs for data reporting and analysis;
3. MnDOT should lead efforts to deploy and demonstrate the feasibility of new automated technologies for bicycle and pedestrian counting, focusing on new technologies not presently used in Minnesota;
4. MnDOT should begin integration of non-motorized traffic counts from existing automated, continuous sensors in Minneapolis into its new databases for vehicular traffic monitoring data; and
5. MnDOT should work with local governments and explore institutional arrangements for (a) establishing a network of permanent, automated continuous monitoring sites across the state and (b) sharing and deploying new technologies for short-duration monitoring to generate traffic counts that provide a more comprehensive understanding of spatial variation in non-motorized traffic volumes.

MnDOT funded the second and third projects (i.e., Implementation and Institutionalization, respectively) to implement these recommendations. Responsibilities for this Implementation study were shared by the University of Minnesota (the University); SRF Consulting (SRF), an independent contractor to MnDOT; and MnDOT. Key tasks in the Implementation study included:

- Acquisition and installation of new technologies for continuous counting of bicyclists and pedestrians at various locations in Minnesota;
- Calibration and validation of sensors;
- Integration of continuous count data into MnDOT traffic monitoring databases;
- Use of portable sensors for short duration counts; and
- Development of models for extrapolation of short duration counts.
- Technical assistance, including collaboration in deployment of counters, training workshops, and preparation of guidance for bicycle and pedestrian data collection.

This Implementation study also included continuation of some activities begun during the Methodologies project such as support for manual counts taken by municipalities and collaboration with local jurisdictions in planning bicycle and pedestrian traffic monitoring.

This report summarizes selected results from the Implementation project. As is evident from the project dates listed above, work on the Implementation and Institutionalization projects overlaps, with the latter continuing and building on tasks initiated in the former. Because work begun in the Implementation project is being continued, additional results will be presented in the report that summarizes the Institutionalization project in 2016.

Throughout the Implementation study, the University, SRF, and MnDOT focused on activities to produce practical data to inform local decision-making and ongoing efforts by MnDOT to establish procedures for use of bicycle and pedestrian traffic data in agency programs and procedures. The Implementation study involved collaboration with partners in several communities and state agencies to deploy monitoring devices and conduct counts. These communities and state agencies included Bemidji, Duluth, Grand Marais, Hennepin County, Minneapolis, Rochester, MDH and MnDOT Districts 1 and 2. Monitoring results were shared with local organizations throughout the process to inform local decision-making.

In addition, the project team presented results at many conferences and meetings and prepared papers for review and publication. Key findings from the Implementation study that already have been summarized in other publications are either referenced in the text of this report or included as appendixes. For example, results from field tests to validate bicycle counts from pneumatic tube sensors were presented at the annual Transportation Research Board conference and accepted for publication in the *Transportation Research Record*. These results are not reproduced in their entirety in this report.

Chapter 2 describes the monitoring devices acquired by MnDOT during the Implementation study and lists locations where devices were deployed. Chapter 3 summarizes work to calibrate, and validate the different devices. Chapter 4 summarizes the results of continuous counts taken in different communities. Chapter 5 demonstrates how factors derived from continuous counts taken at permanent monitoring sites can be used to adjust short duration counts and produce estimates of annual average daily traffic. Chapter 6 summarizes efforts to develop procedures for long-term management of continuous counts from different automated devices. Chapter 7 summarizes important outcomes and outlines work that will be accomplished during the Institutionalizing project.

CHAPTER 2: ACQUISITION AND DEPLOYMENT OF MONITORING DEVICES

MnDOT, SRF, and the University collaborated in the selection of monitoring devices for testing and the choices of locations for deployment. SRF had primary responsibility for reviewing commercially available technologies and recommending devices for testing. SRF identified seven different types of technologies available commercially: pneumatic tubes, video analytics, inductive loop detectors, passive infrared detectors, combined passive infrared and inductive loop detectors, radio beams, and magnetometers (Minge, Erik. 2013). Within each category, SRF reviewed specifications for two or three devices made by different manufacturers. SRF recommended the following devices which subsequently were purchased by MnDOT:

- Inductive Loop Detectors: Eco-Zelt inductive loops
- Pneumatic Tubes: MetroCount MC5600
- Sidewalk Pedestrian Sensors: Chambers RBBP7 (RF beam type)
- Shared Use Path (Bicycle/Pedestrian) Sensor: Eco-Multi.

Details regarding the rationale for selection of these devices are included in SRF's technical memorandum (Minge, Erik. 2013).

MnDOT and the University selected sites for installation of permanent equipment in consultation with SRF and with members of the Technical Advisory Panel (TAP). MnDOT assumed principal responsibility for obtaining agreements with jurisdictions for installation of permanent sensors because MnDOT also retained responsibility for contracting with vendors for installation. Criteria for choice of sites for installation of permanent sensors included:

- Appropriateness of site for technology (e.g., inductive loops for counting bicycles on streets);
- Willingness of jurisdictions to collaborate in monitoring;
- Region within Minnesota (i.e., the goal was to test in in jurisdictions outside the Twin Cities metropolitan region to foster awareness of opportunities for monitoring); and
- Expected traffic volumes at site.

Sites chosen for installation of permanent, automated sensors are listed in Table 2.1.

MnDOT and the University also collaborated in selection of sites for testing of equipment designed for short-duration counts. The number of sites for testing was greater than originally anticipated because of strong local interest, especially in Hennepin County (Table 2.2). Sensor locations were selected on the basis of the capabilities of the monitoring technologies, the type of infrastructure, and the availability of partners for monitoring. Twenty-three locations were monitored in Hennepin County because the County expressed strong interest in collaboration in advance of implementing a permanent bicycle traffic monitoring program. Study team members concluded this collaboration presented a good opportunity to leverage efforts and expand implementation. Counts ultimately were not obtained at all sites because of sensor malfunctions, limited availability of staff, conflicts in schedules, and other reasons. The research team in coordination with Hennepin County also worked with additional technologies (TrailMaster active IR sensors and TimeMark pneumatic tube sensors) which were not included in SRF's recommended list of sensors and are not reflected in Table 2.1 or 2.2.

Table 2.1. Sites selected for permanent sensors

Type of Permanent Sensor	*Location Chosen*	*Reason Selected*
Eco–Zelt Inductive Loop	Minneapolis – Central Ave	MnDOT ROW, bike lane, expect moderately high bicycle traffic
Eco-Zelt Inductive Loop	Eagan – TH 13	MnDOT ROW, road shoulder, near access to regional trails
Eco-Zelt Inductive Loop	Duluth – Scenic 61	Location outside Twin Cities, strong local interest, road shoulder, expect moderately high recreational bike traffic
Eco-Multi – with tape loops	Rochester – McNamara Bridge Trail	Location outside Twin Cities, strong local interest, shared use path, expect moderate bicycle and pedestrian traffic
Eco-Multi – with saw cut loops	Duluth – Lake Walk	Location outside Twin Cities, strong local interest, shared use path; expect high bicycle and pedestrian traffic

Table 2.2. Communities selected for short-duration counts

Type of Short-Duration Sensor	*Locations Chosen*	*Reason Selected*
MetroCount Pneumatic Tubes	Hennepin County	Strong local interest, vehicle lanes, bike lanes, expect variable levels of bicycle traffic
MetroCount Pneumatic Tubes	Bemidji	Strong local interest; road, bike lanes, shoulders
Chambers RadioBeam Bicycle & People Sensor	Hennepin County	Strong local interest, shared use path, expect high levels of bicycle traffic
Chambers RadioBeam Bicycle & People Sensor	Grand Marais	Strong local interest; road, bike lanes, shoulders

CHAPTER 3: CALIBRATION AND VALIDATION OF MONITORING DEVICES

An important goal of the Implementation study was the calibration and validation of monitoring devices. The principal objectives of this task were to ensure the accuracy of the traffic counts that were collected and to summarize key lessons for future monitoring activities. Work focused exclusively on validation of continuous counts taken with automated sensors. Three important steps in calibration and validation include (1) confirmation of sensor operations and calibration; (2) identification and correction for systematic sensor error, and (3) identification of other sensor errors.

Key results from this task have been summarized and are reported in two related publications:

- "DRAFT Bicycle and Pedestrian Data Collection Manual," MnDOT Office of Transit, Bicycle /Pedestrian Section, Minneapolis, MN (Minge, et. al., 2015, forthcoming)
- "Validation of Bicycle Counts from Pneumatic Tube Sensors in Mixed Traffic Flows." *Transportation Research Record* (*TRR*; Brosnan et al. 2015, forthcoming).

"DRAFT Bicycle and Pedestrian Data Collection Manual" describes procedures for calibration and validation and lessons learned from installation of automated sensors during the Implementation study. MnDOT is publishing this manual in DRAFT form in 2015 to facilitate updates that will be forthcoming following the Institutionalizing project which will conclude in 2016.

The research paper, "Validation of Bicycle Counts from Pneumatic Tube Sensors in Mixed Traffic Flows" was presented at the annual meeting of the Transportation Research Board (TRB) in January 2015. The conference draft of this paper is available at the TRB website: http://amonline.trb.rg/trb57535-2015-1.1793793/t006-1.1818822/762-1.1810221/15-5258-1.1819252/15-5258-1.1954068?qr=1, while the revised draft will be published in *TRR* later in

Because detailed results from this task are available in these documents, all results are not repeated here or included as appendixes to this report.

3.1 Confirmation of Sensor Operations and Calibration

An essential step in ensuring the accuracy of counts was confirmation of sensor operations and calibration in the field. For field calibration, members of the research team followed manufacturers' instructions and recommendations.

Manufacturers of each type of automated sensor (i.e., Eco-Counter, MetroCount, and Chambers) recommended specific procedures for ensuring sensors are operating properly. These procedures typically involved installation of the sensors and then observation of devices when bicyclists or pedestrians passed to ensure they were being counted. Eco-Counter provides specific software (i.e., Eco-Link) designed for validation of sensors in the field. Field validation for other devices (e.g., MetroCount pneumatic tube sensors, Chambers radio beam), involved observation of icons or lights to determine whether the sensors were registering bicycles or pedestrians.

Members of the research team typically spent 15 to 30 minutes in the field at each site following installation observing traffic to confirm sensor operations. More formal validation studies were conducted at selected sites to assess sensor accuracy (section 3.2).

3.2 Assessment of Sensor Accuracy

Assessment of sensor accuracy is a systematic process to ensure that the counts obtained from automated sensors are valid and are acceptably accurate measures of actual bicycle and pedestrian traffic volumes. Because of technological limitations and the complexity of traffic flows, no type of automated sensor records bicycle or pedestrian traffic volumes with 100% accuracy. Error is present in all counts obtained with automated sensors. From a practical perspective, the presence of some error is not a problem unless the error is so great that it potentially affects the outcome of decisions made with the data. For this reason, it is important to quantify and understand the relative accuracy of the counts collected with the sensors.
The process of assessing sensor accuracy, or data validation, typically involves manual or video observations of traffic flows and comparison of totals with sensor estimates of traffic.

The most comprehensive report on sensor accuracy published to date is Report 797 from The National Cooperative Highway Research Program (NCHRP), "Guidebook on Pedestrian and Bicycle Volume Data Collection" (Ryus et al. 2014b). This report summarizes methods and technologies for collecting and analyzing bicyclist and pedestrian traffic data and reports the results of field tests to assess sensor accuracy. The NCHRP validation process involved collection of many hours of video at counting locations, manual reduction of video (i.e., counting of bicyclists and pedestrian in the video tape), comparison between hourly totals from the video and sensors, and calculation of both relative error and absolute error.

The NCHRP study included assessment of active and passive infrared monitors, radio beam sensors, bicycle specific pneumatic tubes, inductive loops, piezoelectric strips, and combined or integrated systems (Ryus et al. 2014a). In general, the study found that all devices produce reasonably valid counts depending on the application and the need for accuracy. The average percentage deviation, or error relative to the totals counted manually from the video, ranged from 0.55% to more than 18%, depending on the technology and unique characteristics of deployment. The averages of the absolute percentage differences were higher because false positives (i.e. phantom people detected by the sensor) and false negatives (i.e. people undetected by the sensor) do not offset each other.

The study listed several reasons why observed totals differed from totals generated by automated sensors. These reasons included:

- *Occlusion* - When two or more people cross the detection zone simultaneously, an undercount occurs because the device only detects the person nearest the sensor.
- *Environmental conditions* - Environmental conditions, such as weather and lighting, may cause counting inaccuracies in different counting technologies.
- *Bypass errors* – Even though a sensor may accurately count the pedestrians or bicyclists that pass through its detection zone, it may still not count all of the users if it is possible for users to bypass the detection zone.

- *Mixed-traffic effects* – The count site includes both vehicular and bicycle traffic. This error is primarily a concern for pneumatic tube counting.

Given the reasons why errors occur, automated sensors tend to bias towards undercounting the number of people actually biking and walking.

The research team generally followed procedures used in the NCHRP Study to assess the accuracy of different sensors. These procedures involved

1. Comparing hourly totals from the manual counts taken in the field or from video to the automated counts,
2. Calculating the percentage difference for each hour, and
3. Computing the absolute percentage error per hour.

Validation counts were obtained for the MetroCount 5600 Pneumatic Tubes, the Eco-Zelt Inductive Loop, and the Eco-Multi. Field observations taken for validation of the Chambers could not be reconciled with sensor output, and the validation will be repeated in the summer of 2015 when sensors are redeployed.

While these various technologies were installed and calibrated at several different sites, this project only validated each type of sensor rather than validate all sensors at all sites. Resource constraints allowed only the Eco-Zelt inductive loops installed at Trunk Highway 13 in Eagan and on West River Parkway and Central Ave in Minneapolis to be validated using video. However, additional validation results will be published as they become available.

3.2.1 <u>Validation of Pneumatic Tube Counts</u>

Researchers tested two types of pneumatic tube sensors: MetroCount MC5600 Vehicle Classifier System and TimeMark *Gamma NT*. Although the TimeMark devices were not acquired by MnDOT for testing in the Implementation study, the TimeMark devices were deployed at the request of and in collaboration with Hennepin County. Hennepin County collaborated in the field testing because it maintains a fleet of TimeMark pneumatic tube sensors for counting vehicular flows and was interested in whether they could be used to collect bicycle counts simultaneously with vehicular traffic counts.

Validation of both the MetroCount and TimeMark sensors in mixed traffic flows (i.e., vehicular and bicycle) showed that the tubes generally undercounted and that occlusion was the principal source of error (Brosnan et al. 2015, forthcoming).

The pneumatic tube sensors and video cameras were installed in different configurations at two locations on arterial roadways with different traffic volumes. Researchers compared bicycle counts from the tube sensors to manual counts from video to determine both percentage error and absolute error rates. Researchers also matched time stamps from the sensors and video and inspected discrepancies to determine causes of error. Calibration equations to adjust for systematic sensor error were estimated by regressing hourly manual counts on hourly automated counts.

The tube sensors generally undercounted bicycles: error rates for the observation periods ranged from 6% to 57% depending on the location, configuration of deployment, type of device, and classification algorithm. Absolute error rates were substantially higher than percentage error because false positives and false negative counts were not offsetting.

Error rates were higher on configurations that included three travel lanes and one bicycle lane than on configurations with one travel lane and one bike lane. Inspection of video indicated most false negatives (i.e., undercounts) were due to occlusion.

The classification algorithm used in analysis of data obtained from the pneumatic tube sensors also affected accuracy. The manufacturers of pneumatic tube sensors provide several classification algorithms for determining vehicle type from axle base and speed, two measures which are estimated from recordings of air pulses in the tubes. The field studies showed that use of manufacturer's algorithms for classification generally produced more accurate results than simply sorting by maximum axle base, but that a customized algorithm developed by county employees in Boulder County, Colorado generally produced the most accurate results (Brosnan et al. 2015; Hyde-Wright 2014). The Boulder County algorithm is believed to be more accurate because it also identifies groups of bicycles that typically would be classified as multi-axle vehicles in classification algorithms provided by the manufacturer.

Figure 3.1 is a scatterplot of counts from pneumatic tubes in two locations in Minneapolis and manual counts from video for a one travel lane, one bicycle lane deployment. The values of the manual counts are on the vertical axis to facilitate interpretation of trend lines as correction equations. As is evident from looking at the values of points in the graph, the hourly totals from the tube sensors are lower than the hourly manual counts. In other words, the tube sensors are undercounting. The principal cause, as noted previously, was occlusion.

The trend or regression lines in Figure 3.1 illustrate the relationship between the automated and manual counts. The equations for the lines can be interpreted as hourly "correction" equations. That is, the hourly totals from the automated sensors can be adjusted using the equations to obtain a better estimate of the actual bicycle hourly traffic volumes. Separate equations are included for each of the locations, and a more general equation based on combined data from both sites also is included. Calibration equations generally have moderate to very good fit (R^2 values from 0.88 to 0.92), which means that the automated counts explain 88% - 92% of the variation in the manual counts. If an analyst wanted to adjust automated counts from a particular site, a correction equation developed specifically for that site would be the best equation to use, but if, for example, an analyst wanted to adjust data from a third site for which no validation counts had been taken, the equation based on the combined data might be a better choice. The regression lines have been forced through the origin to eliminate a constant that would add counts if applied to hours where no bicycle traffic was recorded by the automated devices.

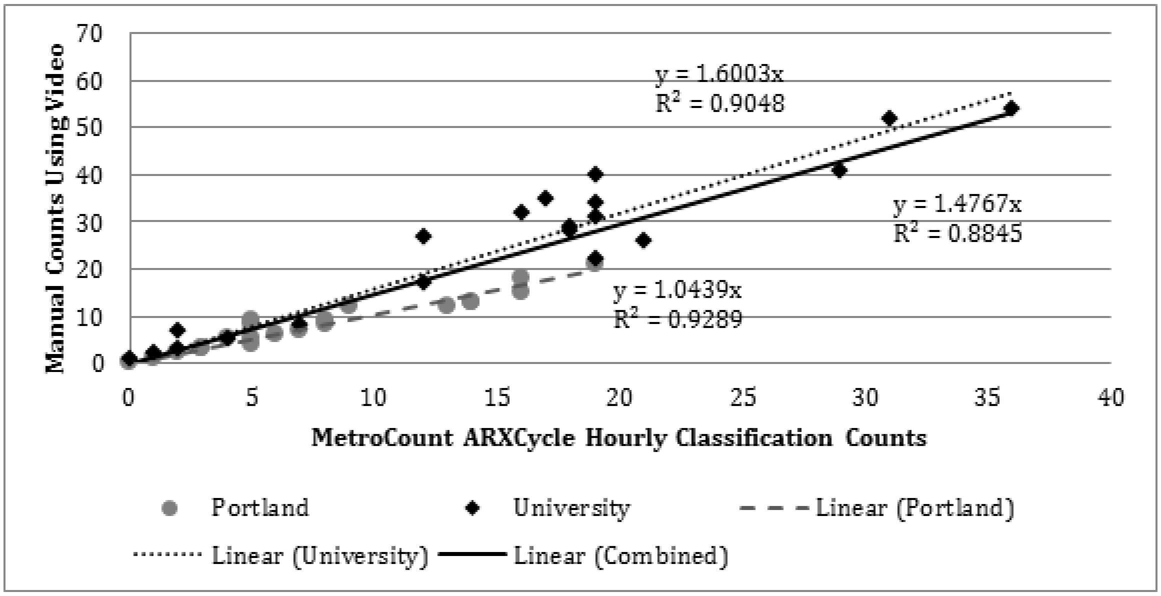


Figure 3.1. Scatterplot of validation counts for tube sensors at two locations

Overall, these results indicate that agencies potentially can adapt standard, commercially available pneumatic tube sensors to collect bicycle counts in mixed traffic flows. Depending on the site, traffic volumes, configuration, and deployment, error rates may be unacceptably high for some purposes. The practicability of using tube sensors to count bicycles in mixed traffic flows depends on the applications, the potential uses of the counts, and the relative need for accuracy in measurement.

3.2.2 Validation of Inductive Loop Counts

Researchers validated counts form Eco-Zelt inductive loop sensors in two locations:

1. North- and south-bound bicycle lanes in Central Avenue north of Lowry Street in Minneapolis, and
2. North- and south-bound shoulders along Trunk Highway 13 near Lone Oak Road in Eagan.

These locations were chosen because they are MnDOT roads, because no inductive loops for counting bicycles were installed elsewhere in Minnesota at the time, and because of the goal to experiment with deployment in diverse settings. Central Avenue is an urban arterial in a heavily trafficked commercial neighborhood believed to be used mainly by bicycle commuters and other utilitarian riders. Trunk Highway 13 is a suburban highway with wide shoulders believed to be used by both bicycle commuters and recreational riders.

3.2.2.1 Central Avenue Inductive Loop Validation

Validation of counts from the Central Avenue inductive loop sensor occurred on June 3, 2014. Results are presented in Table 3.1. Two-hundred and thirteen (213) bicycles were counted from video during the 24-hour period; 206 were in the bicycle lanes where they could be detected by the inductive loop detector. The error rates for the northbound and southbound lanes, respectively, both were approximately -32%. The total undercount, including bicycles in travel lanes out of range of detection, was -34%. Both false positives and false negatives occurred: the absolute error rate for total traffic in both bicycle lanes was approximately 39%.

Table 3.1. Validation results for inductive loops in Central Avenue bicycle lanes.

	Central Avenue, Minneapolis		
	NB	SB	Total
Bikes counted manually from video (total)	106	107	213
Bikes counted in travel lane (beyond sensor range)	5	2	7
Bikes counted manually in bicycle lane	101	105	206
Bikes counted with Eco-Zelt	69	71	140
Error for bikes in bicycle lane	-31.7%	-32.4%	-32.0%
Undercount for total bikes on street	-34.9%	-33.6%	-34.3%
False positives (counted bike when none present)	4	3	7
False negatives (missed bikes)	36	37	73
Absolute Error (excluding bikes in travel lane)	39.6%	38.1%	38.8%

Figure 3.2 is a set of three similar graphs that show bicycles counted by observers and detected by the inductive loop for each hour of the 24-hour validation period for each bicycle lane and both lanes combined (bicycles in the travel lane are excluded). These graphs illustrate the systematic undercount by the inductive loop. The size of the undercount appears to be associated with larger hourly traffic volumes, although volumes were modest throughout the day. An important observation from this graph is that the undercount is generally systematic (likely stemming from occlusion but additional study is needed to confirm) and not idiosyncratic or associated with a particular event (such as a single large group of bicyclists).

Figure 3.3 is a scatterplot that shows the relationship between manual counts from the video and counts from the inductive loop detector. The equations for the trend lines can be used as correction equations to adjust for the systematic undercount. For example, if an analyst needed an estimate of the number of bicyclists travelling in both directions, the analyst could multiply each hourly total by 1.39, which is the coefficient for the variable X in the trend line for the combined data in Figure 3.3. The R^2 value for the combined trend line is 0.86, which is considered a good fit and indicates that the inductive loop counts “explain” 86% of the variation in the manual counts. Correction for systematic error may be more important in practical applications such as assessment of the need for traffic controls than planning applications where the interest principally is in trends relative to other measures.

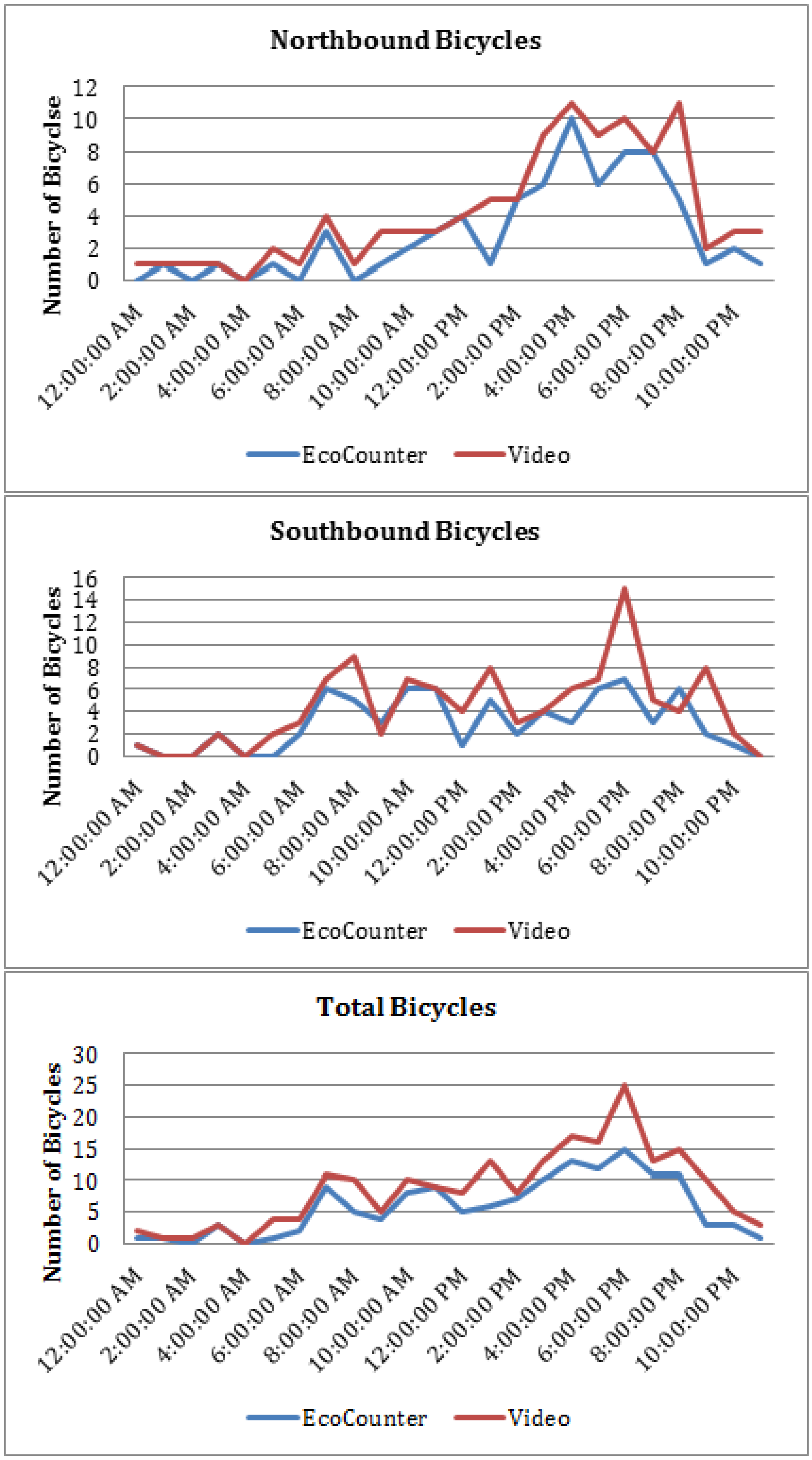


Figure 3.2. Hourly inductive loop and manual counts on Central Avenue Bicycle Lane

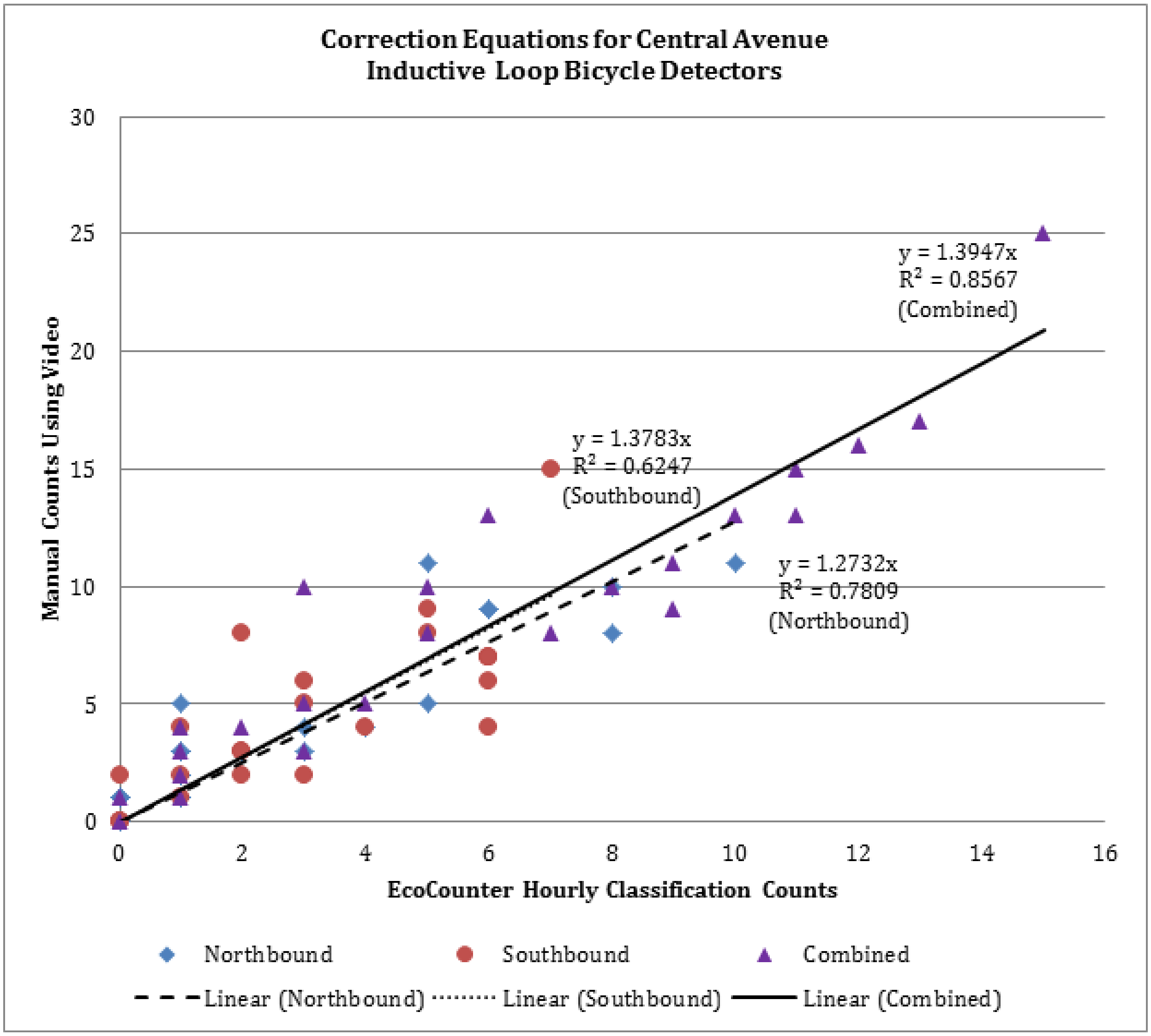


Figure 3.3. Scatterplot of manual and inductive loop bicycle counts, Central Avenue

3.2.2.2 Trunk Highway 13 Inductive Loop Validation

Validation of counts from the Trunk Highway 13 inductive loop sensor occurred on May 13, 2014. Results are presented in Table 3.2. Sixty-five (65) bicycles were counted from video during the 24-hour period; 53 were on the road shoulder where they could be detected by the inductive loop detector. In contrast to the Central Avenue inductive loop that undercounted, the inductive loops on Trunk Highway over-counted. The error rates for the northbound and southbound shoulders, respectively, were 10% and 25%, the average error rate across the road shoulders was 17%. Although no bicyclists were observed in the south-bound travel lane, 12 bicycles in an organized platoon were counted in the north-bound travel lane. Thus, while the inductive loop detectors over-counted bicycles on road shoulders, the inductive loop totals still represented an undercount of approximately 5% for bicycles on Trunk Highway overall on this day. Considering both false positives and false negatives for only bicycles on the shoulder, the absolute error rate for both inductive loops combined was approximately 54%. A limitation of this validation is the small numbers of bicycles on Trunk Highway 13. Because volumes in each direction were small, even small differences may represent large percentage differences. Therefore, care must be taken when comparing results with other locations or technologies.

Table 3.2. Validation results for inductive loops in Trunk Highway 13 road shoulders

	TH 13 Road Shoulder		
	NB	SB	Total
Bikes counted manually from video (total)	41	24	65
Bikes counted in travel lane (beyond sensor range)	12	0	12
Bikes counted manually on road shoulder	29	24	53
Bikes Counted with Eco-Zelt	32	30	62
Error for bikes in bikes in bicycle lane	10.3%	25.0%	17.0%
Error in total bike count for road	-22.0%	25.0%	-4.6%
False positives (counted bike when none present)	13	9	22
False negatives (missed bikes)	10	3	13
Absolute error	56.1%	50.0%	53.8%

Figure 3.4 is a set of three similar graphs that show bicycles counted by observers and detected by the inductive loop for each hour of the 24-hour validation period for each road shoulder and the shoulders combined. In contrast to graphs for the Central Avenue where the validation revealed a systematic undercount by inductive loop detector, these graphs illustrate no consistent pattern and an over-count overall. For example, the inductive loops on both shoulders recorded counts early in the a.m. that were not observed in the video. In addition, the inductive loop detector recorded no bicycles after 2:00 p.m. This may be indicative of a temporary malfunction of the sensor.

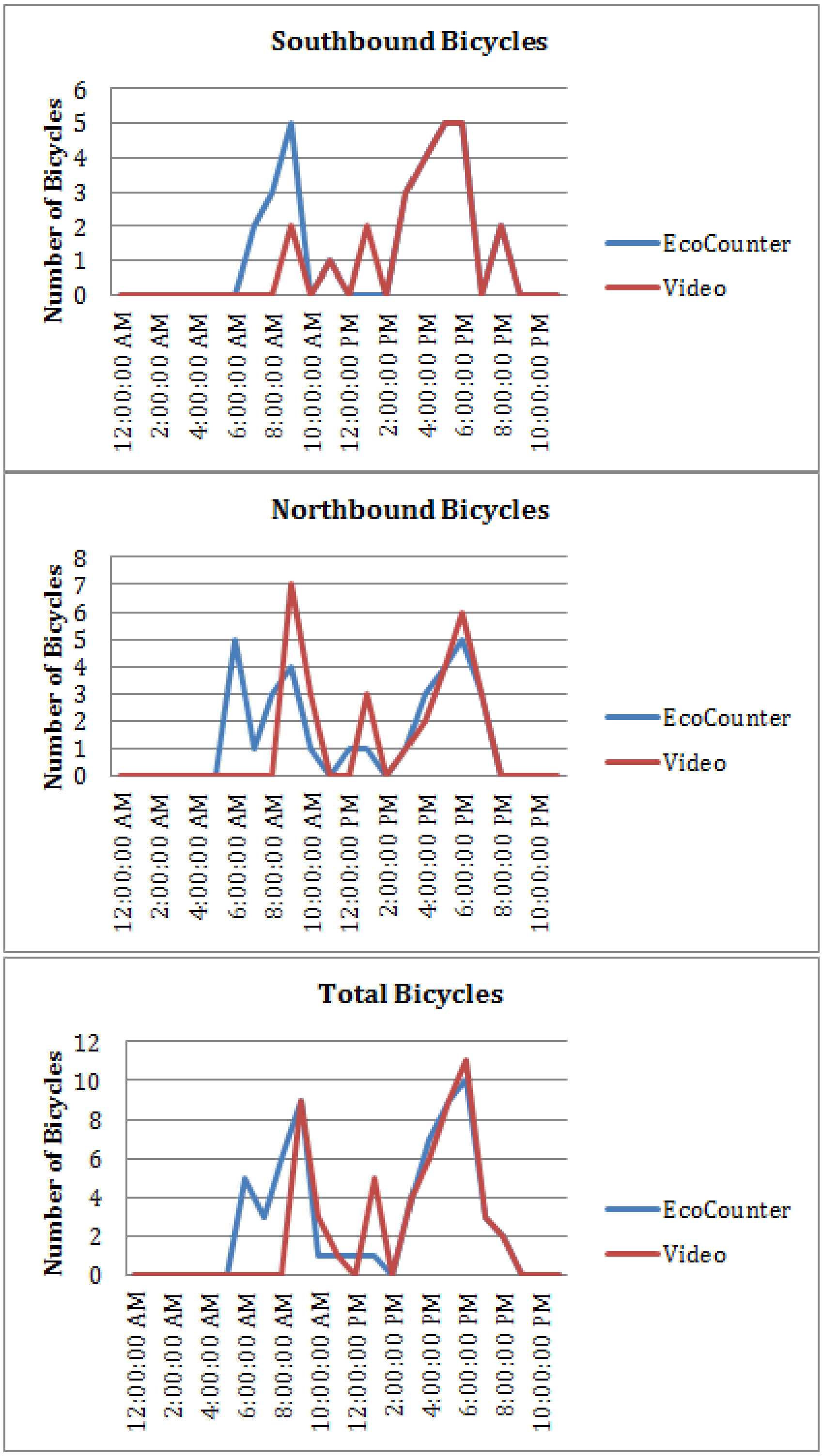


Figure 3.4. Hourly inductive loop and manual counts on Trunk Highway 13 Road Shoulders

Figure 3.5 is a scatterplot that shows the relationship between manual counts from the video and counts from the Trunk Highway 13 inductive loop detector. As noted above, the equations for the trend lines can be used as correction equations to adjust for the systematic undercount. In this case, because the inductive loop detectors on Trunk Highway 13 tended to over-count, adjusting for error means reducing the counts slightly. For example, if an analyst needed an estimate of the number of bicyclists travelling in both directions, the analyst could multiply each hourly total by 0.85, which is the coefficient for the variable X in the trend line for the combined data in Figure 3.3. The R^2 value for the combined trend line is 0.69, which is only a moderately-good fit and reflects the greater variability in the data.

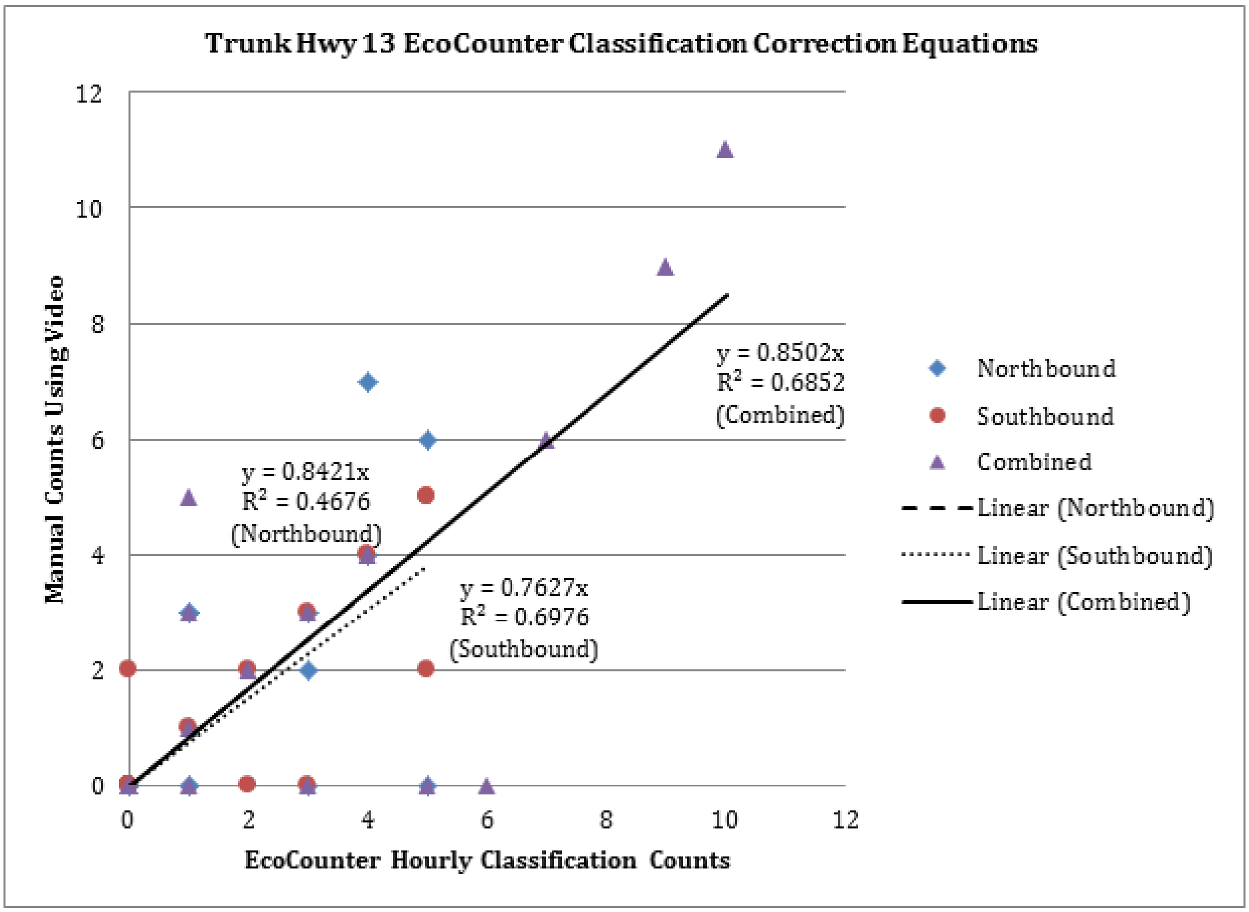


Figure 3.5. Scatterplot of manual and inductive loop bicycle counts, Trunk Highway 13

3.2.3 Validation of Integrated Passive Infrared and Inductive Loop Counts

Validation of counts from the West River Parkway Eco-Multi, an integrated inductive loop sensor occurred over five two-hour blocks in May 2015 and was completed manually in the field rather than from video. Validation was completed separately for bicyclists and pedestrians by direction. Results are presented in Table 3.3.

The field observer counted 1,111 bicycles during the 10 hours of validation counts, 18 fewer than were recorded for the same time periods by the Eco-Multi. The Eco-Multi count therefore was an over-count of approximately 1.6%. The error rates for the directional counts were comparable. Based on observations in the field using Eco-Link, the vendor's software for tracking events during field validation, some of the over-count is associated with baby strollers pushed by pedestrians. Because video tape was not used for this validation, and because of the relatively large traffic flows during some hours (e.g., > 150), specific causes for all errors cannot be determined.

Bicycle traffic on West River Parkway Trail was more than four times the pedestrian traffic during the validation period. The field observer counted 292 pedestrians during the 10 hours, 30 pedestrians more than were recorded by the Eco-Multi. The Eco-Multi count therefore was an undercount of approximately 10.3%. The error rates for the directional pedestrian flows were somewhat different: approximately 5% for the IN direction, but 14% for the OUT direction. Based on observations in the field, occlusion caused by pedestrians walking side by side accounted for some of the error. As noted, pedestrians pushing strollers sometimes were recorded as bicyclists.

Table 3.3. Validation results for Eco-Multi Sensor, W. River Parkway Trail

Source of Count	Peds-IN	Peds-OUT	Bikes-IN	Bikes-OUT	
Eco-Multi	117	145	562	567	
Field observer	123	169	552	559	
Difference (from field observer)	-6	-24	10	8	
Percent difference	-4.9%	-14.2%	1.8%	1.4%	
	All Pedestrian (regardless of direction)		All Bicyclists (regardless of direction)		Total
Eco-Multi	262		1,129		1,391
Field observer	292		1,111		1,403
Difference (from field observer)	-30		18		-12
Percent difference	-10.3%		1.6%		-0.9%

In terms of total traffic, the Eco-Multi sensor was quite accurate. The error rate was a -0.9%, indicating an undercount of pedestrians that was somewhat offset by an over-count of bicyclists. As noted above, the relative magnitude of specific sources of error cannot be determined because the validation was completed in the field and traffic volumes were too high to enable systematic inspection of Eco-Link in the field.

Figures 3.6 (bicycles), 3.7 (pedestrians), and 3.8 (total traffic) are scatterplots that show the relationship between manual counts taken by the field observer and counts from the Eco-Multi sensor. In each case, the plots indicate a high degree of accuracy, although, as noted, greater error is present in the estimates of pedestrian volumes. For the three bicycle equations (i.e., IN, OUT, Total Traffic), the R^2 values are greater than 0.99, indicating that less than one percent of the variation between the field counts and the Eco-Multi counts is due to random factors. The R^2 values for the total traffic trend lines are equally high. The R^2 values for the pedestrian correction equations for total and northbound traffic also are quite good. There is greater scatter in the data for the southbound traffic, indicating greater error, and as a result, the R^2 value for the correction equation is lower.

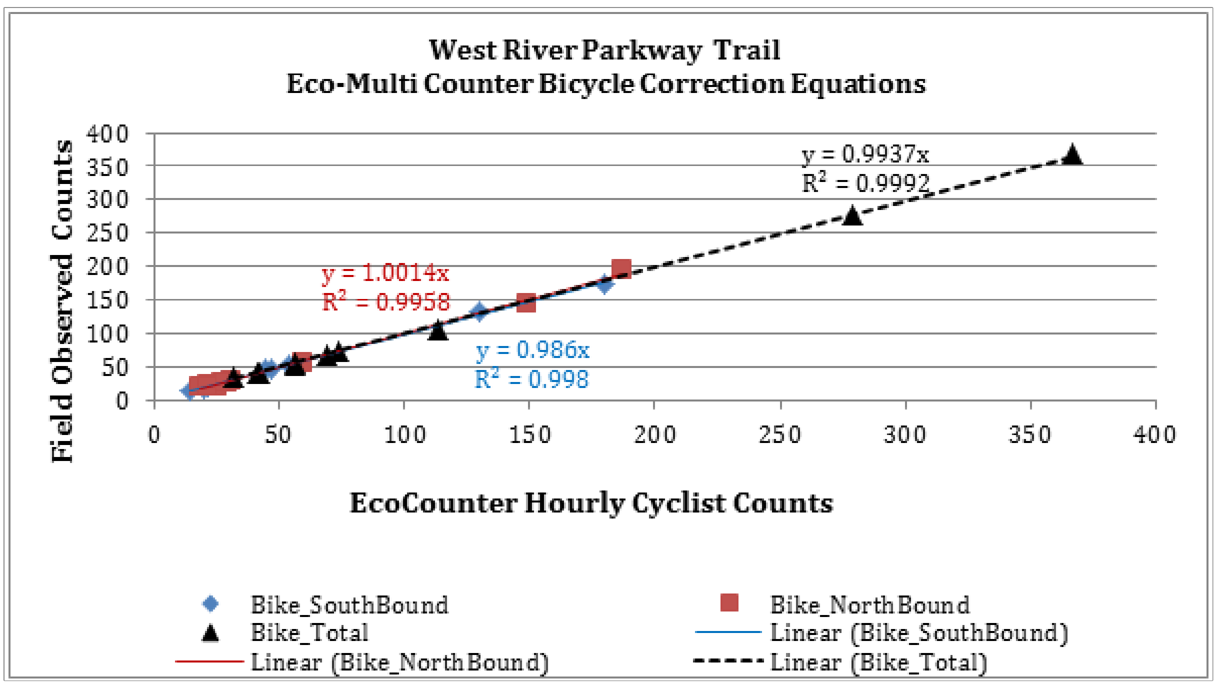


Figure 3.6. Scatterplot of manual and Eco-Multi bicycle counts, W. River Parkway Trail

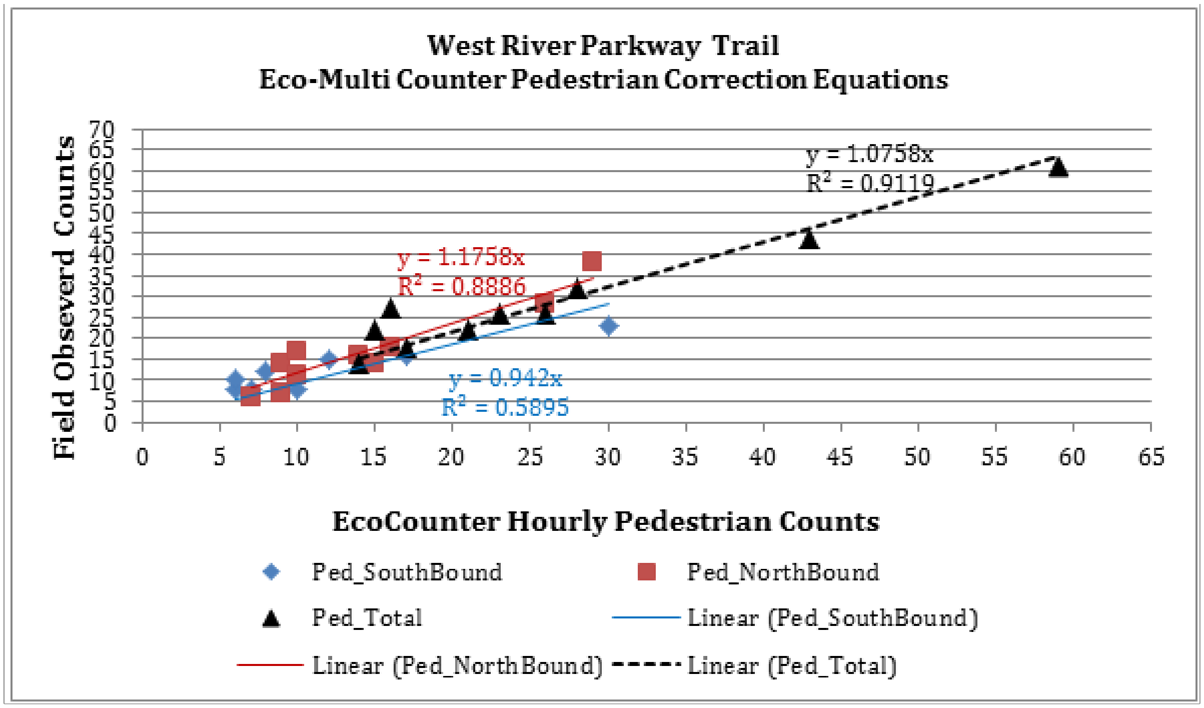


Figure 3.7. Scatterplot of manual and Eco-Multi pedestrian counts, W. River Parkway Trail

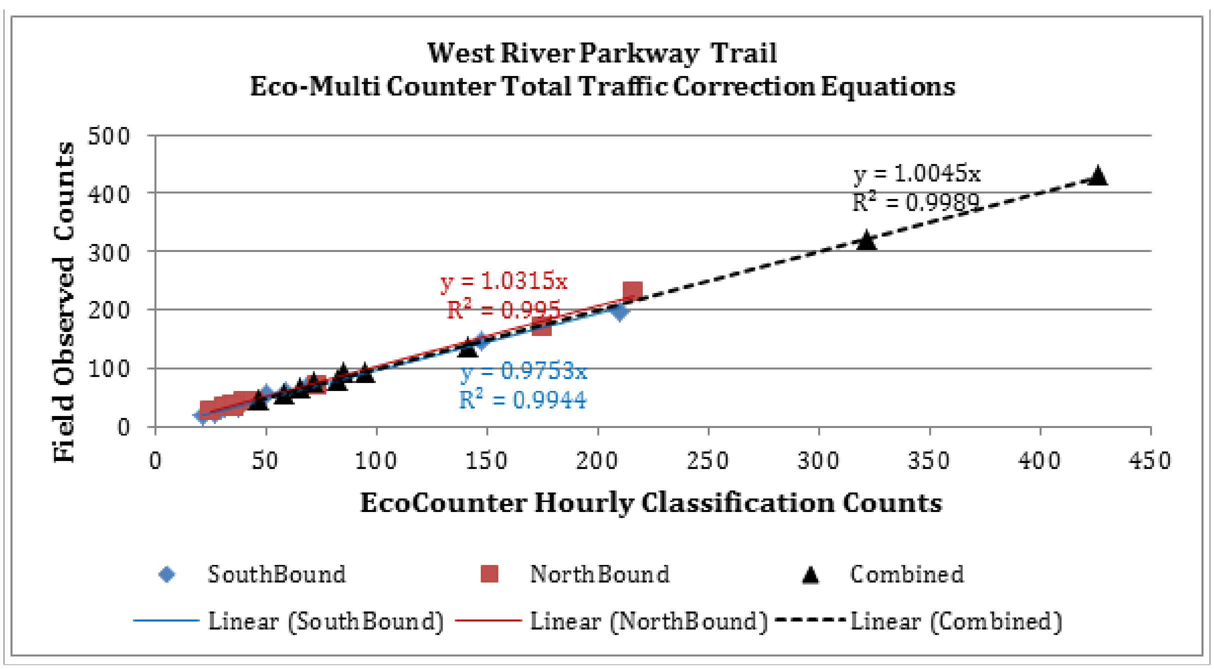


Figure 3.8. Scatterplot of manual and total non-motorized traffic counts, W. River Parkway Trail

As illustrated by these examples, the decision to adjust sensors to account for systematic error depends both on the accuracy of the specific device and the purposes for which the data will be used. If data are to be adjusted, site-specific correction equations are preferred. No general, "all-purpose" estimates of accuracy or widely-accepted correction equations have been published in the transportation engineering literature, even for specific technologies.

3.3 Assessment of Data Validity

A third step in validation of counts involves review of counts to check for suspected errors. This step includes inspection of data for unusually high counts or prolonged periods of zero counts. For example, sometimes hourly counts are observed that are several times larger than the average count for that particular hour of that day-of-week in that month. The analyst then faces the decision of determining whether the count is valid. While it may be valid (e.g., an estimate of the number of runners on a track team that happened to run by), it may not be. Similarly, prolonged periods of zero counts (e.g., 12 hours or more) may be encountered. This situation would be considered unusual in vehicular traffic monitoring, and the period would be "flagged" for an error-check. For non-motorized traffic, however, this may be accurate (e.g., on a cold, windy day). Federal and state guidelines and protocols have been developed for checking for these types of errors in motorized traffic data, but the same types of protocols have not been developed for non-motorized traffic. A study completed by the Texas Transportation Institute for the Colorado Department of Transportation illustrates how these types of error checks can be completed (Turner et al.2012). MnDOT has not established these types of protocols, however, and this type of checking must rely on professional judgment.

CHAPTER 4: SELECTED MONITORING RESULTS

An important goal of the Implementation study was to collaborate with local agencies throughout Minnesota to experiment with and foster bicycle and pedestrian traffic monitoring. One of the main objectives was to demonstrate that bicycle and pedestrian traffic monitoring is feasible and can generate useful information for transportation planning and engineering at the local level.

To achieve this objective, MnDOT and the University worked with individuals from communities that had completed manual counts during the Methodologies study, participated in the Minnesota Bicycle and Pedestrian Counting Initiative, or expressed an interest in monitoring to meet a local need. During the summer of 2014, the project team deployed eight permanent sensors at five locations in four municipalities and obtained access to data from a ninth permanent sensor (Table 4.1). The number of sensors is greater than the number of locations because two sensors were required to monitor traffic in two directions at three locations. MnDOT hired contractors familiar with installation of traffic control devices to install the inductive loops, and personnel from MnDOT, SRF, and the University shared responsibility for overseeing installation in the field. As noted in Chapter 3, all devices initially were calibrated in the field following manufacturer's recommendations, and each type of sensor subsequently was validated with manual counts.

During the project period, the team also completed short duration counts at more than 40 locations in four local jurisdictions (Table 4.2). The type of monitoring and level of collaboration across communities varied. In Hennepin County, two types of pneumatic tube sensors frequently were deployed simultaneously to generate information to inform County efforts to establish a county-wide bicycle traffic monitoring program. The scope of collaboration undertaken in Hennepin County was not envisioned in the original project, but was added to the project to support implementation of what will be the first comprehensive bicycle traffic monitoring program in Minnesota using automated, continuous monitors. Selected results from both permanent and short duration monitoring are summarized in the following sections.

In collaboration with staff from local agencies, researchers completed automated, continuous short duration counts at more than 40 locations in local jurisdictions in Minnesota. Locations for monitoring were chosen by local partners because of particular interests in volumes at those locations or to address local concerns. For most deployments on roads or streets, two sensors were deployed to obtain traffic counts in both travel directions. At some locations, two types of sensors were deployed to obtain information about variation in counts associated with different types of sensors. The short duration counts generally were planned for periods of at least seven full days to illustrate variation in traffic volumes throughout the week, but results were obtained for only one or two days at some locations because devices malfunctioned or were moved or damaged.

Table 4.1. Permanent monitoring sensors by location

Community	Type of Sensor	Location of Permanent Sensor	Number of Sensors	Type of Counts
Duluth	Eco-Multi	Lake Walk (trail)	1	Bikes and Peds
Duluth	Eco-Zelt	Scenic 61 (road shoulder)	2	Bikes
Eagan	Eco-Zelt	Trunk Highway 13 (road shoulder)	2	Bikes
Minneapolis	Eco-Zelt	Central Avenue (bike lane)	2	Bikes
Minneapolis	Eco-Multi	W. River Parkway Trail	1	Bikes & Peds
Rochester	Eco-Multi	Douglas Trail	1	Bikes & Peds

Table 4.2. Portable monitoring sensors by location

Community	Type of Sensors	Number of Short Duration Count Locations*	Type of Counts
Bemidji	• MetroCount pneumatic tubes • Chambers radio beam	• 3 • 1	• Bikes • Bikes & Peds
Grand Marais	• MetroCount pneumatic tubes • Chambers radio beam • TrailMaster Active Infrared	• 4 • 1 • 3	• Bikes • Bikes & Peds • Mixed-mode (undifferentiated bikes &peds)
Hennepin County* (Minneapolis)	• MetroCount pneumatic tubes • TimeMark pneumatic tubes • Chambers radio beam	• 17 • 10 • 3	• Bikes • Bikes • Bikes & Peds
Rochester	• Chambers radio beam	• 1	• Bikes & Peds

*Hennepin County and the study team deployed sensors at 23 different locations during 2013-2014. Both MetroCount and TimeMark tubes were deployed simultaneously at two locations as part of a test to inform decisions by Hennepin County about acquisition of pneumatic tube sensors for a new county-wide bicycle traffic monitoring program.

4.1 Summary of Results from Permanent Monitoring Sites

Results from monitoring at the six permanent locations are summarized in Table 4.3. The results have not been adjusted to account for systematic error measured during validation. Therefore, the total presented generally underestimate actual volumes somewhat. Detailed traffic summaries from each location that are produced by Eco-Counter software are included as appendixes:

- Appendix A: Duluth Lake Walk Monitoring Results;
- Appendix B: Duluth Scenic 61 Monitoring Results;
- Appendix C: Eagan Trunk Highway 13 Monitoring Results;
- Appendix D: Minneapolis Central Avenue Monitoring Results;
- Appendix E: Minneapolis, W. River Parkway Trail Monitoring Results;
- Appendix F: Rochester Trail Monitoring Results.

At each of the three bicycle monitoring locations on streets and roads, average daily bicycle traffic volumes counting traffic in both directions were less than 100 (Table 4.3). Average daily volumes were highest in Minneapolis and comparable at the Duluth and Eagan locations.

Table 4.3. Selected results: permanent monitoring locations

Location	Mode / Direction	Period Analyzed	Average Daily Traffic During Period	Maximum Monthly Average Daily Traffic	Day of Week with Highest Volume	Highest Recorded Daily Traffic in Period
Street/ Road Locations						
Duluth: Scenic 61	Bikes #1	7/1/2014 – 4/30/2015	21	73 (July)	Sat.	302 (7/9/14)
	Bikes #2	7/1/2014 – 4/30/2015	18	67 (July)	Sun.	317 (8/24/14)
Eagan: Trunk Highway 13	Bikes #1	5/1/2014 – 4/30/2015	23	52 (July)	Sat.	89 (6/8/14)
	Bikes #2	5/1/2014 – 4/30/2015	21	43 (July)	Tues.	74 (6/10/14)
Minneapolis: Central Avenue	Bikes #1 NB	5/1/2014 – 4/30/2015	37	61 (July)	Sat.	121 (7/22/14)
	Bikes #2 SB	5/1/2014 – 4/30/2015	58	67 (July)	Wed.	144 (7/27/14)
Trail Locations						
Duluth: Lake Walk	Bikes	7/1/2014 – 4/30/2015	137	454 (August)	Sat.	
	Peds	7/1/2014 – 4/30/2015	752	1,762 (July)	Sat.	
Minneapolis: W. River Parkway	Bikes	7/1/2014 – 4/30/2015	765	1,854 (July)	Sun.	
	Peds	7/1/2014 – 4/30/2015	380	586 (August)	Sat.	
Rochester: McNamara Bridge Trail	Bikes	6/1/2014 – 4/30/2015	128	307 (July)	Sun.	
	Peds	6/1/2014 – 4/30/2015	71	149 (June)	Sat.	

Differences reflect both differences in the periods for which data are available and differences in location characteristics. While the Minneapolis and Eagan average daily volumes are for 12 months, the Duluth measures are for a 10 month period that excludes May and June. Hence, the measures are not strictly comparable. If data for May and June were available, average daily bicycle traffic estimates for Scenic 61 in Duluth likely would be somewhat higher.

The monthly maximum average daily traffic was highest in July at each location, although the specific days with the highest totals varied across the summer months of June, July, and August. A ratio that reflects the seasonality of bicycle traffic is the ratio of monthly average daily traffic to annual average daily traffic (AADT). The average daily traffic values for Eagan and the northbound Central Avenue lane in Minneapolis may be interpreted as AADTs, but the average daily traffic values for the southbound Central Avenue lane in Minneapolis and the Scenic 61 in Duluth are not AADTs because their periods of record are less than one year. With this caveat, the results indicate that seasonal variation in bicycle traffic is highest on Scenic 61 in Duluth (with ratios 3.5 and 3.7, respectively, for locations #1 and #2), followed by traffic at the suburban Trunk Highway 13 location in Eagan (with ratios of 2.3 and 2.0 for locations #1 and #2). Seasonal variation seems lowest in Minneapolis where the ratios both are less than 1.6. These indicate that the Minneapolis Central Avenue location is characterized more by utilitarian, commuter traffic that continues throughout the year. Differences in land uses near each of the three locations support this hypothesis. Specifically, the Central Avenue site is near to many places of employment, including commercial retail stores and restaurants, while the Scenic 61 location is at the edge of Duluth at the beginning of a scenic byway and the Trunk Highway 13 location is in a suburban location with no adjacent commercial or retail facilities.

Compared to the bicycle traffic volumes observed at the three monitoring locations on roads, bicycle traffic volumes observed on separated multiuse trails (i.e., Class I bicycle facilities) were much higher (Table 4.3). Average daily bicycle volumes were highest on the W. River Parkway Trail in Minneapolis (765), followed by the Duluth Lake Walk (137), and the Rochester Multiuse Trail (128). Across the three locations, the monthly maximum average daily traffic was highest in July or August. The ratios of monthly maximum average daily traffic to average daily traffic for the monitoring period of record were 3.3 in Duluth, and 2.4 in both Minneapolis and Rochester.

Next to differences in volume overall, the greatest difference in use at the three trails was differences in mode split (Table 4.3). At the Duluth Lake Walk, pedestrians accounted for 85% of traffic, while at the trail locations in Minneapolis and Rochester, pedestrians accounted for 33% and 36% of traffic, respectively. Average daily pedestrian traffic on the Duluth Lake Walk was 752, while the average daily pedestrian traffic volumes at the Minneapolis and Rochester sites, respectively, were 380 and 71. As with bicycle traffic, average daily pedestrian volumes were highest in summer months, but the seasonal variation was not as great. For the three trail locations in Duluth, Minneapolis, and Rochester, the ratios of maximum monthly average daily traffic to average daily traffic for the monitoring periods were 2.3, 1.5, and 2.1, respectively.

4.2 Summary of Selected Results from Short-Duration Monitoring

The short-duration monitoring results presented here illustrate the variation in bicycle and pedestrian volumes measured at various locations throughout the state. Because short-duration monitoring results generally were shared with local partners following monitoring, not all results are presented in this report.

4.2.1 Hennepin County Bicycle Traffic Monitoring Results

The study team completed short-duration monitoring in collaboration with Hennepin County in both 2013 and 2014 (Table 4.4). In 2013, Hennepin County selected locations on roadways and trails in both Minneapolis and suburban locations to gain a better understanding of variation of volumes in different settings. Only MetroCount sensors were deployed. In 2014, all of the monitoring locations were in Minneapolis, and both MetroCount and TimeMark sensors were deployed, sometimes at the same location.

Over both years, sensors were deployed at 23 locations, including 16 locations on roads and seven locations on trails. Data are reported in this chapter, however, for only 19 locations because problems in the field (e.g., damage to tubes) limited acquisition of data at two sites and because results for two other road sites are summarized in the validation paper forthcoming in the *Transportation Research Record* (Brosnan et al. 2015). In 2013, the number of days sensors were deployed at monitoring locations ranged from six to 14; the mean duration of deployment was 9.7 days. In 2014, the mean duration of monitoring was shorter, 5.2 days. Across all 2014 short-duration monitoring locations, sensors were deployed from three to eight days.

Bicycle traffic volumes measured on roads and streets in Hennepin County during 2013 and 2014 are summarized in Table 4.5. Appendix G includes detailed results for each of the locations. As noted in Chapter 3, different algorithms are available for classification of data from tube sensors. MetroCount, for example, provides classification algorithms that generate counts with and without bicycle counts and outputs that conform to classification standards used by different countries. Boulder County, Colorado developed a customized classification algorithm for use with MetroCount output because county employees observed that groups of cyclists were being classified as multi-axle trucks (Hyde-Wright 2014). Table 4.5 includes two estimates of bicycle traffic for each location where MetroCount sensors were deployed; one derived using MetroCount's ARX Cycle algorithm and one using the Boulder County "BOCO" algorithm. While field studies indicate the BOCO algorithm may be more accurate, the principal purpose of presenting both here is to demonstrate that the process of classification also involves error and introduces additional uncertainty into estimates. Table 4.5 also includes results from deployment of TimeMark sensors. To illustrate the magnitude of variation in bicycle traffic, Table 4.5 includes the minimum and maximum mean traffic volumes for all days, weekdays, and weekend days across monitoring sites for both 2013 and 2014.

Across all locations over both years, the maximum mean daily bicycle traffic observed on roads or streets was 1,070; the minimum mean daily bicycle traffic was nine (Table 4.5; Appendix G). Bicycle traffic on roads was generally higher on weekdays than weekends. For example, the maximum weekday mean daily bicycle traffic on roads was 1,659; the highest average count for bicycle traffic on roads on weekend days for any sample was 482. The numbers of bicycles estimated using the BOCO classification algorithm in most cases, but not all, was higher than the number estimated with the ARX Cycle algorithm.

The study team adapted procedures developed by Miranda-Moreno et al. (2013) for classifying sites into factor groups based on hourly and daily traffic patterns. They identified four general types of patterns: utilitarian, mixed utilitarian, recreational, and mixed recreational. The study team renamed these patterns as commuter, commuter-mixed, multi-purpose, and multi-purpose mixed to better reflect trip purposes associated with the patterns. For example, the utilitarian pattern includes morning a.m. and evening p.m. peak hours consistent with commuter traffic, and utilitarian traffic includes trips made for purposes other than commuting, so commuter pattern better reflects the observed weekday hourly pattern. Consistent with the observation that bicycle traffic volumes on roads and streets tend to be higher on weekdays than weekends, the sites were classified as commuter locations or mixed traffic locations; none was classified as multipurpose.

Bicycle traffic on multiuse trails or Class 1 bicycle facilities was higher at many locations that traffic observed on roads. Across all locations over both years, the maximum mean daily bicycle traffic observed at the trail locations was 2,170, double the highest volume on roads (Table 4.6; Appendix G). The minimum mean daily bicycle traffic was less than one. Bicycle traffic on trails was generally higher on weekend days than weekdays, even on sites with mixed traffic flows. For example, the maximum weekend day mean daily bicycle traffic on trails was 2,506; the highest average count for bicycle traffic on roads on weekdays for any sample was 2,036. The numbers of bicycles on trails estimated using the BOCO classification algorithm in most cases was higher than the number estimated with the ARX Cycle algorithm. Most of the traffic patterns identified on the trails were classified as mixed; one site was multi-purpose and another was commuter (Table 4.6; Appendix G).

4.2.2 Bemidji Bicycle Traffic Monitoring Results

The study team completed short-duration monitoring in Bemidji in October 2014 in collaboration with MnDOT District 2 and Bemidji Park staff. The study team completed monitoring at three locations:

1. The Lake Bemidji Trail, south of Paul Bunyan Park, from the Ace Hardware Store, 670 Paul Bunyan Drive (Rt. 197);
2. Claussen Avenue (both northbound and southbound traffic), between Roosevelt and Rako Streets; and
3. First Street (westbound traffic only), west of Gould Avenue.

Monitoring results are summarized in Table 4.7 and Appendix H. The Bemidji results were shared with MnDOT District 2 and also with Blue Cross Blue Shield and Nice Ride Minnesota to inform an assessment of a new bike share program that was initiated in Bemidji in the summer of 2014 (Schoner, Lindsey, and Levinson 2015).

4.2.2.1 Lake Bemidji Trail Results

The Lake Bemidji Trail location was chosen because the trail is used by both local residents and by visitors to the community and because local officials believe volumes at the location would be illustrative of volumes on the trail. In addition, the location is near an ice cream store which draws bicycle and pedestrian traffic. The study team deployed Chambers radio beam sensor from October 3 through October 21, 2014 (Appendix H). Although the Chambers monitor is designed to provide both bicycle and pedestrian counts, only bicycle counts were obtain. The pedestrian sensor malfunctioned for unknown reasons.

Table 4.4. Hennepin County 2013-14 short-duration monitoring activities

Year	Locations	Road Sites	Trail Sites	Number of Sites Reported	Mean Monitoring Days / Sites Reported	Minimum Monitoring Days for Sites Reported	Maximum Monitoring Days for Sites Reported
2013	11	7	4	9*	9 .7	6	14
2014	12	9	3	10**	5.2	3	8
Total	23	16	7	19	7.8	3	14
*Data from 2 of the 7 road sites are not reported because installation problems resulted in collection of one or fewer days of data. **Data from two sites not reported.							

Table 4.5. Hennepin County 2013-14 monitoring results: bicycle traffic on roads and streets (see Appendix G for site-specific results).

		Mean Daily Bike Traffic		Mean Weekday Bike Traffic		Mean Weekend Daily Bike Traffic		Hourly Traffic Patterns (factor group)			
Year (sites)	Device: classification algorithm	Min	Max	Min	Max	Min	Max	Commuter	Mixed	Multi-purpose	Not enough data to classify
2013 (5)	MetroCount: ARX Cycle	11	162	12	175	9	123	2	3	0	0
	MetroCount: BOCO	40	191	45	202	27	156	2	3	0	0
2014 (4)	MetroCount: ARX Cycle	9	407	13	407	0	262	0	2	0	2
	MetroCount: BOCO	10	372	15	379	0	357	0	2	0	2
2014 (8)	TimeMark	15	1,070	21	1,659	4	482	2	5	0	1

Table 4.6. Hennepin County 2013-14 monitoring results: bicycle traffic on trails (see Appendix G for site-specific results).

		Mean Daily Bike Traffic		Mean Weekday Bike Traffic		Mean Weekend Daily Bike Traffic		Hourly Traffic Patterns (factor group)			
Year (sites)	Device: classification algorithm	Min	Max	Min	Max	Min	Max	Commuter	Mixed	Multi-purpose	Not enough data to classify
2013 (4)	MetroCount: ARX Cycle	<1	263	<1	323	<1	162	1	1	1	1
	MetroCount: BOCO	<1	287	<1	344	<1	192	1	1	1	1
		M.G. Cedar	M.G Hen-nepin		M.G Hen-nepin	M.G. Cedar	M.G Hen-nepin				
2014 (2)	MetroCount: ARX Cycle	1,700	1,701	1,673	1,683	1,756	1,747	0	2	0	0
	MetroCount: BOCO	1,981	2,170	1,790	2,036	2,361	2,506	0	2	0	0
	TimeMark	1,409	1,703	1,271	1,691	1,683	1,733	0	2	0	0

Table 4.7. Bemidji monitoring results

Location	Type of Sensor	Complete Days of Monitoring	Mean Daily Traffic	Mean Weekday Traffic	Mean Weekend Day Traffic
Lake Bemidji Trail	Chambers Radio Beam (bikes & peds)	19	55	56	54
Claussen Avenue					
• Northbound	MetroCount pneumatic tube	19	7	8	6
• Southbound			6	6	6
• Total			13	14	12
First Avenue (Westbound)	MetroCount pneumatic tube	3			

Daily bicycle volumes on the Lake Bemidji Trail during the monitoring period ranged from 0 to 104. The mean daily traffic volumes on weekdays and weekend days were comparable: 56 and 54, respectively (Table 4.7). On weekdays, peak hour traffic occurred between 4:00 and 5:00 p.m.; approximately 18% of all weekday bicycle traffic occurred during this time. Given weekday bicycle traffic volumes (mean = 56), the peak hour traffic volumes were approximately 10. On weekend days, bicycle traffic was spread more consistently through the day, with peak hours (12% of traffic) occurring at noon and 2:00 p.m. These patterns (late afternoon peak traffic on weekdays and more even traffic volumes on weekends) are consistent with patterns seen on other recreational trails in Minnesota. Based on trail traffic monitoring in Minneapolis, it is expected that summertime bicycle volumes (e.g., June – August) would be higher than those monitored in October.

4.2.2.2 Claussen Avenue Results

Claussen Avenue is a residential street with a bike lane that connects two segments of the Paul Bunyan Trail. The Claussen Avenue location was selected because local officials were interested in whether bicyclists were using the bike lanes as a connecting route between the trail segments.

The study team deployed MetroCount pneumatic tubes across both the northbound and southbound bicycle and travel lanes for 19 days from October 3 through October 21, 2014 (Appendix H). Northbound average weekday and weekend daily bicycle traffic volumes were 8 and 6 bicycles, respectively (Table 4.7). Southbound average weekday and weekend daily bicycle traffic volumes were comparable, 6 and 6 bicycles, respectively. Summing traffic in both directions, average daily weekday bicycle traffic was 14 bicycles; average weekend daily totals were slightly lower, approximately 12 bicycles per day. Weekday peak hour traffic occurred between 4:00 p.m. and 5:00 p.m.; weekend bicycle traffic was spread more evenly throughout the day. In general, however, hourly volumes are difficult to characterize given the small volumes of traffic, even when aggregated over multiple days.

A useful feature of the MetroCount sensors is that they also provide estimates of total vehicular traffic volumes so that bicycle mode share can be computed. Bicycle mode share for Claussen

Avenue southbound was 2.9% and 2.8%, respectively, for weekdays and weekends. Bicycle mode share for Claussen Avenue northbound was slightly higher, 3.8% and 3.1%, respectively, for weekdays and weekends.

4.2.2.3 First Avenue Westbound Results

First Avenue is east-west arterial located south of Lake Bemidji. The First Avenue location was selected because local officials were interested in whether bicyclists were using the road to access off-street trails that connect to the Lake Bemidji trail. The study team deployed one MetroCount pneumatic tube connector across the westbound travel lane on October 3. Monitoring results are available for only three days because the tubes were damaged sometime on October 6 and ceased to collect traffic data. Bicycle traffic on First Avenue was very low: 3 bikes on one weekday and an average of six bikes per day for the two weekend days (Table 4.7; Appendix H. Vehicular traffic on First Avenue was fairly high; bicycle mode share for the three days of monitoring was very low, less than two-tenths of one percent.

4.2.3 Grand Marais Bicycle and Pedestrian Traffic Monitoring Results

The study team completed short-duration monitoring in Grand Marais in collaboration with staff from the Sawtooth Mountain Clinic Moving Matters program and MnDOT District 1. The Moving Matters program was interested in counting bicyclists and pedestrians as part of a health impact assessment on a proposed project to redesign the Highway 61 corridor through Grand Marais. The goals of the Rt. 61 corridor project, which include alternatives to improve bicycle and pedestrian infrastructure, are to improve safety, access, and the economics and livability of the community. The study team initiated monitoring in July 2014. Moving Matters staff then continued monitoring using equipment provided by MnDOT and the University through the fall of 2014 and into 2015. Moving Matters staff summarized monitoring results in a DRAFT Health Impact Assessment in 2014 (Moving Matters 2014). Because the Health Impact Assessment reports data for a longer time period than initially was planned for monitoring by the study team, results are summarized here.

Moving Matters and the study team monitored traffic at 8 locations (Figure 4.1; Moving Matters 2014):

- One location on the Wisconsin Avenue sidewalk that continues from the Gitchee Gami Trail along Rt. 61 in downtown Grand Marais (bicycles and pedestrians separately; Chambers sensor);
- Three locations along the Gitchee Gami Trail (mixed-mode traffic; TrailMaster sensor); and
- Four locations on state and county roads leading into and out of Grand Marais (bicycles only; MetroCount sensor).

The monitoring at the Wisconsin Avenue and Gitchee Gami trail locations continued through the fall of 2014. Monitoring of on-road bicycle traffic for approximately one week to 10 days occurred at each site in late summer and early fall of 2014.

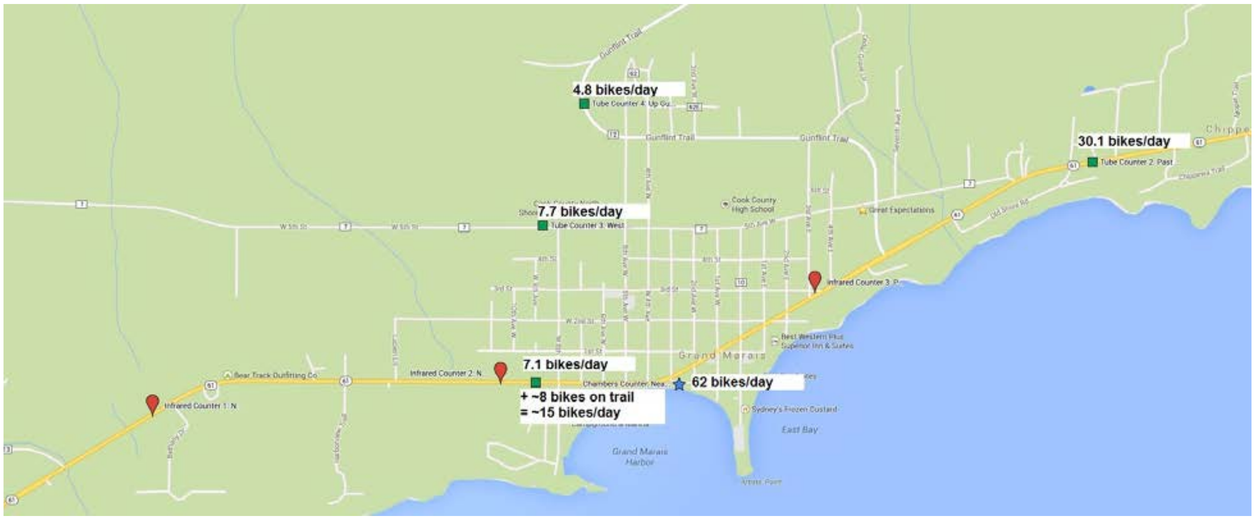


Figure 4.1. Grand Marias bicycle and pedestrian traffic monitoring locations

Volumes were highest at the Wisconsin Avenue site at the east end of downtown Grand Marais. Between July and October 2014, the average daily pedestrian and bicycle traffic volumes, respectively, were 575 and 62 (Figure 4.2; Moving Matters 2014). Pedestrians accounted for 90.3% of daily traffic; bicycles accounted for 9.7% of daily traffic. Higher volumes generally occurred on weekend days and were associated with tourism-related traffic. The maximum daily pedestrian and bicyclist count of 3,607 occurred on Saturday, August 2. Daily pedestrian and bicycle traffic declined from July, the peak of the tourist season, through October.

The north sidewalk on Wisconsin Avenue was not monitored because of a lack of equipment. Hence, the total pedestrian and bicycle traffic on Wisconsin Avenue is higher. Field observations indicates traffic on the south sidewalk on closest to Lake Superior is higher, but the relative volumes are not known.

Mixed-mode traffic (i.e., undifferentiated pedestrians and bicycles) was monitored at three locations on the Gitchee Gami Trail from July through November 2014. From west to east, the locations were (Figure 4.1):

- Near the U.S. Forest Service office;
- Near the Grand Marais Municipal Recreation Park to the west of downtown; and
- Near the U.S. Post Office to the east of downtown.

Daily traffic volumes at the three locations are presented in Figure 4.3 (Moving Matters 2014). Daily traffic generally was highest near the U.S. Post Office; the peak traffic volume observed was 405. Daily traffic on the Trail near the Recreation Park generally was lower than near the U.S. Post Office but sometimes was higher. The highest daily traffic observed near the Municipal Park was 286. Trail traffic was lowest near the U.S. Forest Service Office on the western-most section furthest from downtown. The highest daily traffic volume observed on this section, which was monitored only from July into September, was 68. Like the pedestrian and trail traffic on Wisconsin Avenue, trail traffic volumes reflected seasonal tourism, declining from mid-summer through late fall.

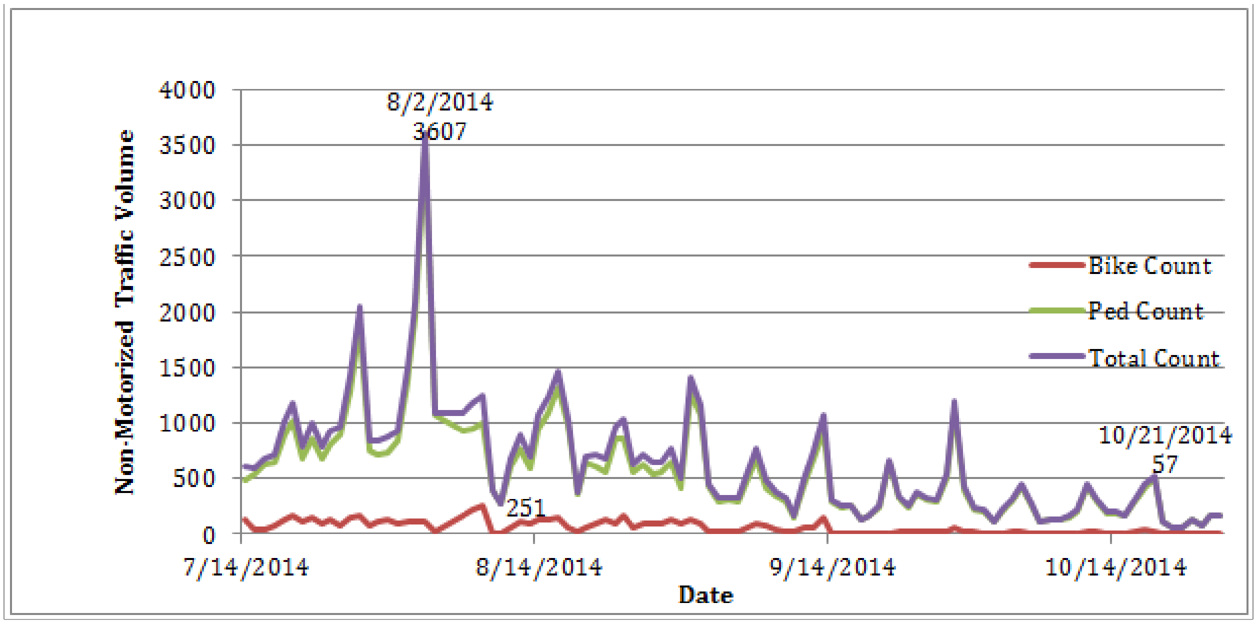


Figure 4.2. Wisconsin Avenue south sidewalk pedestrian and bicycle traffic, July – October, 2014

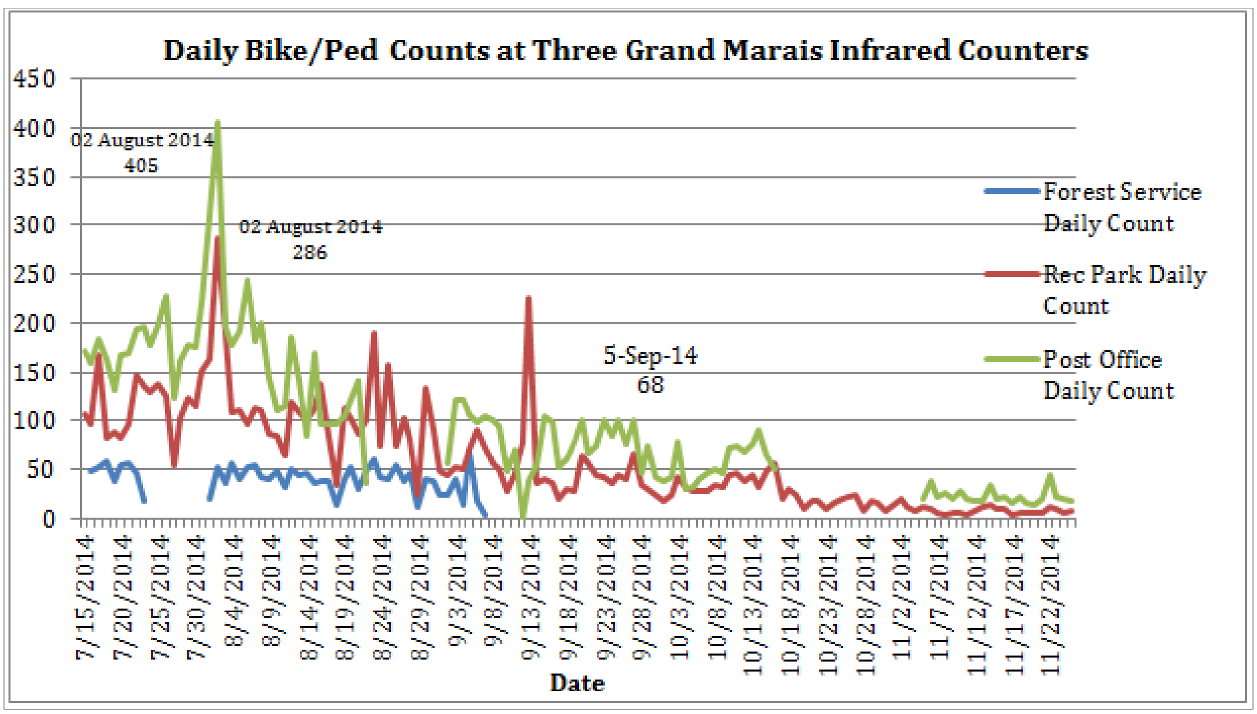


Figure 4.3. Gitchee Gami Trail, daily mixed-mode traffic volumes, July – November, 2014

Bicycle traffic on the principal roadways in and out of Grand Marais was monitored using pneumatic tubes in late summer. Bicycle volumes on the Rt. 61 road shoulders east of downtown Grand Marais were highest: total bicycles in both directions were 31 per day. Bicycle volumes on Rt. 61 and the Gitchee Gami Trail west of downtown were approximately 15 per day. Bicycle volumes on County Roads 7 and 12 (the Gunflint Trail) averaged 8 and 5 per day.

Taken together, these counts reflect the effects of tourism related pedestrian and bicycle traffic in Grand Marais. Pedestrian and bicycle traffic is seasonal, diminishing from the summer through fall, and concentrated near downtown Grand Marais and the Lake Superior lakefront where retail stores, restaurants, cafes, bars, and other destinations are located. Bicycle traffic in and out of the community varies, with higher traffic on Rt. 61 than county roads, and the highest traffic on the eastern edge of the community.

CHAPTER 5: A CASE STUDY OF DATA ANALYSIS AND FACTORING

One of goals of the Implementation study was to illustrate now traffic engineers and planners can use traffic counts to develop measures of AADT, one of the most commonly used performance measures in transportation planning. One the principal objectives of the study, therefore was to collect data to develop models for extrapolating short duration counts to estimates of AADT.

Although procedures for estimating AADT from short duration (e.g., 48 hour) motorized vehicle counts are well established, examples in which similar factoring approaches have been used to estimate AADT for bicycles or pedestrians on street, sidewalk, or trail networks are rare. This is because few local agencies have an adequate number of permanent reference sites for developing the factors required to extrapolate the short duration counts. In addition, because of the variability of bicycle and pedestrian traffic in response to weather and other factors, the standard two-step factoring approach used with motorized vehicular traffic counts does not produce as accurate estimates of AADT. Researchers recently have shown (Nordback, 2013; Hankey et. al. 2014) both longer short-duration samples (e.g., five to seven days) and factors that reflect variability in daily weather are needed to maximize the accuracy of estimates of AADT produced from short duration counts.

To illustrate how factors can be used to estimate AADT, the research team built on work done in the Methodologies study (Lindsey et al. 2013) and in a related paper subsequently published in the *Transportation Research Record* (Hankey et al. 2014). This work, which was based on a simulation modeling exercise, illustrated a new day-of-year factoring approach that produces more accurate estimates of AADT from short duration counts than the standard approach for factoring motorized traffic counts described in the *Traffic Monitoring Guide*. Specifically, the research team used mixed-mode traffic counts taken at six permanent monitoring reference sites on Minneapolis trails during 2012 to assess the accuracy of different length samples on estimates of AADT at the reference sites. Because short duration counts were not available for the entire trail network, the factors could not be applied to short duration counts and AADT for other segments in the trail network could not be estimated. During the Implementation study in the summer of 2013, the University collaborated with the Minneapolis Park and Recreation Board and the Minneapolis Department of Public Works to sample each mile of the Minneapolis trail network, use the day-of-year factoring approach to estimate AADT for all segments in the trail network, and estimate miles traveled by bicyclists and pedestrians on the trail network. A DRAFT manuscript that describes the factoring methodology and results was presented at the annual meeting of the Association of Collegiate Schools of Planning in the fall of 2014.

The principal findings of this case study are summarized in Figures 5.1, 5.2, and 5.3 and Table 5.1. Figure 5.1.A illustrates average daily traffic per month at the six reference monitoring sites and daily variation in trail traffic across the six sites as a ratio to AADT (Figure 5.1.B). A key insight from these graphs is that although absolute trail traffic volumes across sites vary greatly, the response to daily weather in traffic volumes across the sites is consistent. This fact means that factors based on the ratio of any given days traffic to AADT can be used to extrapolate short duration samples taken elsewhere in the network, so long as it is assumed responses to variations in weather are the same.

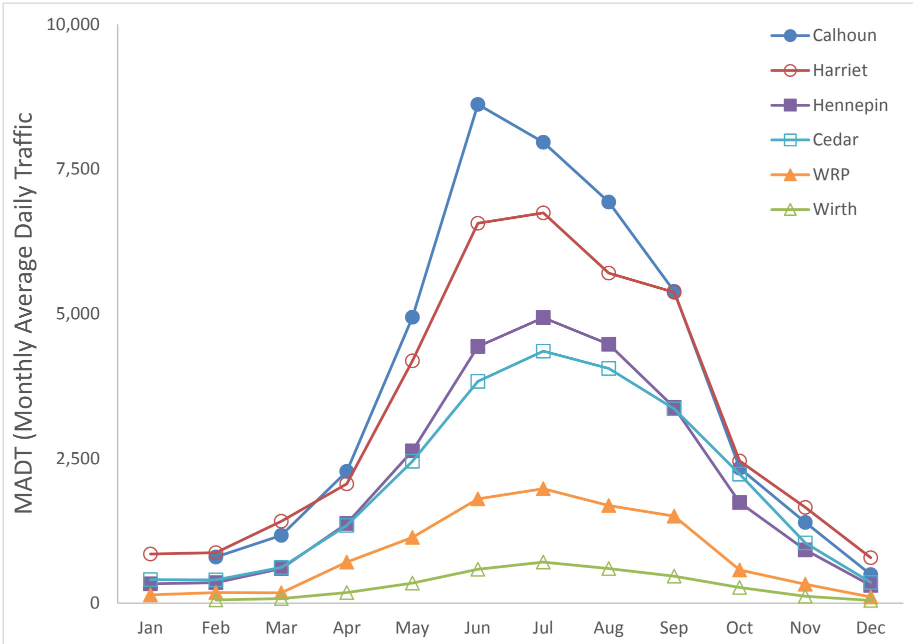
Figure 5.2 presents estimates of 2013 AADT for every mile of trail in the 80-mile Minneapolis trail network at the permanent and short-duration monitoring sites and the estimates of AADT by quartile along each segment length. These maps show that trail traffic volumes tend to be largest around recreational destinations (e.g., the network of lakes and along the Mississippi River in downtown Minneapolis). The maps also show evidence of commuting: trail traffic volumes on segments that lead to the central business district (i.e., a jobs center) tend to get larger. The maps also show that trails, which are unconnected to the network, tend to have lower traffic volumes.

Standard procedures for estimating vehicle miles traveled (VMT) on road networks involves multiplying estimates of AADT times segment length and summing across the network. Table 5.1 summarizes variation in AADT and miles traveled on individual segments of the trail network. AADT varies over three orders of magnitude across the network. Using this approach, researchers estimate that trail users traveled more than 28 million miles on Minneapolis trails in 2013.

From the short duration samples at each monitoring location, researchers also identified four different hourly traffic patterns on different segments of the trail network. Examples of these patterns are presented in Figure 5.3. The four patterns are commuting, multipurpose, mixed commuting, and mixed multipurpose. One of the main reasons for classifying hourly traffic patterns is to establish factor groups that can be used to increase the accuracy of estimates of AADT. Details on the procedure for classifying are included in the draft manuscript in Appendix I (Lindsey et. al. (2015). By identifying factor groups and then producing extrapolation factors from permanent monitoring sites with the same sites, more accurate results can be achieved. A related benefit of classifying hourly traffic patterns is to demonstrate that trails, or Class 1 bicycle facilities, are used for multiple purposes, not just recreation.

An important insight from this analysis is that the process of establishing permanent or reference bicycle or pedestrian monitoring sites, developing factors, sampling the transportation network, and estimating AADT is an iterative one that, for any particular network of interest, will require years to develop and implement.

A. Average Daily Trail Traffic by Month and Reference Monitoring Sites



B. Ratio of Daily Variation in Trail Traffic to AADTT at Reference Monitoring Sites

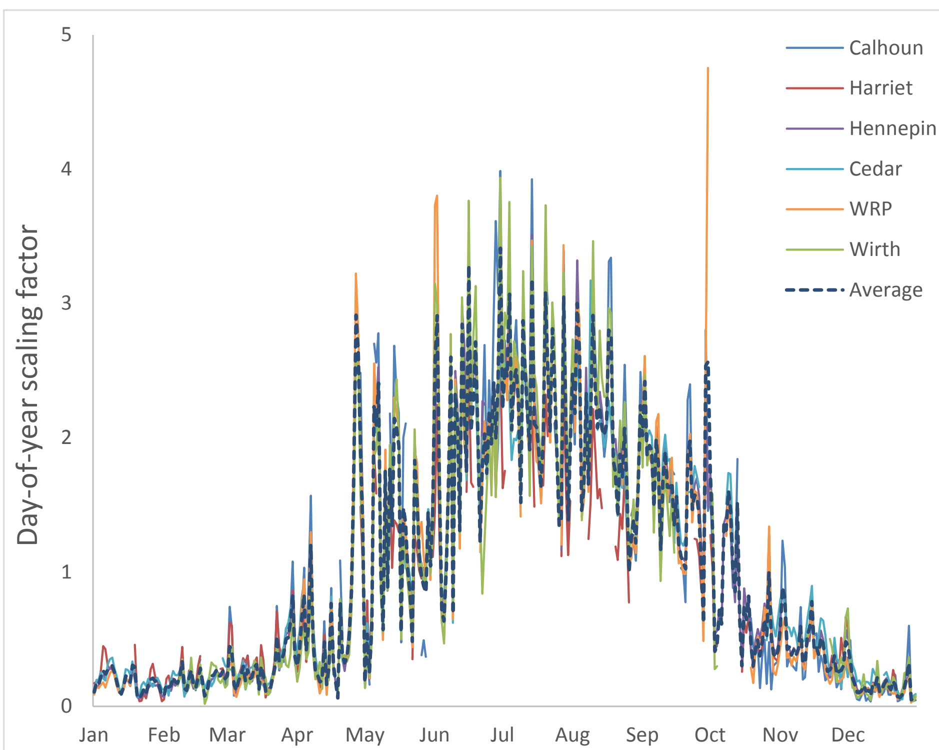


Figure 5.1. Monthly and daily variation in trail traffic at six reference monitoring sites

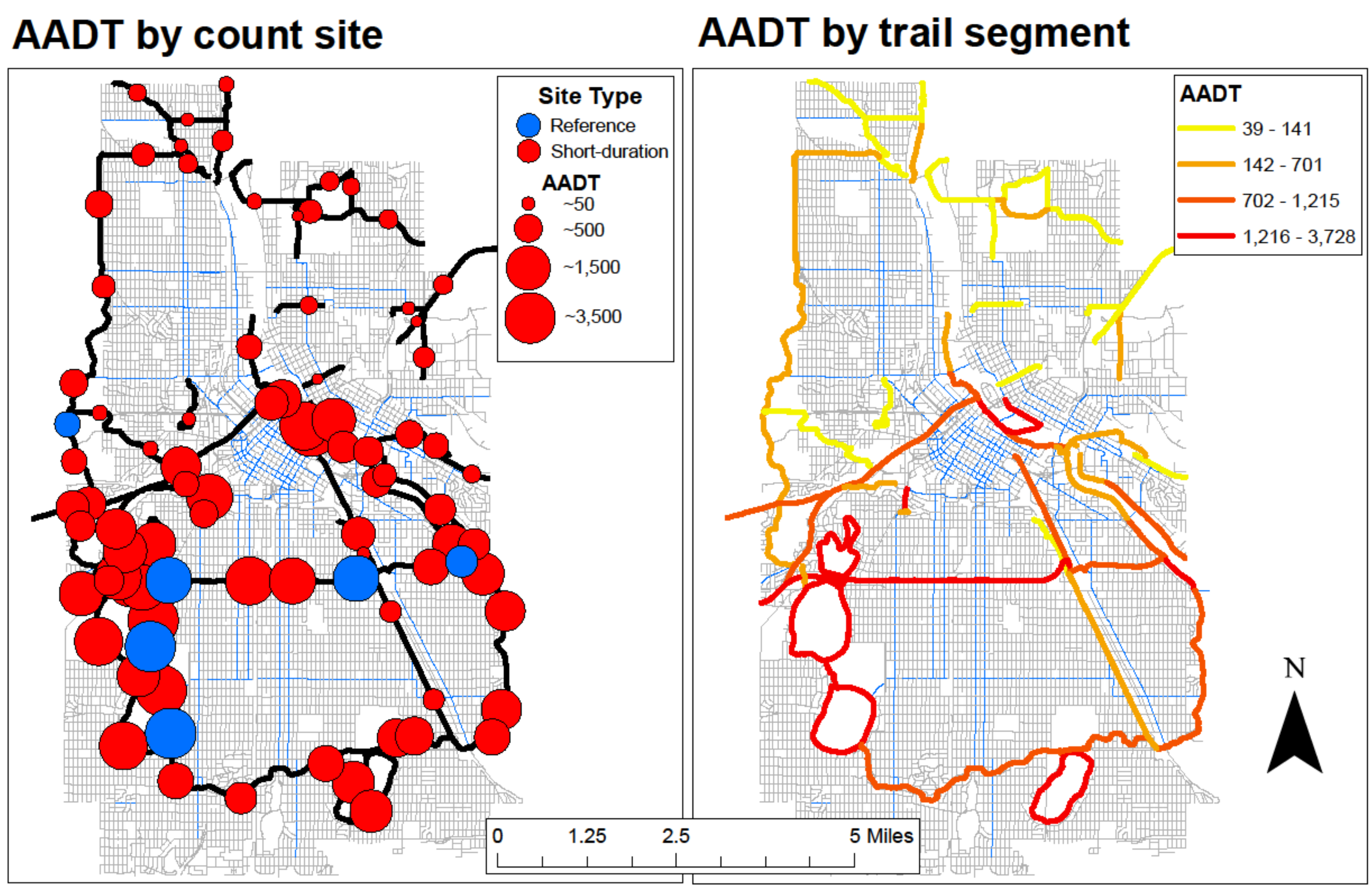
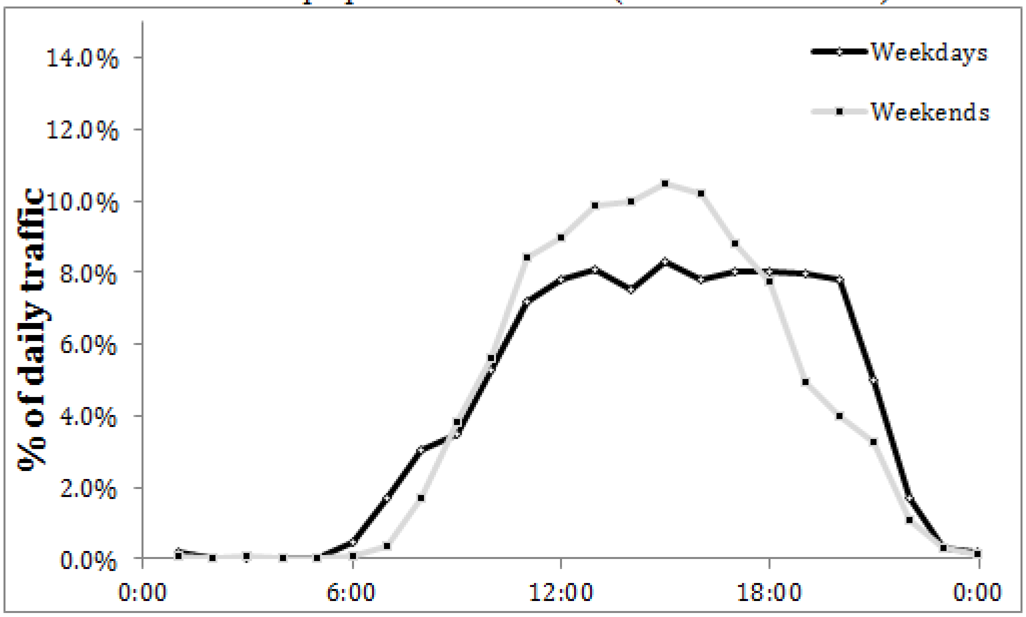
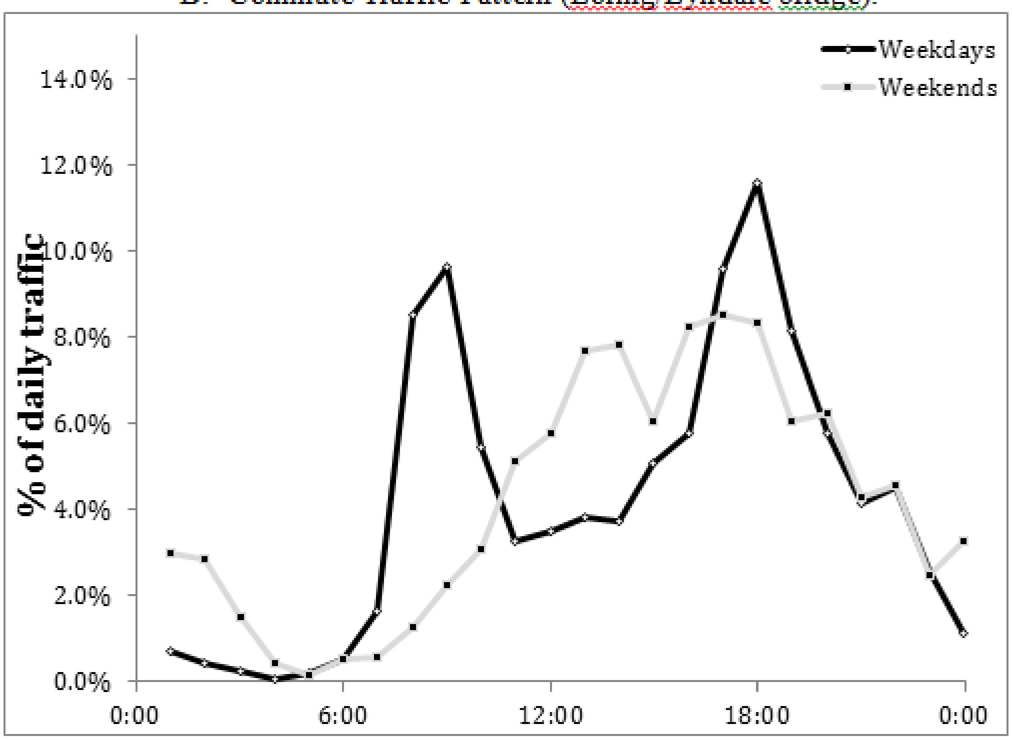


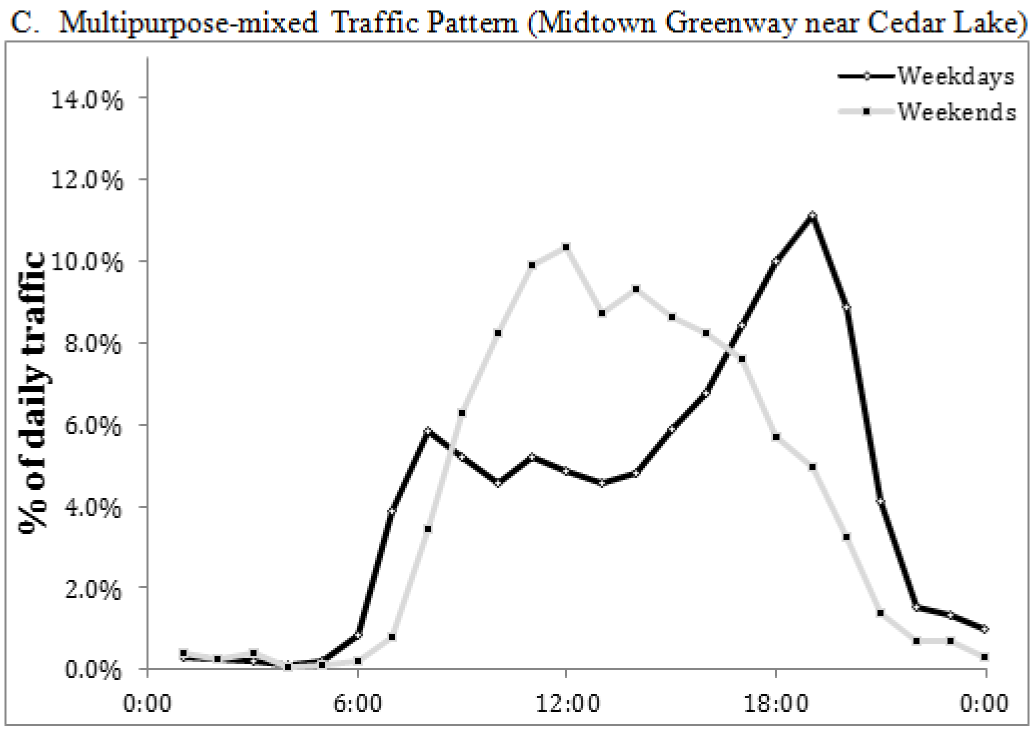
Figure 5.2. 2013 AADT by trail segment in Minneapolis

A. Multipurpose Traffic Pattern (near Lake Hiawatha)



B. Commute Traffic Pattern (Loring/Lyndale bridge).





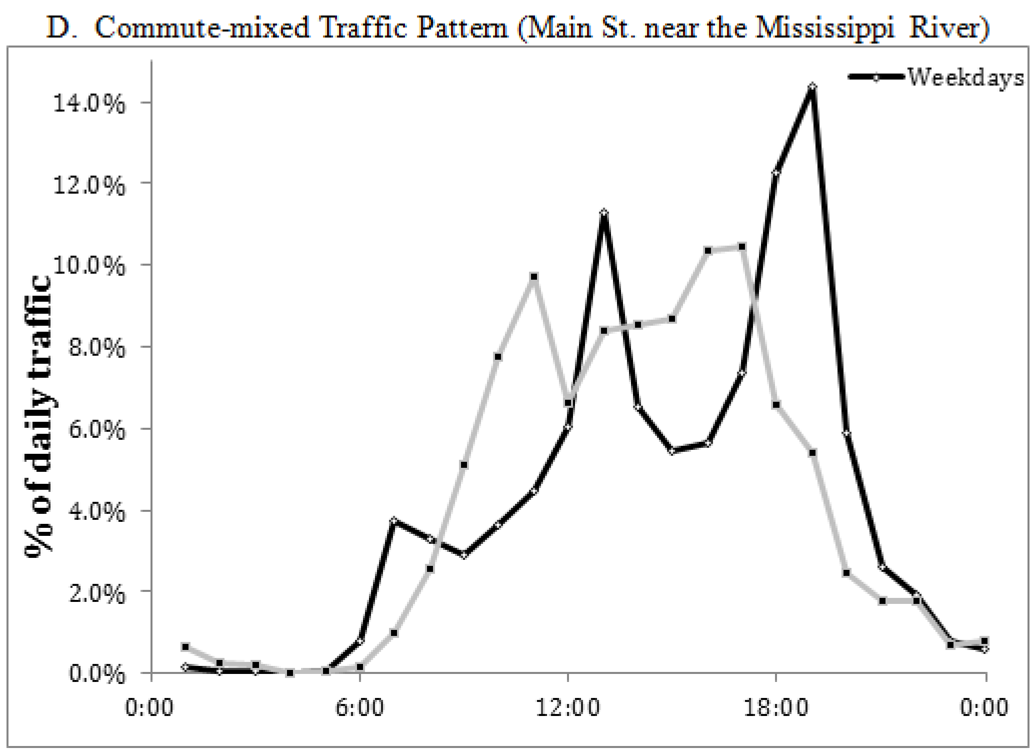


Figure 5.3. A, B, C and D show variations in hourly trail traffic patterns in Minneapolis

Figure 5.4. Variation in annual average daily trail traffic and miles traveled

	Annual Average Daily Trail Traffic		Annual Miles Traveled	
	Segment AADTT	**Trail Segment Name**	**Segment Miles Traveled**	**Trail Segment Name (segment length)**
Maximum	3,728	Lake Calhoun (north side)	1,916,500	Lake Harriet (west side; 1.6 miles)
Mean	954	--	350,100	--
Median	750	Cedar Lake Trail (Kenilworth to 394)	230,600	West River Parkway (Stone Arch to Plymouth; 0.6 miles)
Minimum	39	Diagonal Trail (Stinson to Broadway)	8,500	Diagonal Trail (Stinson to Broadway; 0.59 miles)

CHAPTER 6: CHALLENGES IN DATA MANAGEMENT

An important goal of the project was to begin integration of bicycle and pedestrian traffic counts into MnDOT traffic monitoring databases. At the time the project was initiated, MnDOT had contracted with Chaparral Systems, a traffic database vendor, to implement a new data management system for all the state's motorized data with some hopes to also incorporate non-motorized traffic data. Although MnDOT began the transition to TRADAS from its existing database systems, implementation of TRADAS was suspended because of contractual problems with the vendor unrelated to this project. MnDOT has not determined how traffic data (both motorized and non-motorized) will be archived in the future. As a result, integration of non-motorized traffic monitoring data into the MnDOT traffic monitoring database system was not achieved.

Prior to suspension of work on this task, key findings included:

- The TRADAS database had capacity to integrate and manage non-motorized traffic data. The Colorado Department of Transportation (CDOT), which adopted the TRADAS system before MnDOT, is storing continuous and short duration non-motorized traffic counts within the TRADAS system. However, CDOT has not used all the capacities of the database for procedures such as QA/QC because analytic procedures used for vehicular traffic cannot be applied to non-motorized data, and automated QA/QC for non-motorized traffic data have not been developed. The implication is that, regardless of the database system that MnDOT eventually implements, new procedures for QA/QC must be developed.

- MnDOT is in transition between database systems, and final decisions about future systems have not been made. MnDOT traffic monitoring staff remain committed to the goal of integrating continuous, non-motorized traffic data in a single database system with motorized traffic data.

- New protocols and procedures for collection, analysis, and management of non-motorized traffic data need to be developed to support integration of continuous and short duration counts into future data management systems. At least eight different types of automated sensors have been deployed in Minnesota. Examples of the types of protocols needed include decision rules to:

    - Aggregate data from different types of continuous sensors into time bins (e.g., 15 minutes, one hour);
    - Check whether automated, continuous sensors are operating properly,
    - Determine whether to apply adjustment factors to correct for error associated with occlusion or other factors;
    - Extrapolate short duration counts to obtain estimates of AADT; and
    - Determine the length of roadway segments represented by a continuous or short-duration sensor.

- Continuous, automated counts of non-motorized traffic now are available from a number of permanent monitoring stations and dozens of short-duration monitoring sites across Minnesota

The study team also contacted the FHWA to determine the feasibility of archiving counts into federal databases. The FHWA's Traffic Monitoring Guide (2013) outlines protocols for monitoring site identification and documentation required for entering data into the Traffic Monitoring and Analysis System (TMAS). TMAS provides "online data submitting capabilities to State traffic offices"; FHWA division offices in each state provide access to TMAS (FHWA 2015: http://www.fhwa.dot.gov/ohim/tvtw/tvtfaq.cfm, accessed May 25, 2015). Although FHWA has plans to incorporate bicycle and pedestrian traffic monitoring data into TMAS, the agency does not anticipate this capability will be provided for a few years. The study team experimented with formatting data to meet TMAS protocols and documented time required for formatting. These data will be submitted to FHWA as part of the Institutionalization project to determine if reliance on TMAS is a viable strategy for MnDOT for archiving bicycle and pedestrian traffic monitoring data.

CHAPTER 7: OBSERVATIONS, OUTCOMES, AND NEXT STEPS

MnDOT launched the Minnesota Bicycle and Pedestrian Counting Initiative in 2011 to encourage and support non-motorized traffic monitoring by local, regional, and state organizations. To support the Initiative and provide agencies the tools they need for monitoring bicycle and pedestrian traffic, MnDOT has funded three research and implementation projects. This Implementation study built on findings from the initial Methodologies report and established the basis for funding the third project to institutionalize the use of pedestrian and bicycle traffic counts in Minnesota.

The overall goal for this Implementation study was to demonstrate the feasibility of using automated sensors to collect bicycle and pedestrian traffic data in Minnesota. The main objectives of this Implementation study were to:

- Acquire and install new technologies for continuous counting of bicyclists and pedestrians at various locations in Minnesota;
- Calibrate and validate sensors;
- Integrate continuous count data into MnDOT traffic monitoring databases;
- Use portable sensors for short duration counts;
- Develop models for extrapolation of short duration counts; and
- Provide technical assistance including assistance with deployment of counters, training workshops, and preparation of guidance for bicycle and pedestrian data collection.

Each task was undertaken in collaboration with local units of government in Minnesota.

Key findings from this Implementation study include:

- Automated sensors for monitoring bicycle and pedestrian traffic are available at reasonable cost and can be deployed in Minnesota at both permanent and at short-duration monitoring sites. These sensors include inductive loop sensors for monitoring bicycle traffic on roads or on trails; pneumatic tube sensors for monitoring bicycle traffic on roads or trails; integrated passive infrared and inductive loop sensors for monitoring bicycle and pedestrian traffic on trails; and radio beam sensors for monitoring bicycle and pedestrian traffic on trails.

- All sensors tested in the study can produce reasonably accurate measures of bicycle and pedestrian traffic, although accuracy varies with the specific technology, care taken in deployment, maintenance following deployment, and specifics of the configuration, including traffic volumes. Most technologies tend to undercount. Occlusion, or multiple users passing a sensor simultaneously, is a principal source of error. Correction equations and adjustment factors can be developed to correct counts for systematic error, but the process requires additional labor, and the need for correction depends on the application.

- Portable sensors can be deployed efficiently and provide useful measures of bicycle and pedestrian traffic. Because of hourly and day-of-week variations in bicycle and pedestrian traffic, short-duration monitoring results are most useful if they include a minimum of seven complete days (i.e., the weekdays and weekend days). However, if the goal of monitoring is simply to obtain an indicator of the general order of magnitude of bicycle or pedestrian traffic, shorter monitoring periods may suffice provided that care is taken to avoid circumstances that could produce atypical outcomes (e.g., rainfall that reduces traffic or organizing cycling or walking events that increase it).

The approach outlined in the *Traffic Monitoring Guide* (2013) that involves the use of factors derived from permanent monitoring locations to generate estimates of annual average daily traffic from short-duration counts can be used in non-motorized traffic monitoring. The study team used data from permanent and short-duration monitoring on an 80-mile multiuse trail network in Minneapolis to estimate AADT on each trail segment. These estimates then were used to estimate miles traveled by bicyclists and pedestrians on the network. This estimate is analogous to vehicle miles traveled (VMT), a performance indicator for motorized traffic used widely in transportation planning and engineering.

- A major challenge in implementing bicycle and pedestrian traffic monitoring is data management, specifically the challenge of formatting data from different sensors and integrating data into motorized traffic monitoring systems. The goal of integrating data collected during the Implementation study into MnDOT's traffic data management was not achieved because the vendor that was supporting implementation of the new data management system went out business. A task of the ongoing Institutionalizing project will be to explore alternatives for managing data.

In addition to these findings, an additional outcome from this project is a new MnDOT guidance document, "DRAFT Bicycle and Pedestrian Data Collection Manual." Team members used this manual in training workshops in spring 2015. The DRAFT Manual includes a set of case studies that summarize how local officials have and are using bicycle and pedestrian accounts to inform transportation planning, engineering, and policy-making. For example, the City of Mankato and the Blue Earth County State Health Improvement Program (SHIP) manually counted nearly 2000 pedestrians crossing Monks Avenue midblock without crossing treatments during a non-consecutive 25 hour period. The findings were presented to Mankato's Engineering Department and three midblock crossings were incorporated into the reconstruction plan for the street. Case studies like this one illustrate the demand for better data that exists in Minnesota.

The study team made several important observations during the Implementation study that have implications for the long-term future of bicycle and pedestrian monitoring in Minnesota. The most important observation is that there is high demand for bicycle and pedestrian traffic monitoring data in local agencies, other administrative units within MnDOT, and in other state agencies. These agencies seek data for different but related purposes, including transportation systems management, evaluation of infrastructure used for transportation, recreation, and other purposes, and planning for active living and other health-related initiatives. For example, in Hennepin County, engineers collaborated in the Implementation study to obtain data to inform investments in new sensors to establish its own bicycling monitoring network. Hennepin County intends to monitor bicycle traffic at 80 locations on roads in the County using pneumatic tubes. In Grand Marias, program staff from the Sawtooth Mountain Clinic supported monitoring to inform planning efforts to enhance opportunities for active travel in the Rt. 61 corridor. In Rochester and Bemidji, staff from local planning and park departments prioritized monitoring on multiuse trails. Within MnDOT, engineers responsible for traffic safety envision new data to inform analyses that historically have relied on ad hoc counts or values published in the literature. The Minnesota Department of Health is supporting traffic monitoring as part of broad efforts to assess outcomes associated with the SHIP. These observations about increasing demand for bicycle and pedestrian traffic data were factors in MnDOT's decision to implement the ongoing project to institutionalize bicycle and pedestrian data collection in Minnesota.

Important outcomes based in part on findings from this Implementation study include:

- MnDOT's publication of the state's first guidance document for collection of bicycle and pedestrian monitoring data, "DRAFT Bicycle and Pedestrian Data Collection Manual."
- MnDOT's decision to fund the follow-up implementation project, "Institutionalizing the Use of State and Local Pedestrian and Bicycle Traffic Counts;"
- MnDOT's decisions to include commitments to bicycle and pedestrian traffic monitoring in its forthcoming statewide bicycle and pedestrian plans;
- MnDOT's decision to invest in a network of permanent monitoring sites that includes monitors in each MnDOT administrative district and additional portable monitoring equipment for use in local communities;
- MDH's decision to use data to measure SHIP's active transportation strategy;
- Hennepin County's decision (based on validation studies) to purchase new pneumatic tube sensors to use in its new bicycle traffic monitoring program;
- Use of bicycle and pedestrian traffic monitoring data in presentations to elected officials and agency staff in Hennepin County, Minneapolis, Rochester, Bemidji, and Grand Marais; and
- Publication of research findings in the academic peer-reviewed literature that help advance the state-of-the-art in non-motorized traffic monitoring.

These outcomes indicate that many agencies and individuals will continue to collaborate to institutionalize monitoring programs and that the data generated by these programs will be used by local and state officials to inform decisions that affect the quality of lives of residents throughout the state.

Years will be required to institutionalize bicycle and pedestrian traffic successfully. The next step will be to complete the Institutionalizing project, acquire the sensors to establish the statewide monitoring network, and build the collaborations across local and state government needed to operate the monitoring network efficiently. The study team for the implementation project observed that decision-makers tended to express more support for investments in monitoring devices and programs when they were shown evidence of how data could improve policy and management decisions. Therefore, one strategy that may be useful as staff work to institutionalize monitoring is to complete case studies that illustrate how officials have used data to make decisions on projects affect the efficiency and safety of transportation systems.

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APPENDIX A:
DULUTH LAKE WALK MONITORING RESULTS

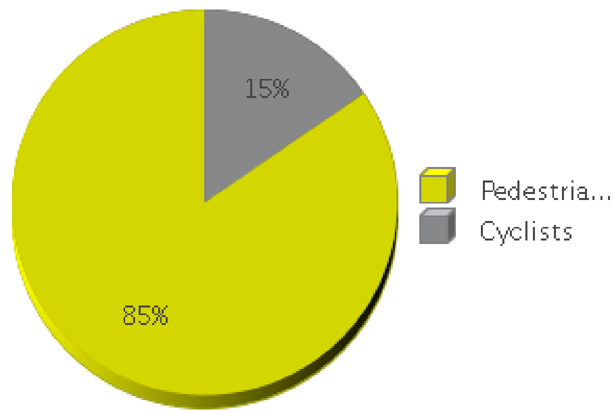
Duluth Lake Walk Multi 01

Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015

GPS coordinates not filled-in.
You can enter GPS coordinates in the counter's Eco-Visio file.

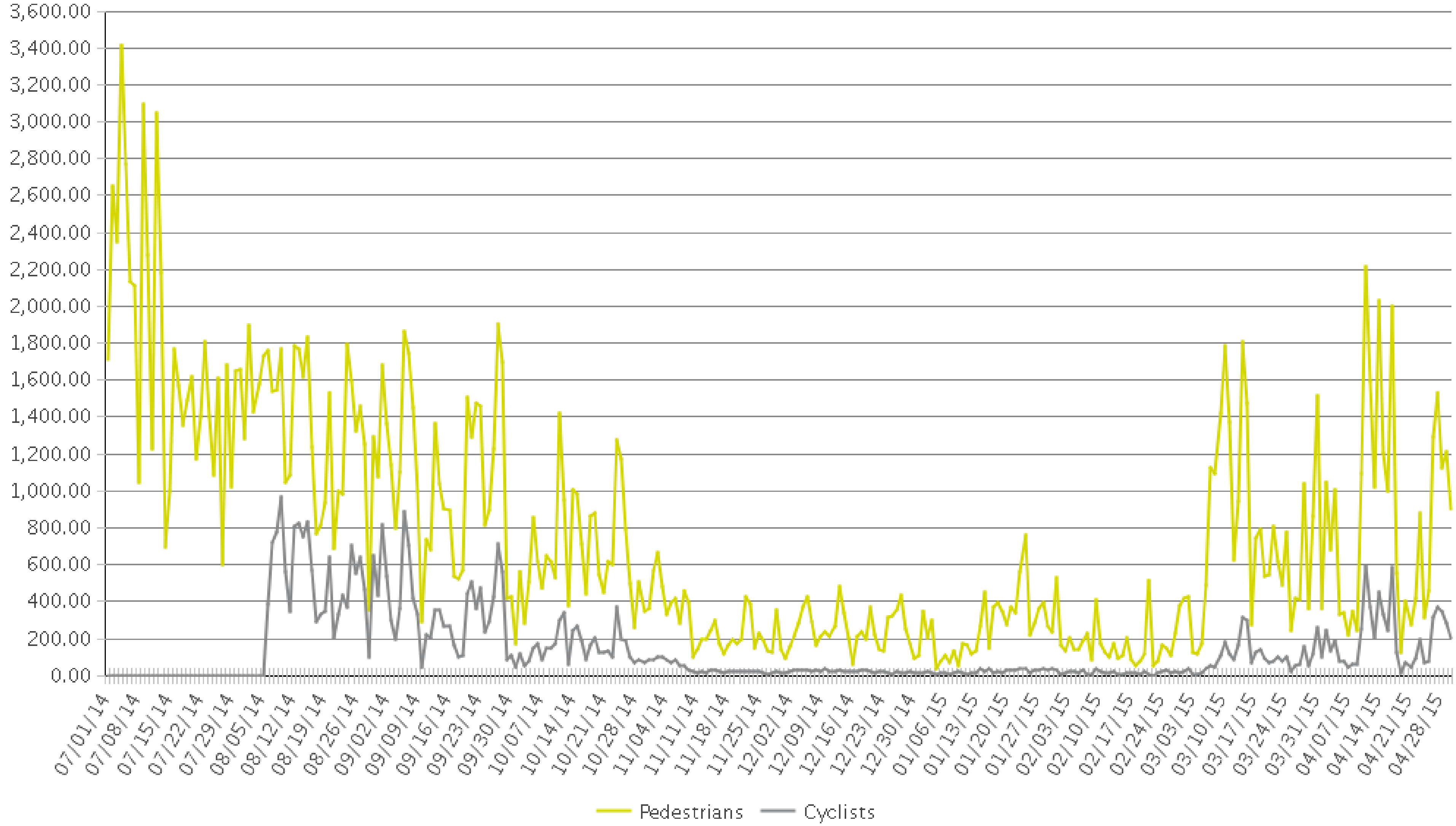
	Total Traffic for the Analyzed Period	Daily Average	Busiest Day of the Week	Busiest Month of the Year	Distribution	
					IN	OUT
Pedestrians	228,646	752	Saturday	July 14 : 54,626	53	47
Cyclists	41,741	137	Saturday	August 14 : 14,060	54	46

No picture available.
You can add a picture in the counter's Eco-Visio file.



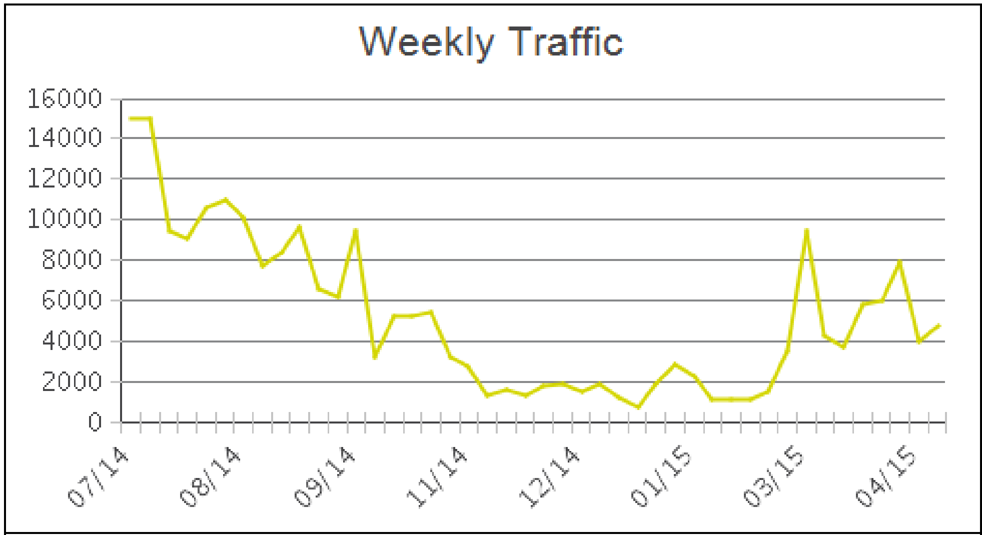
Duluth Lake Walk Multi 01

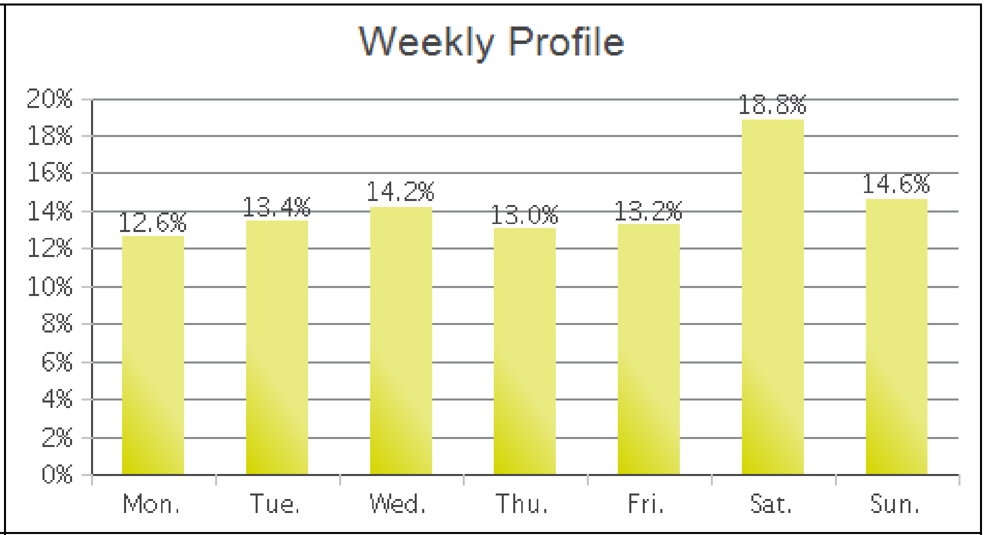
Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015

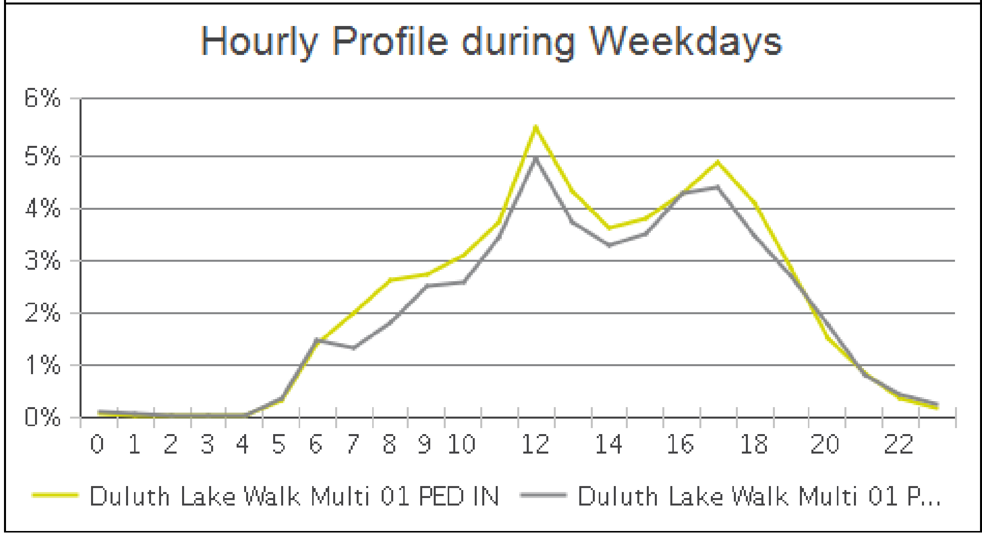


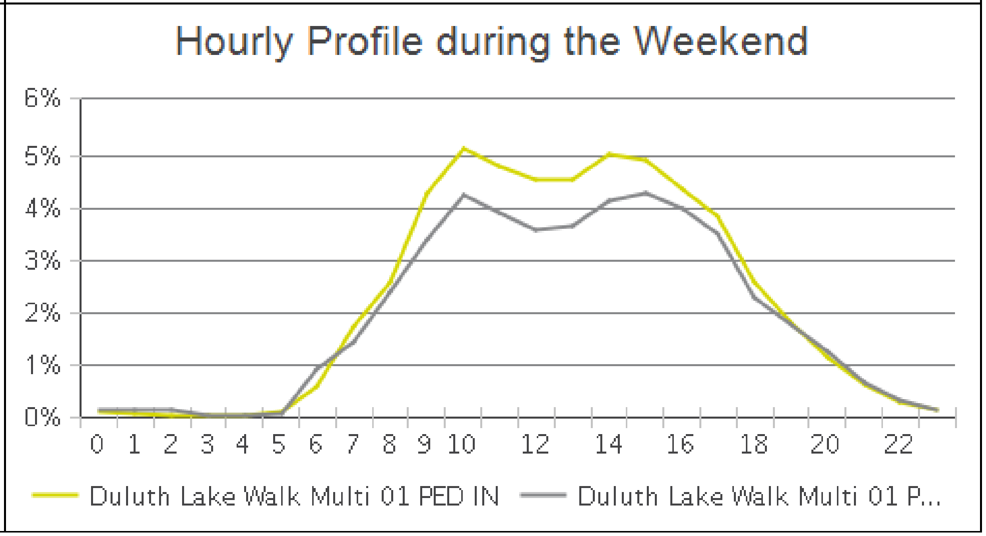
Duluth Lake Walk Multi 01 (Pedestrians)

Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015





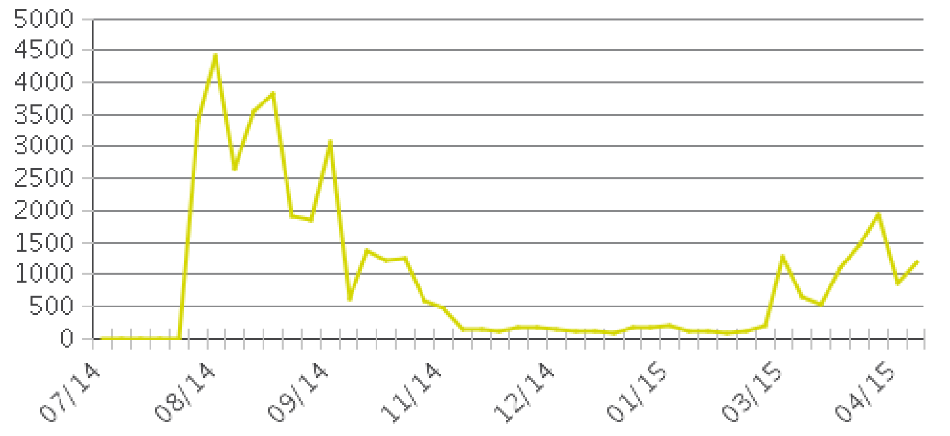




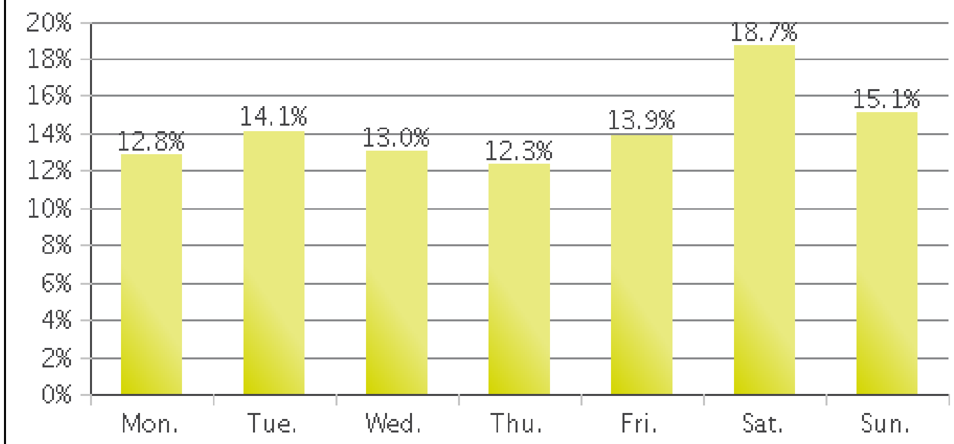
Duluth Lake Walk Multi 01 (Cyclists)

Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015

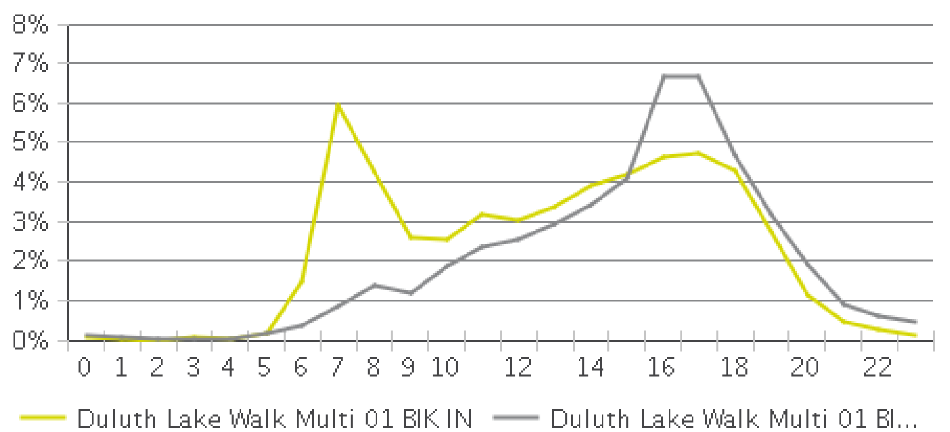
Weekly Traffic



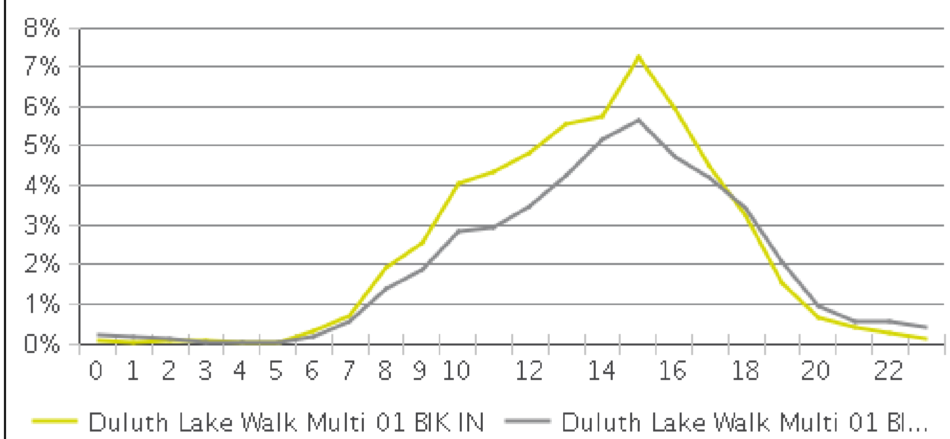
Weekly Profile



Hourly Profile during Weekdays



Hourly Profile during the Weekend



APPENDIX B:
DULUTH SCENIC 61 MONITORING RESULTS

Duluth - Scenic 61 #1

Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015

GPS coordinates not filled-in.
You can enter GPS coordinates in
the counter's Eco-Visio file.

No picture available.
You can add a picture
in the counter's Eco-Visio file.

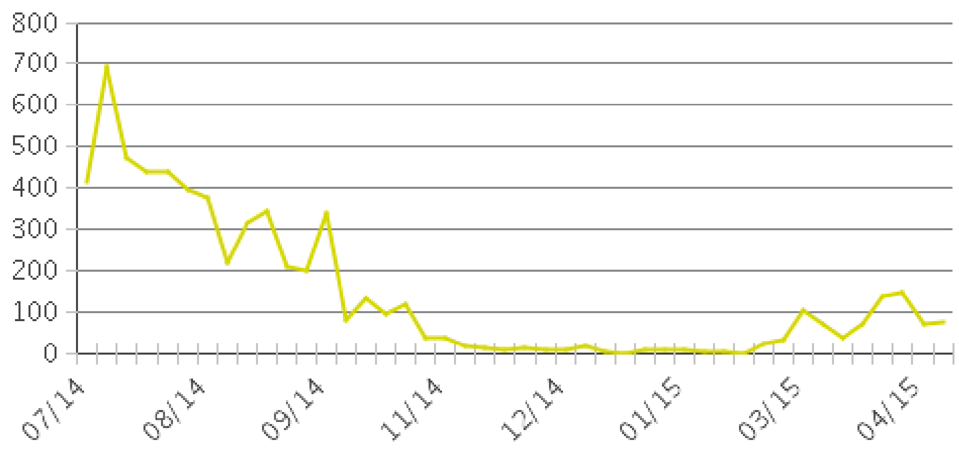
Key Figures

- Total Traffic for the Period Analyzed: 6,269
- Daily Average : 21
  - Max. Average Value (July) : 73
  - Min. Average Value (February) : 1
- Busiest Day of the Week : Saturday
- Busiest Days of the Period Analyzed:
  1. Wednesday 09 July 2014 (302)
  2. Saturday 19 July 2014 (122)
  3. Saturday 26 July 2014 (121)

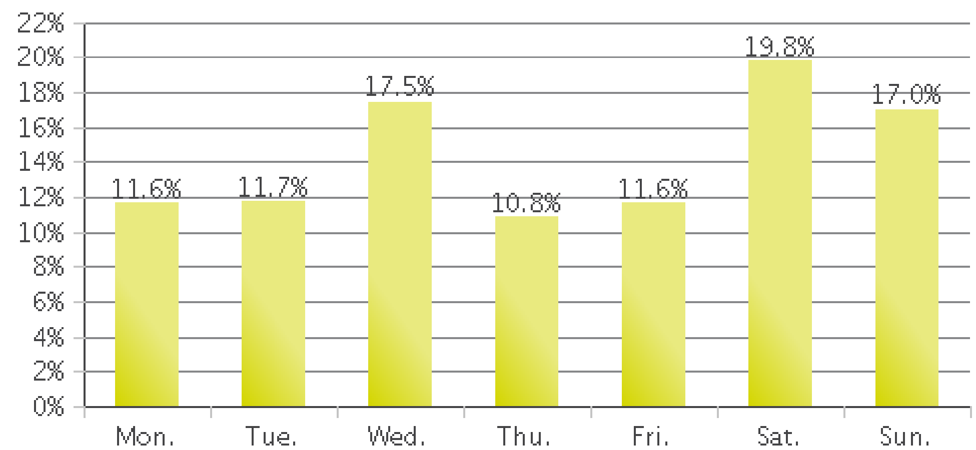
Duluth - Scenic 61 #1

Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015

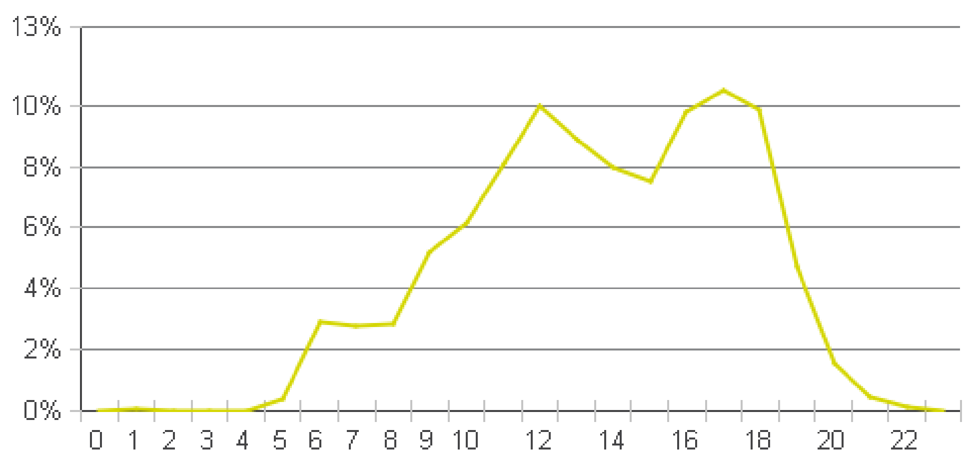
Weekly Traffic



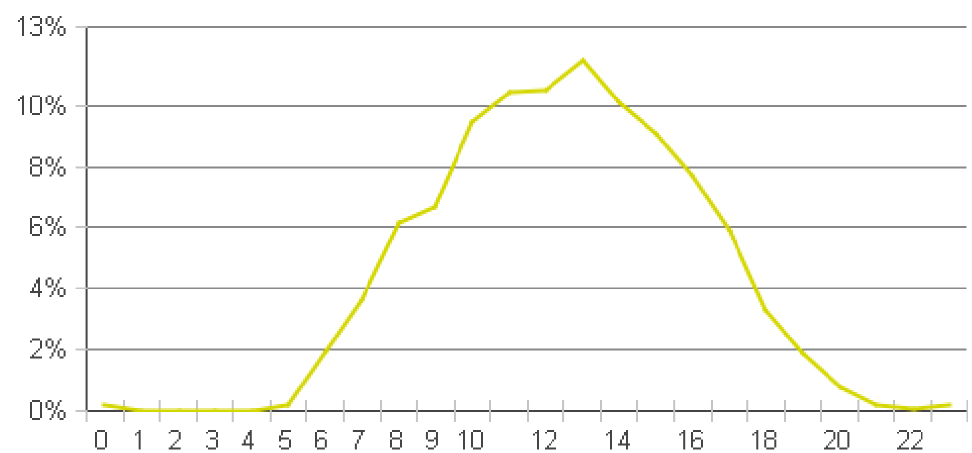
Weekly Profile



Hourly Profile during Weekdays



Hourly Profile during the Weekend



Duluth - Scenic 61 #2

Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015

GPS coordinates not filled-in.
You can enter GPS coordinates in
the counter's Eco-Visio file.

No picture available.
You can add a picture
in the counter's Eco-Visio file.

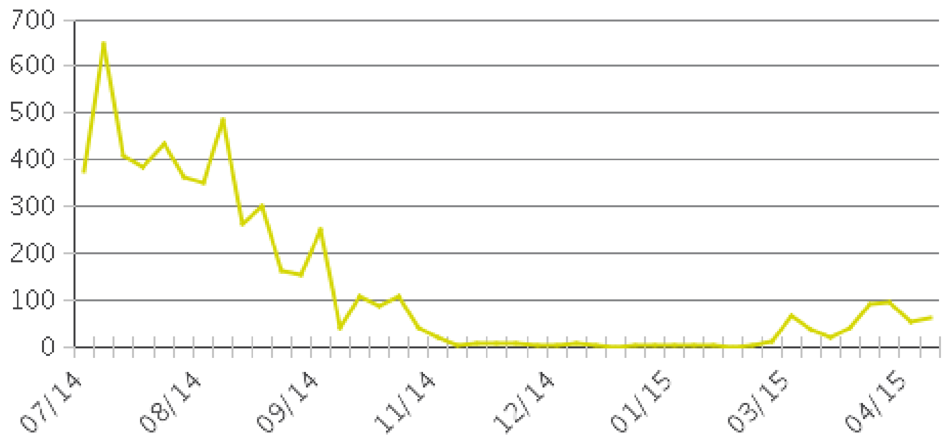
Key Figures

- Total Traffic for the Period Analyzed: 5,551
- Daily Average : 18
  - Max. Average Value (July) : 67
  - Min. Average Value (January) : 0
- Busiest Day of the Week : Sunday
- Busiest Days of the Period Analyzed:
  1. Sunday 24 August 2014 (317)
  2. Wednesday 09 July 2014 (280)
  3. Saturday 12 July 2014 (114)

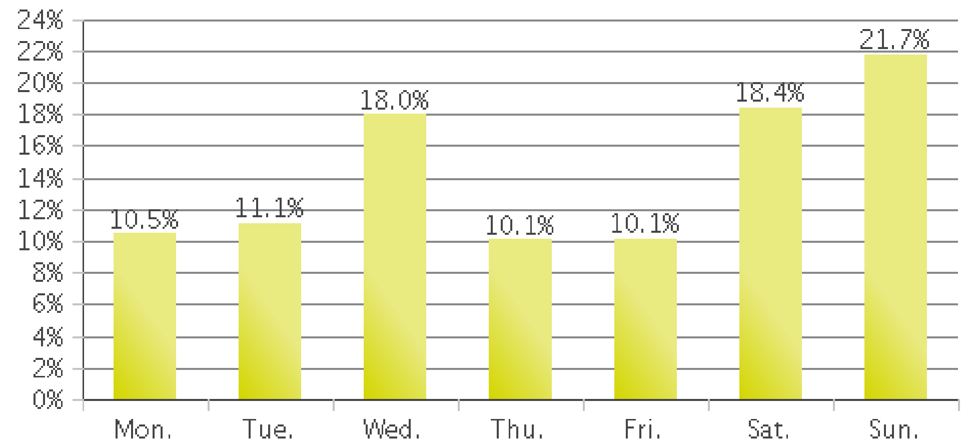
Duluth - Scenic 61 #2

Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015

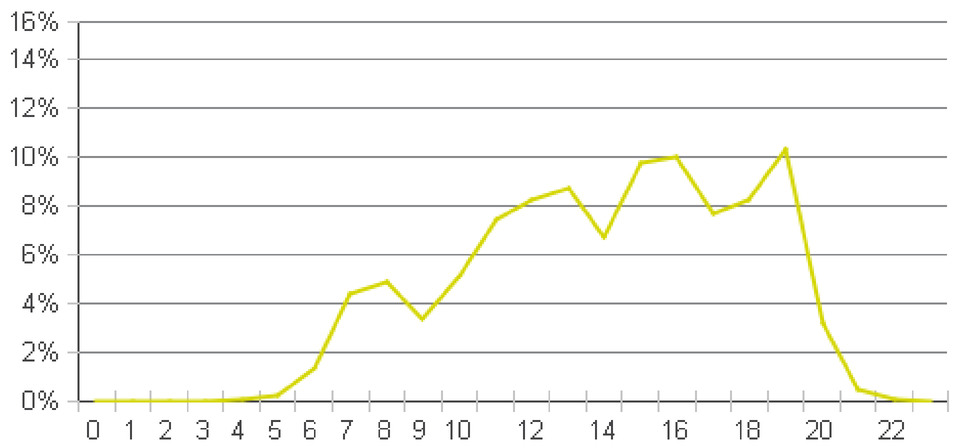
Weekly Traffic



Weekly Profile



Hourly Profile during Weekdays

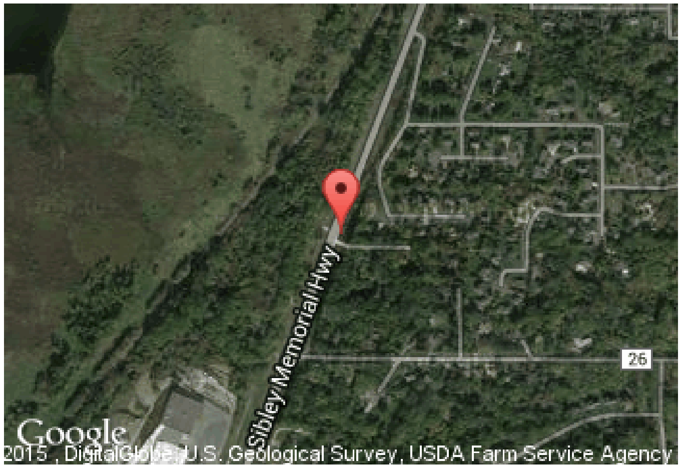


Hourly Profile during the Weekend

APPENDIX C:
EAGAN TRUNK HIGHWAY 13 MONITORING RESULTS

Eagan - TH 13 #1

Period Analyzed: Thursday 01 May 2014 to Thursday 30 April 2015



No picture available.
You can add a picture
in the counter's Eco-Visio file.

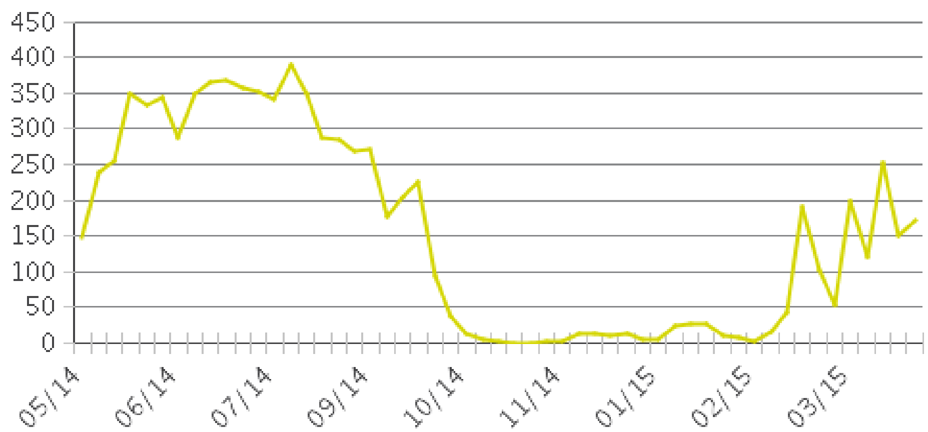
Key Figures

- Total Traffic for the Period Analyzed: 8,159
- Daily Average : 23
  - Max. Average Value (July) : 52
  - Min. Average Value (November) : 0
- Busiest Day of the Week : Saturday
- Busiest Days of the Period Analyzed:
  1. Sunday 08 June 2014 (89)
  2. Saturday 09 August 2014 (82)
  3. Wednesday 28 May 2014 (80)

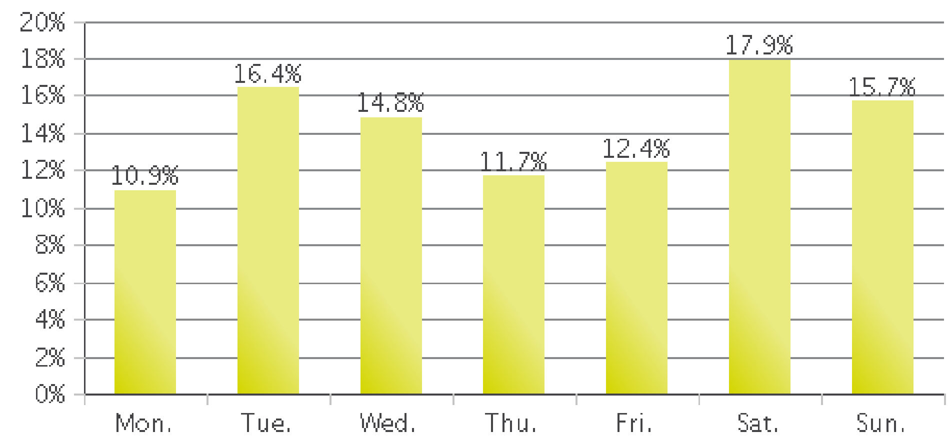
Eagan - TH 13 #1

Period Analyzed: Thursday 01 May 2014 to Thursday 30 April 2015

Weekly Traffic

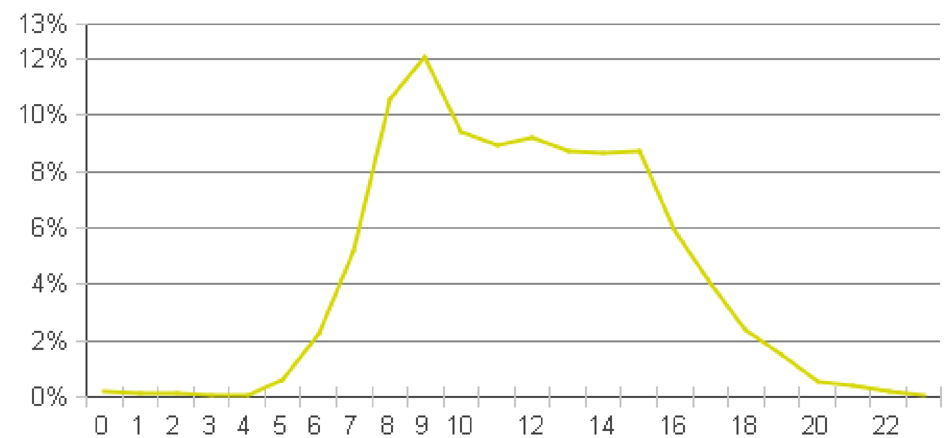


Weekly Profile



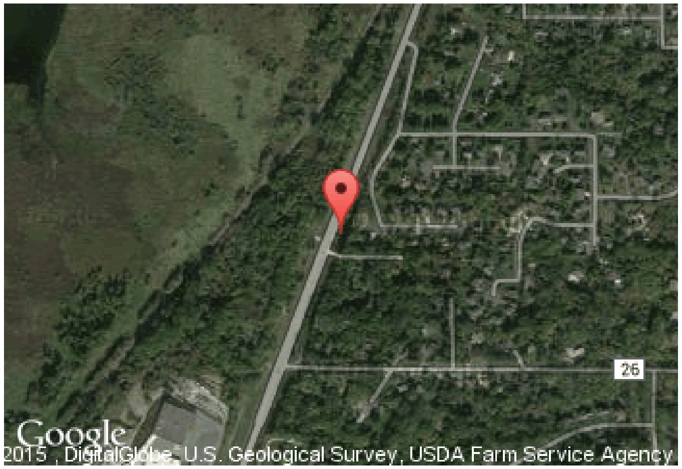
Hourly Profile during Weekdays

Hourly Profile during the Weekend



Eagan - TH 13 #2

Period Analyzed: Thursday 01 May 2014 to Thursday 30 April 2015



No picture available.
You can add a picture
in the counter's Eco-Visio file.

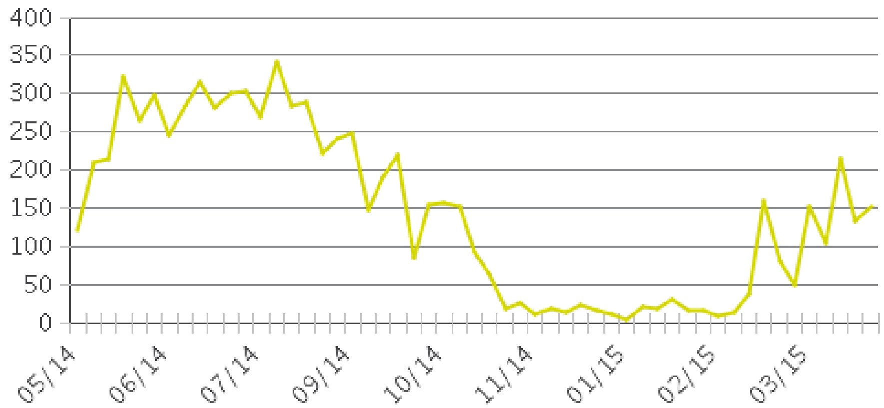
Key Figures

- Total Traffic for the Period Analyzed: 7,695
- Daily Average : 21
    - Max. Average Value (July) : 43
    - Min. Average Value (February) : 2
- Busiest Day of the Week : Tuesday
- Busiest Days of the Period Analyzed:
    1. Tuesday 10 June 2014 (74)
    2. Tuesday 29 July 2014 (73)
    3. Tuesday 20 May 2014 (72)

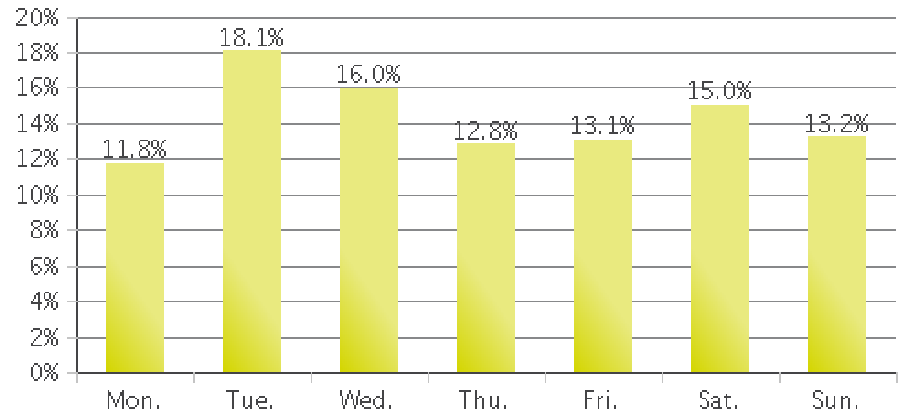
Eagan - TH 13 #2

Period Analyzed: Thursday 01 May 2014 to Thursday 30 April 2015

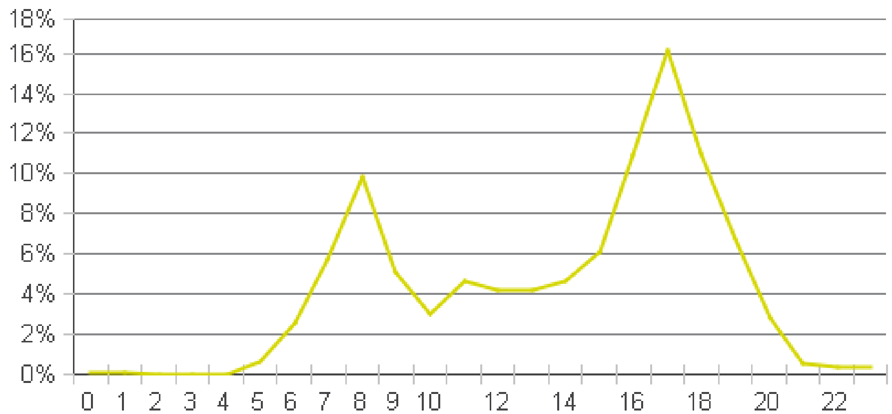
Weekly Traffic



Weekly Profile



Hourly Profile during Weekdays



Hourly Profile during the Weekend

APPENDIX D:
MINNEAPOLIS CENTRAL AVENUE MONITORING RESULTS

Minneapolis - Central Avenue NB #1

Period Analyzed: Thursday 01 May 2014 to Thursday 30 April 2015

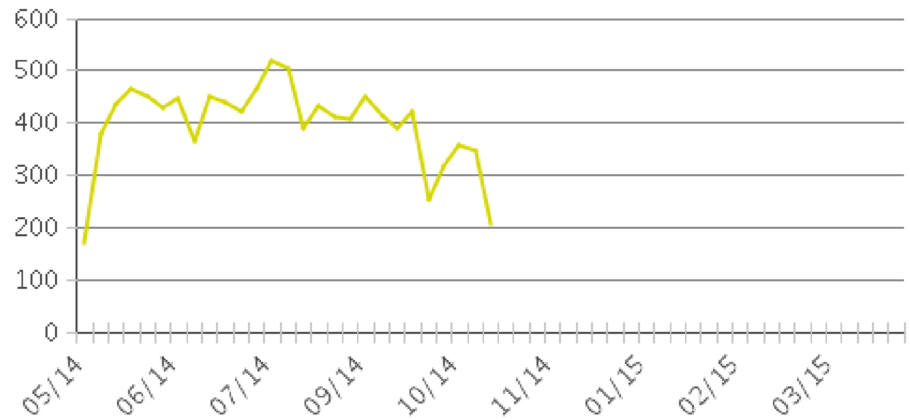
Key Figures

- Total Traffic for the Period Analyzed: 13,336
- Daily Average : 37
  - Max. Average Value (July) : 61
  - Min. Average Value (February) : 8
- Busiest Day of the Week : Saturday
- Busiest Days of the Period Analyzed:
  1. Sunday 27 July 2014 (121)
  2. Saturday 17 May 2014 (104)
  3. Sunday 18 May 2014 (93)

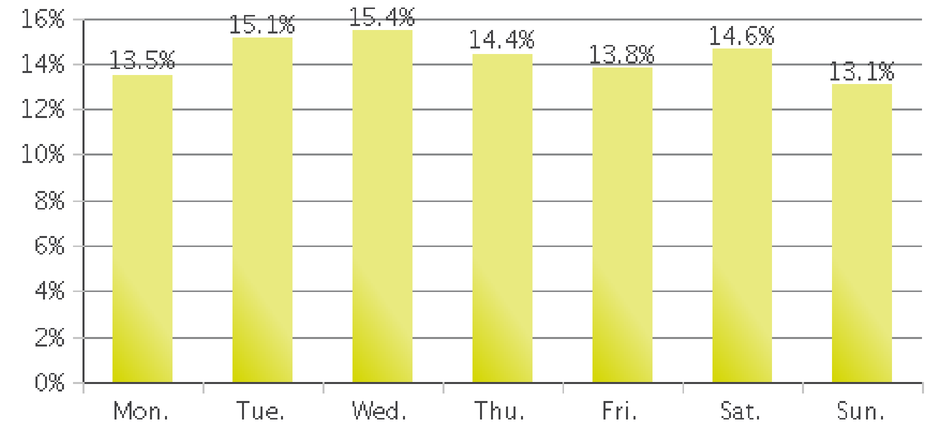
Minneapolis - Central Avenue SB #2

Period Analyzed: Thursday 01 May 2014 to Thursday 30 April 2015

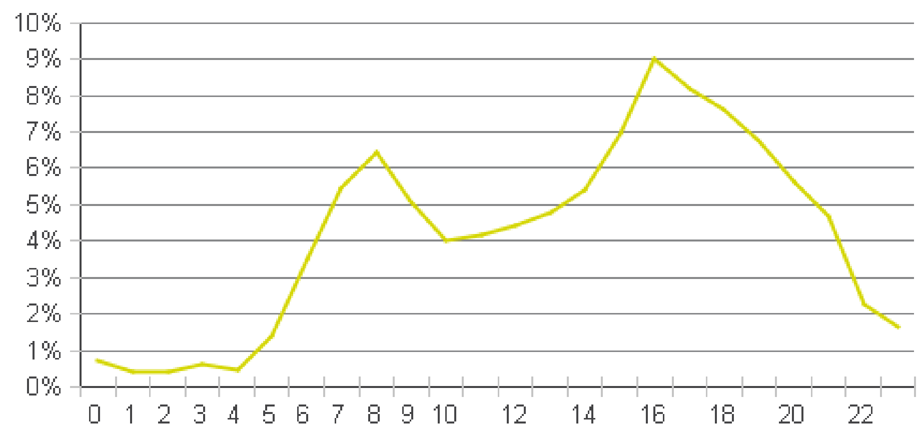
Weekly Traffic



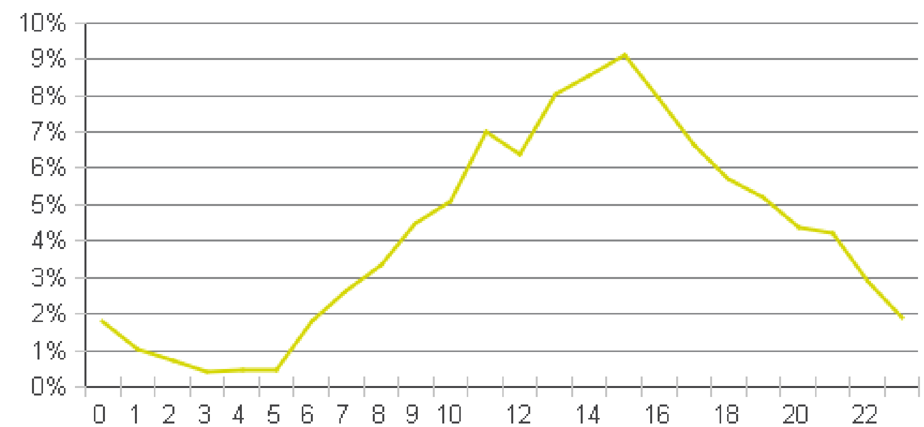
Weekly Profile



Hourly Profile during Weekdays



Hourly Profile during the Weekend



Minneapolis - Central Avenue SB #2

Period Analyzed: Thursday 01 May 2014 to Thursday 30 April 2015

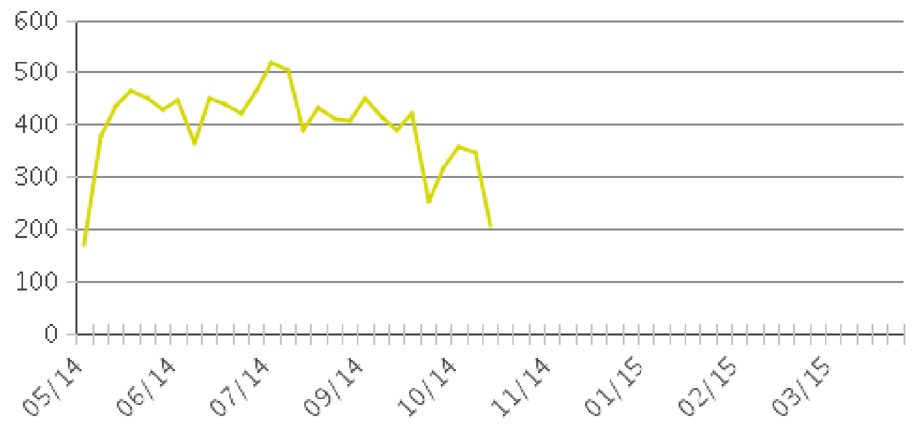
Key Figures

- Total Traffic for the Period Analyzed: 10,766
- Daily Average : 58
    - Max. Average Value (July) : 67
    - Min. Average Value (November) : 26
- Busiest Day of the Week : Wednesday
- Busiest Days of the Period Analyzed:
    1. Sunday 27 July 2014 (144)
    2. Saturday 17 May 2014 (136)
    3. Wednesday 28 May 2014 (96)

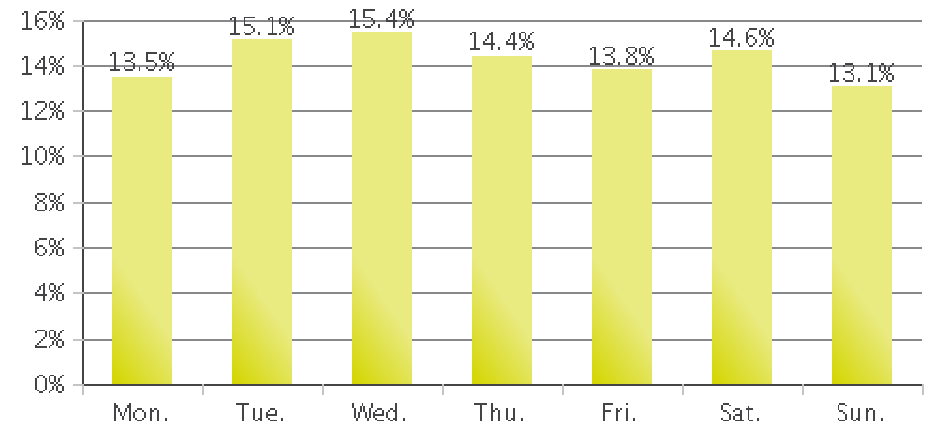
Minneapolis - Central Avenue SB #2

Period Analyzed: Thursday 01 May 2014 to Thursday 30 April 2015

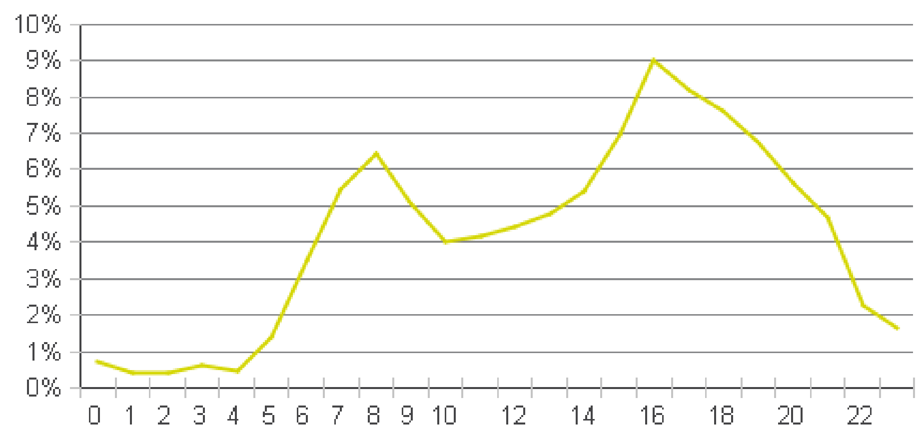
Weekly Traffic



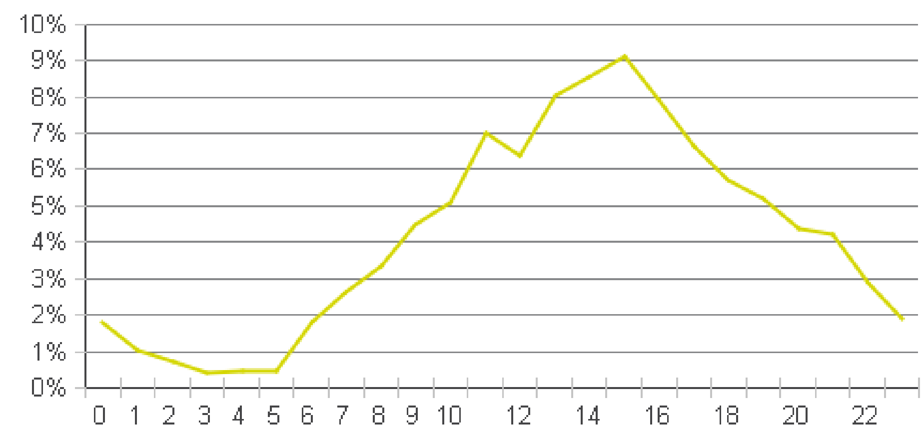
Weekly Profile



Hourly Profile during Weekdays



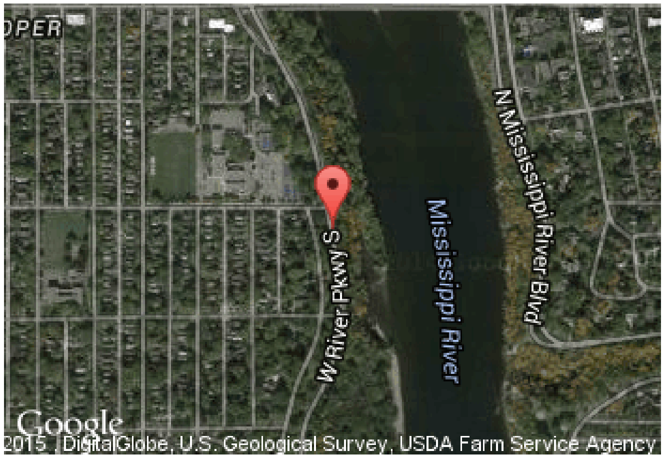
Hourly Profile during the Weekend



APPENDIX E:
MINNEAPOLIS W. RIVER PARKWAY TRAIL MONITORING RESULTS

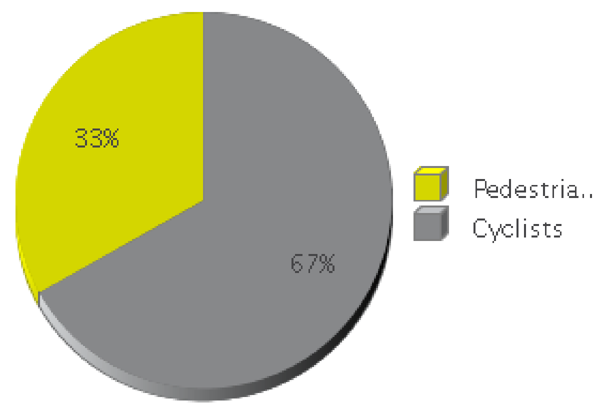
W. River Greenway

Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015



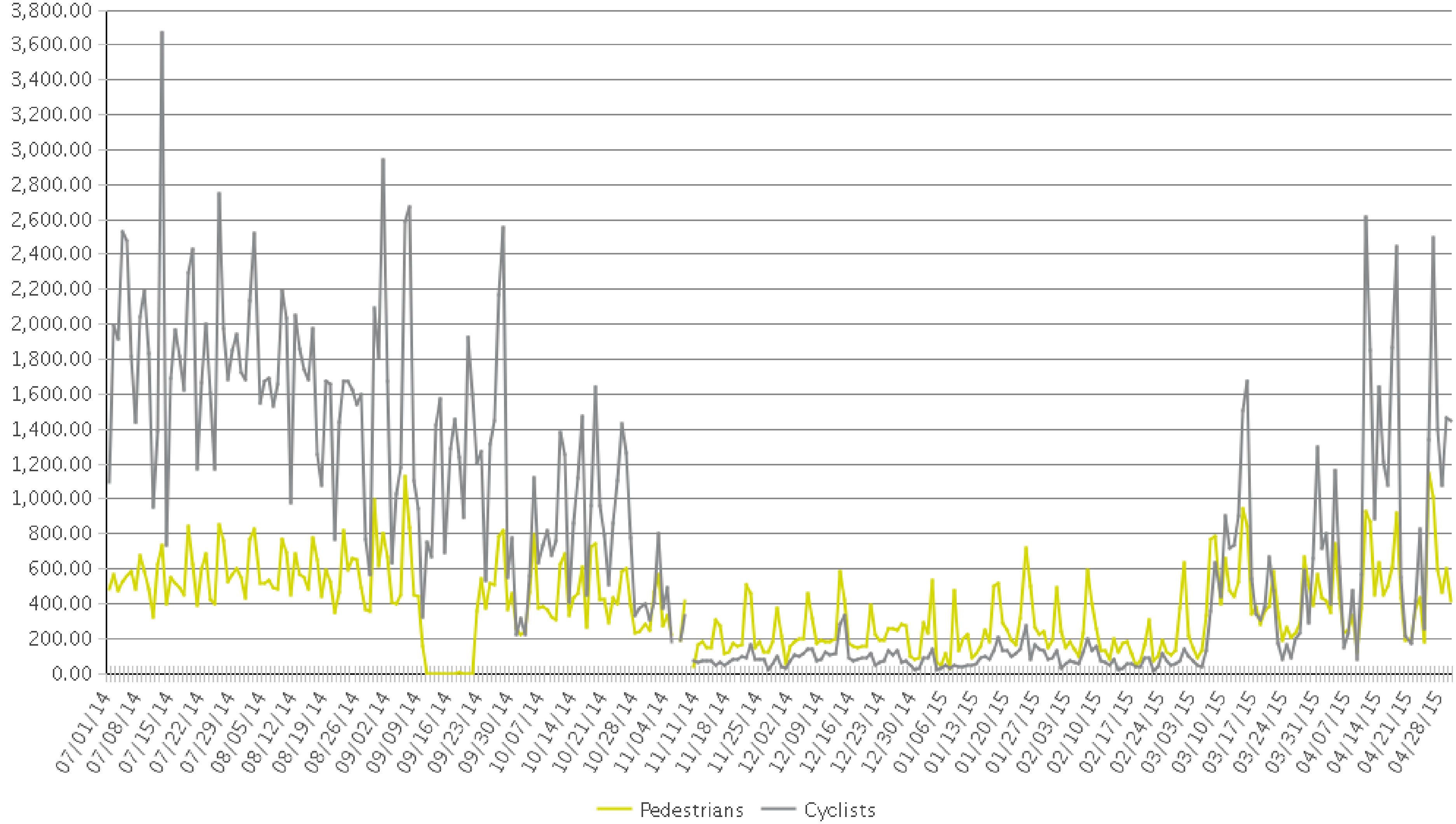
No picture available.
You can add a picture in the counter's Eco-Visio file.

	Total Traffic for the Analyzed Period	Daily Average	Busiest Day of the Week	Busiest Month of the Year	Distribution	
					IN	OUT
Pedestrians	114,634	380	Saturday	August 14 : 18,155	47	53
Cyclists	230,908	765	Sunday	July 14 : 57,476	48	52



W. River Greenway

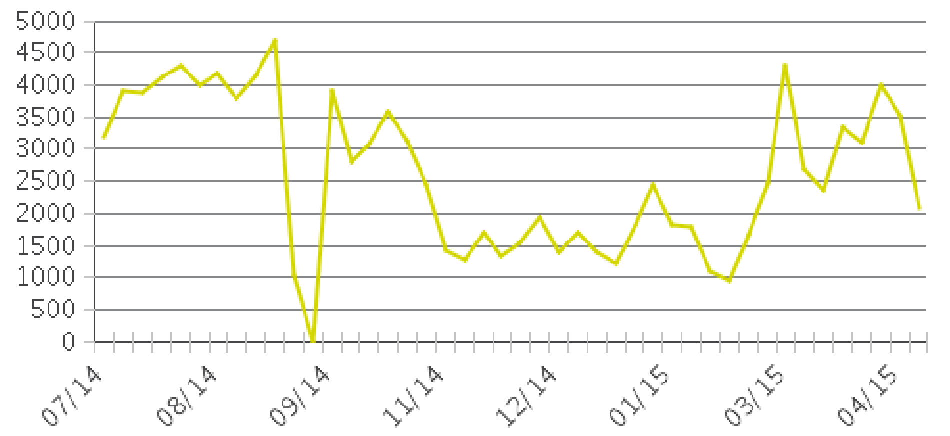
Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015



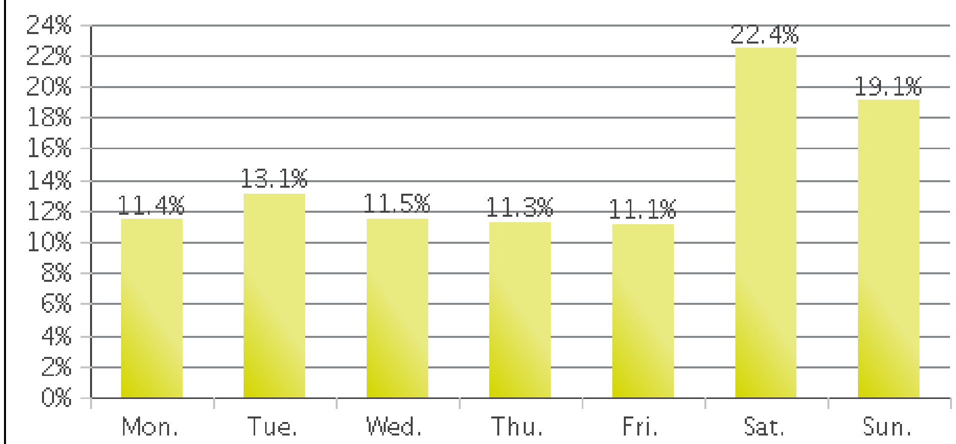
W. River Greenway (Pedestrians)

Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015

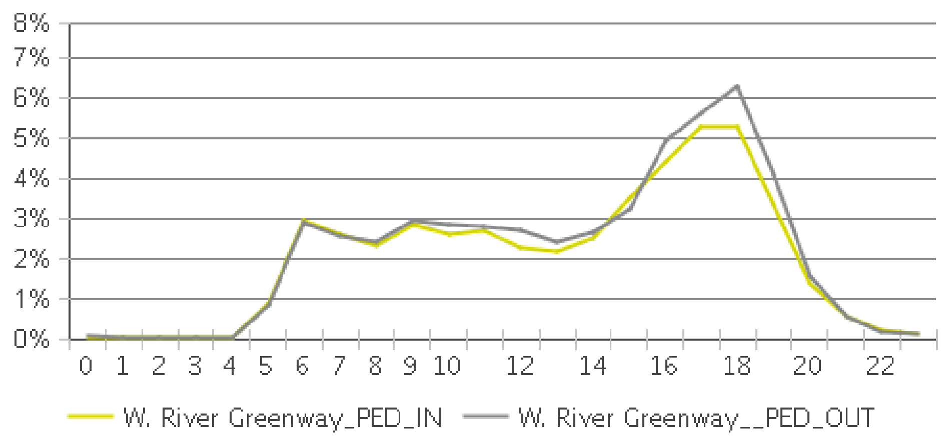
Weekly Traffic



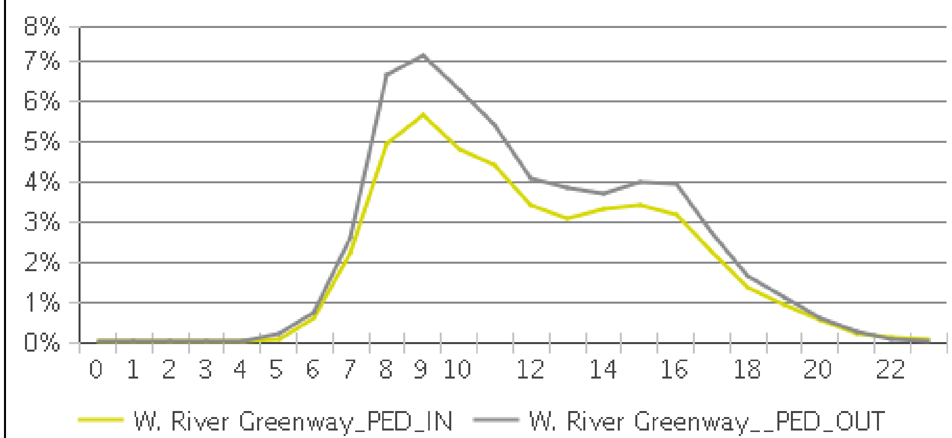
Weekly Profile



Hourly Profile during Weekdays



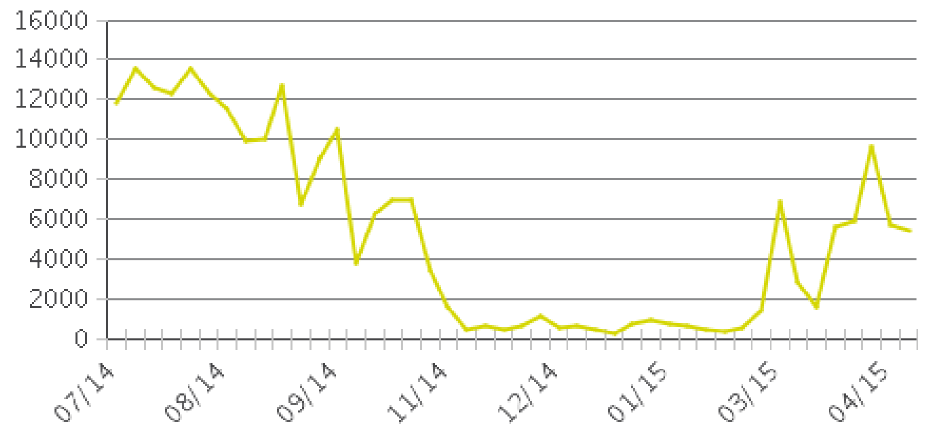
Hourly Profile during the Weekend



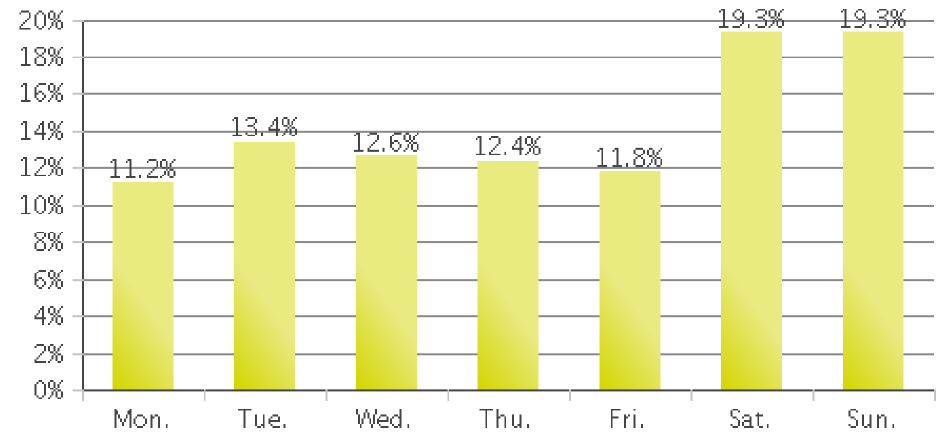
W. River Greenway (Cyclists)

Period Analyzed: Tuesday 01 July 2014 to Thursday 30 April 2015

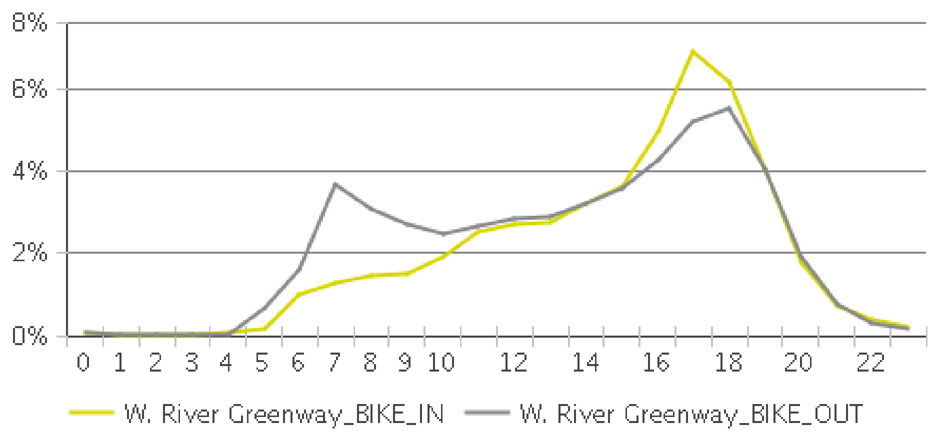
Weekly Traffic



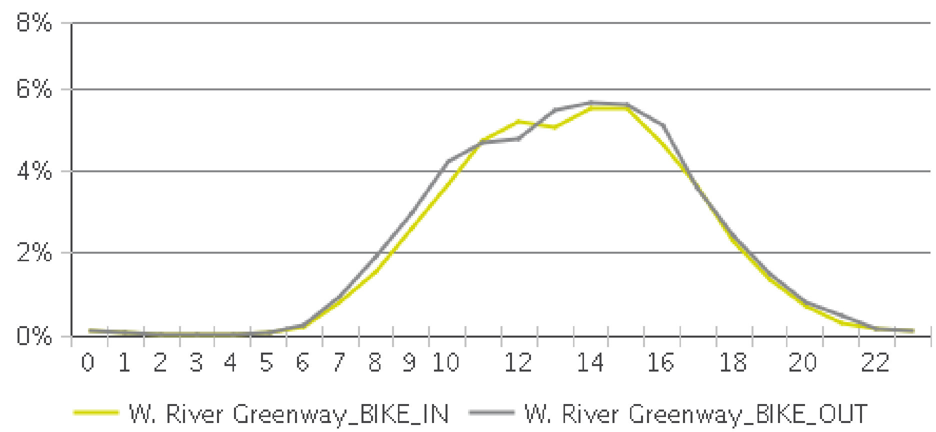
Weekly Profile



Hourly Profile during Weekdays



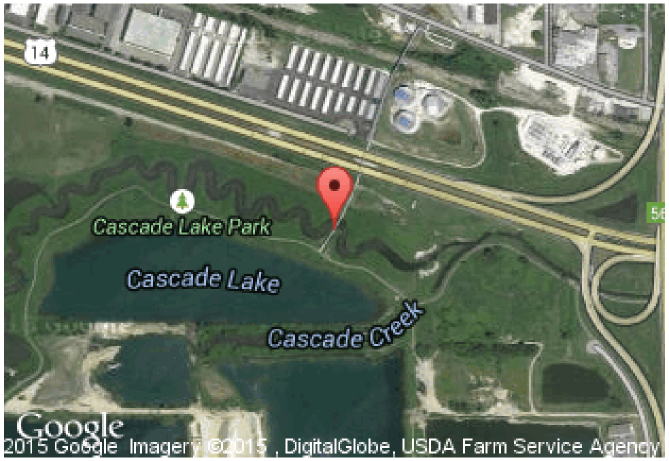
Hourly Profile during the Weekend



APPENDIX F:
ROCHESTER TRAIL MONISTORING RESULTS

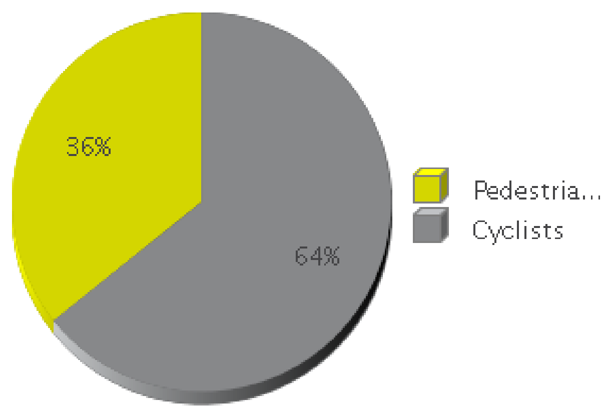
Rochester Multi 02

Period Analyzed: Sunday 01 June 2014 to Thursday 30 April 2015



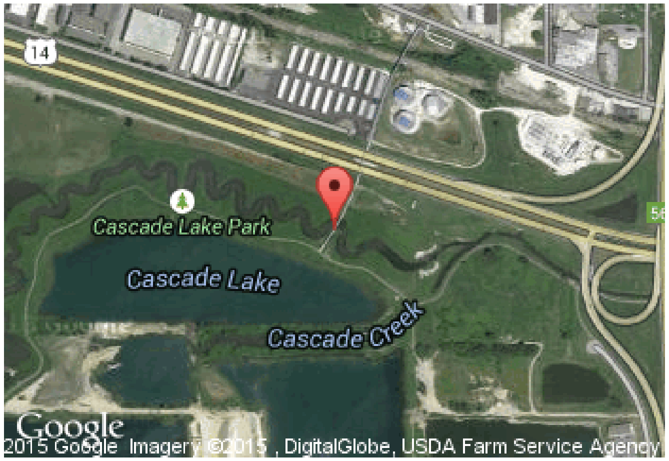
	Total Traffic for the Analyzed Period	Daily Average	Busiest Day of the Week	Busiest Month of the Year	Distribution	
					IN	OUT
Pedestrians	19,979	71	Saturday	June 14 : 4,479	62	38
Cyclists	35,882	128	Sunday	July 14 : 9,523	50	50

No picture available.
You can add a picture in the counter's Eco-Visio file.



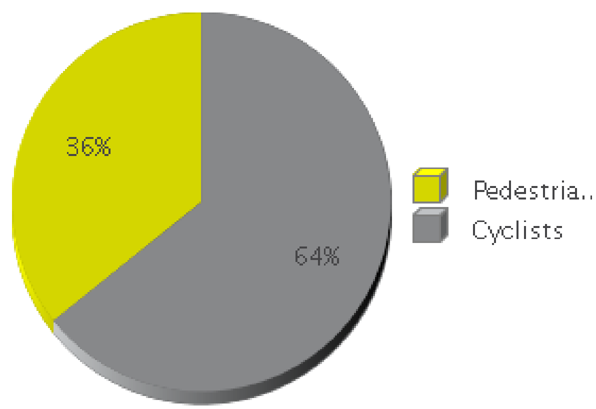
Rochester Multi 02

Period Analyzed: Sunday 01 June 2014 to Thursday 30 April 2015



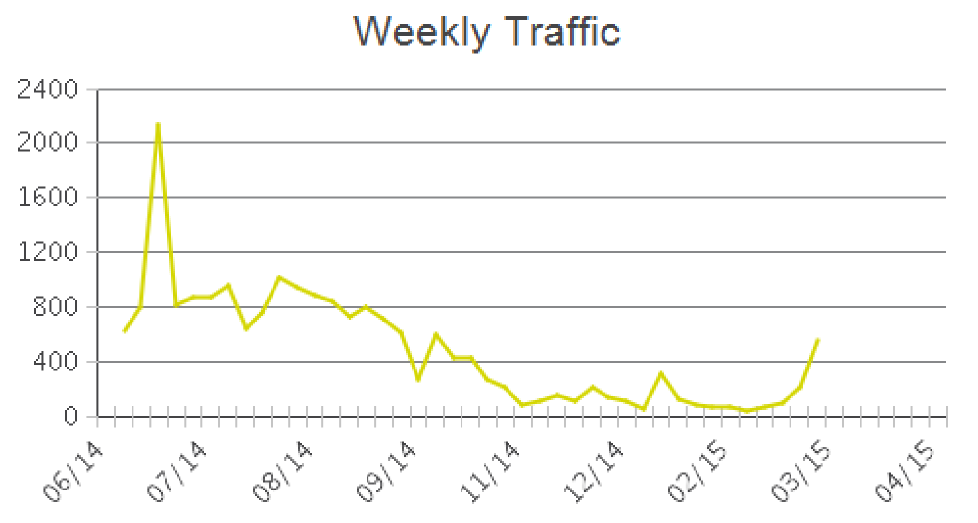
No picture available.
You can add a picture in the counter's Eco-Visio file.

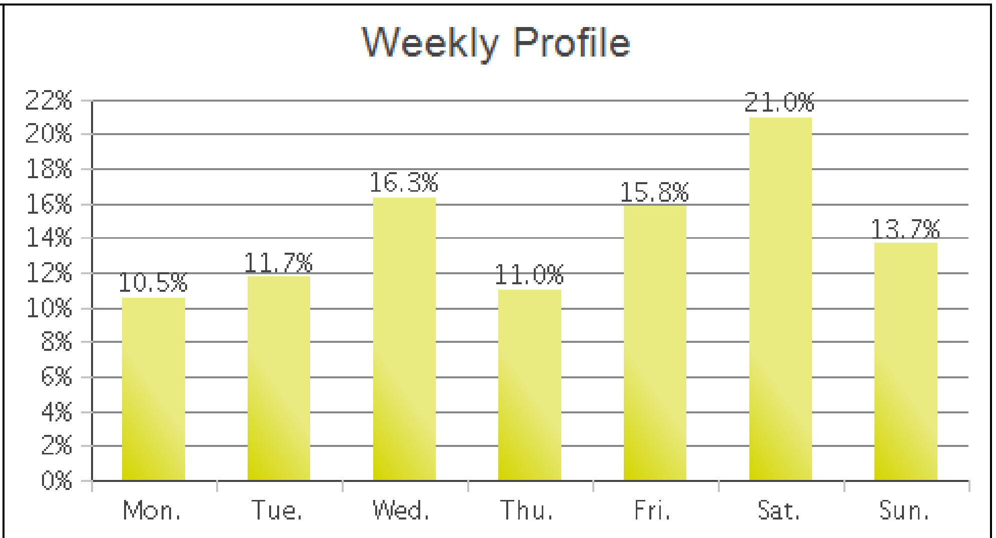
	Total Traffic for the Analyzed Period	Daily Average	Busiest Day of the Week	Busiest Month of the Year	Distribution	
					IN	OUT
Pedestrians	19,979	71	Saturday	June 14 : 4,479	62	38
Cyclists	35,882	128	Sunday	July 14 : 9,523	50	50

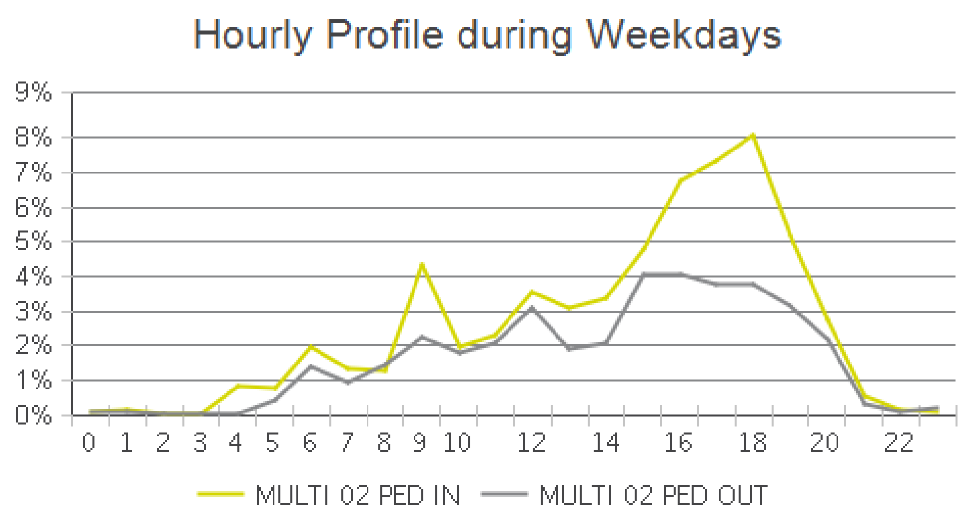


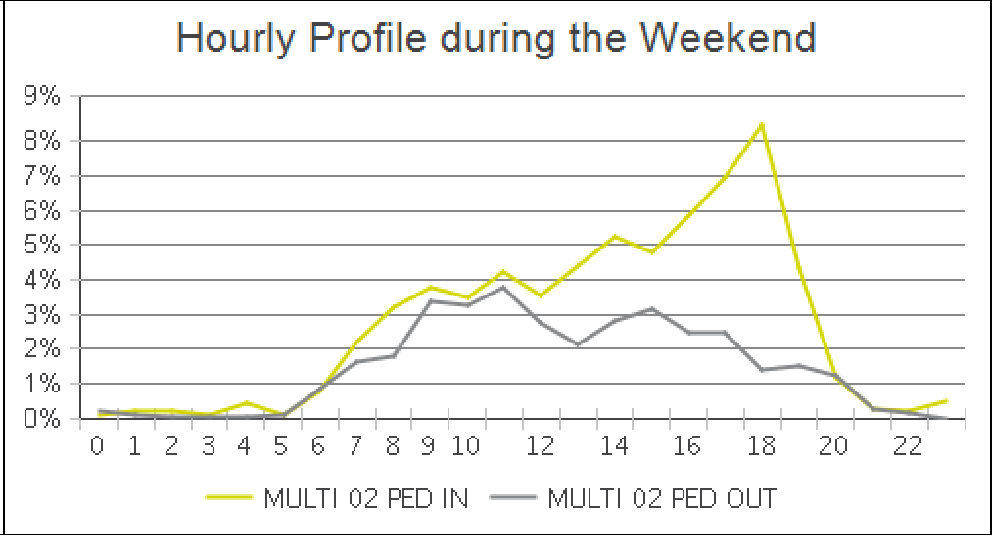
Rochester Multi 02 (Pedestrians)

Period Analyzed: Sunday 01 June 2014 to Thursday 30 April 2015



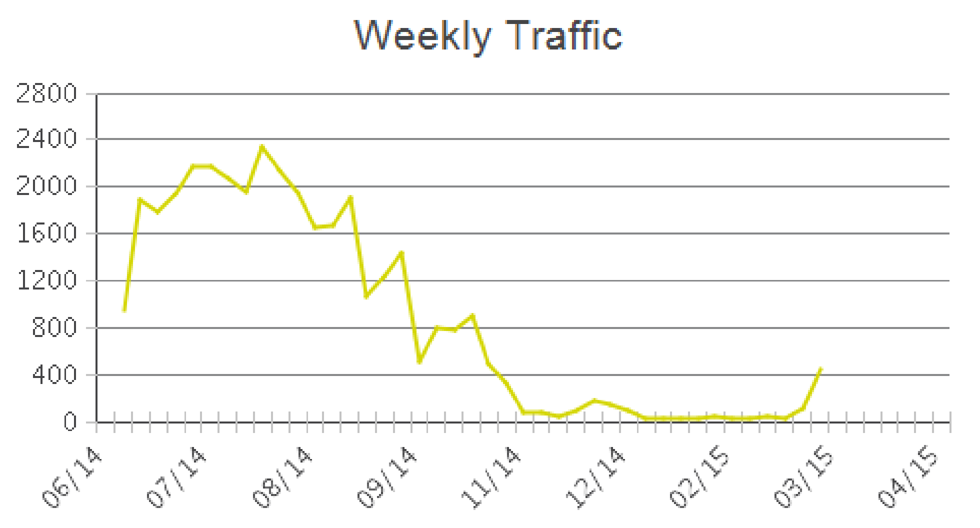


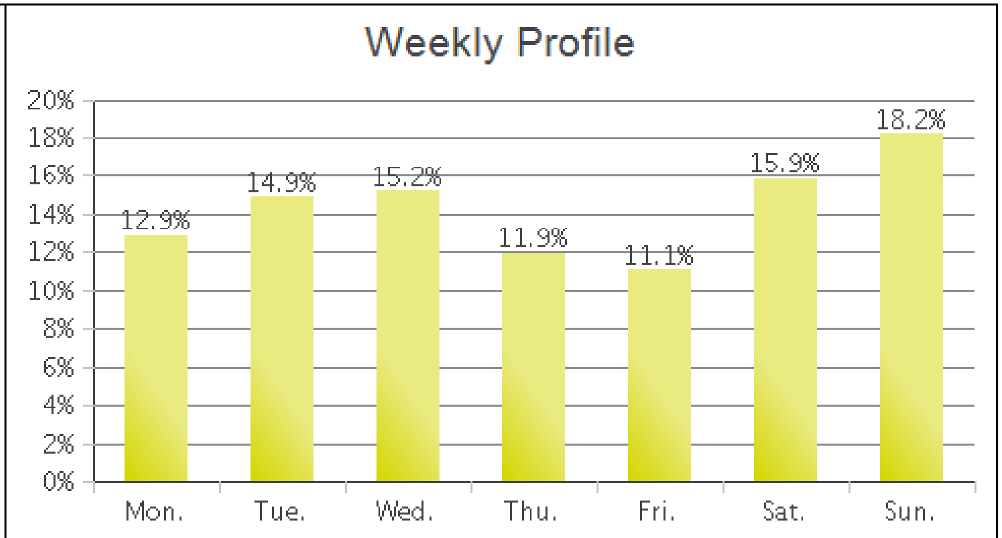


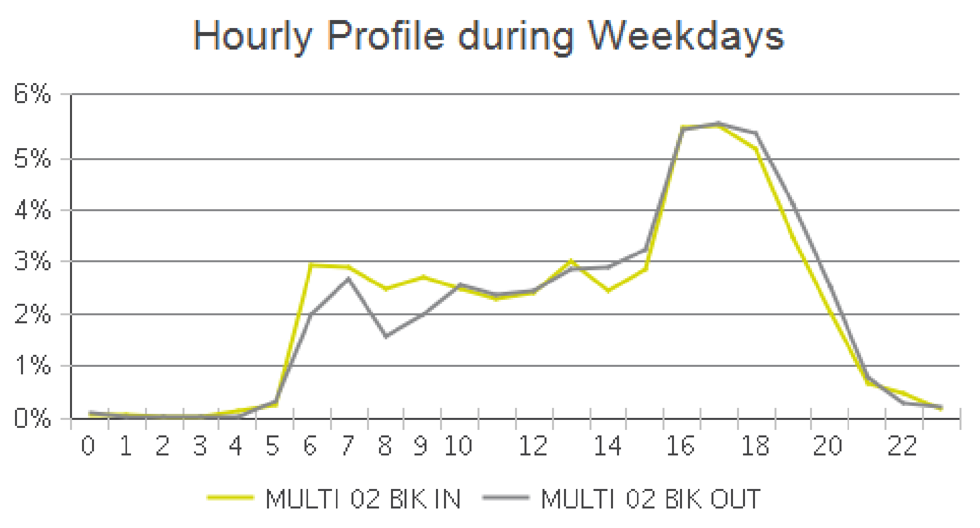


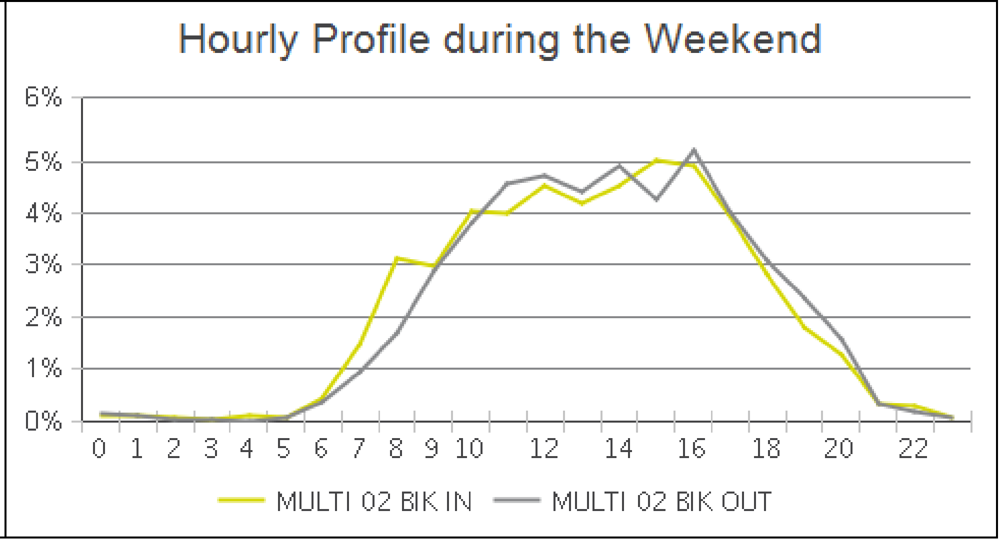
Rochester Multi 02 (Cyclists)

Period Analyzed: Sunday 01 June 2014 to Thursday 30 April 2015









APPENDIX G:
HENNEPIN COUNTY SHORT DURATION MONITORING RESULTS

Table 0.1. Bicycle and pedestrian count locations (2013)

Location	Bike Facility Type	County Location	Location ID & sensor type	Date Deployed	Date Removed	COUNTcam Data?	Data Retrieved?
Road & Streets							
1. CSAH 3 (Excelsior Blvd), W of CSAH 61 (Shady Oak Rd), Minnetonka	On-road bikeway (shoulder)	2nd Ring Suburban	MetroCount	9/26/2013	10/11/2013	Yes	Yes
2. CSAH 8 (W. Broadway St.), S of Lakeland Ave N, Robbinsdale	No bikeway, ADT >10,000	2nd Ring Suburban	MetroCount	10/25/2013	11/8/2013	No	Yes
3. CSAH 33 (Park Ave S), S of 3rd St S	On-road bikeway (bike lane)	Minneapolis	MetroCount	10/14/2013	10/25/2013	Yes	Yes
4. CSAH 35 A (Portland Ave S), S of 55th St E	On-road bikeway (bike lane)	Minneapolis	MetroCount	9/4/2013	9/17/2013	Yes	Yes
5. CSAH 35 B (Portland Ave S), S of 3rd St S Downtown	On-road bikeway (bike lane)	Minneapolis	MetroCount	10/14/2013	10/25/2013	Yes	Yes
6. CSAH 53 (66th St W), W of CSAH 52 (Nicollet Ave), Richfield	No bikeway, ADT >10,000	1st Ring Suburban	MetroCount	9/17/2013	9/26/2013	No	Yes
7. CSAH 66 (Broadway St NE), E of TH65 (Central Ave NE)	No bikeway, ADT >10,000	Minneapolis	MetroCount	9/6/2013	9/17/2013	Yes	Yes
Trails							
1. CSAH 5 (Minnetonka Blvd.), W of Honeywood Ln, Hopkins	Off-road Trail	2nd Ring Suburban	(a) MetroCount	10/17/2013	11/1/2013	No	Yes
			(b) Chambers	10/17/2013	11/1/2013	No	Yes
2. CSAH 19 S of Larsen Rd, Corcoran	Off-Road Trail	Rural	MetroCount	11/2/13	11/7/13	No	Yes
3. CSAH 27 (Stinson Blvd NE), N of CSAH 52 (Hennepin Ave NE)	Off-road Trail	Minneapolis	(a) MetroCount	9/20/2013	9/29/2013	Yes	Yes
			(b) Chambers	9/20/2013	9/23/2013	Yes	No
			(c) Chambers	9/23/2013	9/27/2013	No	Yes
4. Shingle Creek Parkway, W of CSAH 10 (Bass Lake Rd), Brooklyn Center	Off-road Trail	1st Ring Suburban	(a) MetroCount	10/14/2013	10/25/2013	No	Yes
			(b) Chambers	10/14/2013	10/25/2013	No	Yes

Table 0.2. Summary of ARXm Scheme Data (2013)

	CSAH 3 (Excelsior Blvd), W of CSAH 61 (Shady Oak Rd), Minnetonka	CSAH 35 A (Portland Ave S), S of 55th St E	CSAH 35 B (Portland Ave S), S of 3rd St S Downtown	CSAH 53 (66th St W), W of CSAH 52 (Nicollet Ave), Richfield	CSAH 66 (Broadway St NE), E of TH65 (Central Ave NE)	CSAH 5 (Minnetonka Blvd.), W of Honeywood Ln, Hopkins	CSAH 19 S of Larsen Rd, Corcoran	CSAH 27 (Stinson Blvd NE), N of CSAH 52 (Hennepin Ave NE)	Shingle Creek Parkway, W of CSAH 10 (Bass Lake Rd), Brooklyn Center
Off-Road Trail?						TR	TR	TR	TR
Complete Days	14	8	10 (1)*	8	10	14	6	8	10
Mean Daily Bike Count	37.5	161.8	**	10.9	85.2	0.3	2.5	262.6	11.8
Direction 1 (N or E)	18.1	78.9	65.0	4.6	31.2	0.0	1.7	144.8	6.4
Direction 2 (S or W)	19.4	82.9	141.9	6.3	54.0	0.3	0.8	117.9	5.4
Daily Bike %	0.4	1.8	25.6***	0.1	0.5	20.0	88.2	95.3	94.4
Mean WD Bike Count	38.0	174.7	**	11.7	102.7	0.4	0.3	323.2	12.1
Direction 1 (N or E)	18.7	84.5	65.0	5.0	33.3	0.0	0.3	177.6	6.9
Direction 2 (S or W)	19.3	90.2	158.1	6.7	69.3	0.4	0.0	145.6	5.3
WD Bike %	0.3	1.8	26.7***	0.1	0.5	21.1	50.0	96.7	94.2
Mean WE Bike Count	36.3	123.0	**	8.5	59.0	0.0	7.0	161.7	10.5
Direction 1 (N or E)	16.8	62.0	**	3.5	28.0	0.0	4.5	90.0	4.5
Direction 2 (S or W)	19.5	61.0	77.0	5.0	31.0	0.0	2.5	71.7	6.0
WE Bike %	0.5	1.5	19.2***	0.1	0.5	0.0	93.3	91.2	95.5
WWI	0.96	0.70	0.49***	0.73	0.57	0.00	23.33	0.50	0.87
AMI	0.98	1.68	1.90***	0.88	0.74	n/c	0.5	1.52	0.90
Bike Traffic Classification	Mixed	Utilitarian	Utilitarian	Mixed	Mixed	N/A	Recreatio nal	Utilitarian	Mixed

* 10 days southbound, 1 day northbound
** Not computed: bi-directional data available for 1 of 10 days
*** Computed for southbound traffic only
****Table 2 shows nine of the 11 locations in Table 1 because CSAH 33 and CSAH 8 were excluded since only one or fewer days of complete days of data were collected from those locations.

Table 0.3. Summary of BOCO Scheme Data (2013)

	CSAH 3 (Excelsior Blvd), W of CSAH 61 (Shady Oak Rd), Minnetonka	CSAH 35 A (Portland Ave S), S of 55th St E	CSAH 35 B (Portland Ave S), S of 3rd St S Downtown	CSAH 53 (66th St W), W of CSAH 52 (Nicollet Ave), Richfield	CSAH 66 (Broadway St NE), E of TH65 (Central Ave NE)	CSAH 5 (Minnetonka Blvd.), W of Honeywood Ln, Hopkins	CSAH 19 S of Larsen Rd, Corcoran	CSAH 27 (Stinson Blvd NE), N of CSAH 52 (Hennepin Ave NE)	Shingle Creek Parkway, W of CSAH 10 (Bass Lake Rd), Brooklyn Center
Off-Road Trail?						TR	TR	TR	TR
Complete Days	14	8	10 (1)*	8	8	14	6	8	10
Mean Daily Bike Count	59.0	190.6	**	40.3	151.7	0.3	2.5	287.3	12.2
Direction 1 (N or E)	35.7	94.0	66	14.0	74.0	0.0	1.7	157.0	6.5
Direction 2 (S or W)	23.3	96.6	152	26.3	77.7	0.3	0.8	130.3	5.7
Daily Bike %	0.6	2.1	27.1***	0.2	0.9	20.0	88.2	94.7	92.4
Mean WD Bike Count	61.6	202.2	**	44.8	173.5	0.4	0.3	344.0	12.6
Direction 1 (N or E)	39.0	98.5	66	15.2	82.8	0.0	0.3	189.4	7.1
Direction 2 (S or W)	22.6	103.7	168	29.7	90.7	0.4	0.0	154.6	5.5
WD Bike %	0.5	2.1	28.2***	0.3	0.9	21.0	50.0	96.1	93.5
Mean WE Bike Count	52.5	156.0	**	26.5	119.0	0.0	7.0	192.7	10.5
Direction 1 (N or E)	27.5	80.5	**	10.5	60.8	0.0	4.5	103.0	4.0
Direction 2 (S or W)	25.0	75.5	84.5	16.0	58.3	0.0	2.5	89.7	6.5
WE Bike %	0.7	1.9	20.8***	0.2	1.0	0.0	93.3	90.9	87.5
WWI	0.85	0.77	0.50***	0.59	0.69	0.00	23.33	0.56	0.83
AMI	0.90	1.52	1.83***	1.29	0.81	n/c	0.50	1.42	0.82
Bike Traffic Classification	Mixed	Utilitarian	Utilitarian	Mixed	Mixed	N/A	Recreational	Utilitarian	Mixed

* 10 days southbound, 1 day northbound
** Not computed: bi-directional data available for 1 of 10 days
*** Computed for southbound traffic only
****Table 2 shows nine of the 11 locations in Table 1 because CSAH 33 and CSAH 8 were excluded since only one or fewer days of complete days of data were collected from those locations.

Table 0.4. ARXm and BOCO Summary Data (2013)

	CSAH 3 (Excelsior Blvd), W of CSAH 61 (Shady Oak Rd), Minnetonka	CSAH 35 A (Portland Ave S), S of 55th St E	CSAH 35 B (Portland Ave S), S of 3rd St S Downtown	CSAH 53 (66th St W), W of CSAH 52 (Nicollet Ave), Richfield	CSAH 66 (Broadway St NE), E of TH65 (Central Ave NE)	CSAH 5 (Minnetonka Blvd.), W of Honeywood Ln, Hopkins	CSAH 19 S of Larsen Rd, Corcoran	CSAH 27 (Stinson Blvd NE), N of CSAH 52 (Hennepin Ave NE)	Shingle Creek Parkway, W of CSAH 10 (Bass Lake Rd), Brooklyn Center
Complete Days	14	8	10.0	8	10	14	6	8	10
ARXm Mean Daily Bike Count	37.5	161.8	**	10.9	85.2	0.3	2.5	262.6	11.8
BOCO Mean Daily Bike Count	59.0	190.6	**	40.3	151.7	0.3	2.5	287.3	12.2

*Table 2 shows nine of the 11 locations in Table 1 because CSAH 33 and CSAH 8 were excluded since only one or fewer days of complete days of data were collected from those locations.

Table 0.5. Bicycle and Pedestrian Count Locations (2014)

Location	Bike Facility Type	County Location	Sensor Type	Date Deployed	Date Removed	COUNTcam Data?	Data Retrieved?	Complete Days of Data
Roads & Streets								
1. 15th Ave SE N of CSAH 36 (University Ave SE)	On-road bikeway (shoulder)	Minneapolis	(a) TimeMark (Northbound bike lane)	10/3/2014	10/7/2014	Yes	Yes	3
			(b) TimeMark (Southbound bike lane)					3
2. CSAH 33 (Park Ave) S of 3rd Ave S (Downtown)	On-road bikeway (bike lane)	Minneapolis	MetroCount	4/15/2014	4/18/2014	No	Yes	2
3. CSAH 35 (Portland Ave S) S of E 28th St	On-road bikeway (shoulder)	Minneapolis	(a) TimeMark (6' spacing)	7/24/2014	8/1/2014	Yes	Yes	8
			(b) TimeMark (10' spacing)	7/24/2014	8/1/2014	Yes	Yes	8
4. CSAH 36 (University Ave Se) E of 10th Ave SE	On-road bikeway (bike lane)	Minneapolis	(a) MetroCount (All traffic lanes)	6/17/2014	6/23/2014	Yes	Yes	6
			(b) MetroCount (Bike lane & S traffic lane)	6/18/2014	6/26/2014			7
			(c)TimeMark (Bike lane & S traffic lane)	6/18/2014	6/26/2014			7
			(d) TimeMark (All traffic lanes)	6/18/2014	6/26/2014			8
5. CSAH 40 (Glenwood Ave) E of Xerxes Ave N	On-road bikeway (bike lane)	Minneapolis	(a) TimeMark (6' spacing)	7/11/2014	7/15/2014	No	Yes	3
			(b) TimeMark (10' spacing)					3
6. CSAH 152 (Washington Ave) E of TH 65 (3rd Ave S)	No bikeway, ADT >10,000	Minneapolis	(a) TimeMark (Eastbound)	6/26/2014	6/30/2014	Yes	Yes	0 (was removed by construction crew)
			(b) TimeMark (Westbound)					3
7. CSAH 152 (Washington Ave) E of 11th Ave S	No bikeway, ADT >10,000	Minneapolis	(a) MetroCount (Eastbound)	6/26/2014	6/30/2014	Yes	Yes	3
			(b) MetroCount (Westbound)					3
			(c) TimeMark (Eastbound)					3
8. CSAH 152 (Washington Ave) S of Dowling Ave N	On-road bikeway (bike lane)	Minneapolis	(a) TimeMark (Northbound)	7/7/2014	7/11/2014	Yes	Yes	0 (removed by street sweeper)
			(b) TimeMark (Southbound)					3
9. CSAH 153 (Lowry Ave) E of Lyndale Ave	On-road bikeway (bike lane)	Minneapolis	TimeMark (Eastbound)	7/7/2014	7/11/2014	Yes	Yes	3

Table 0.6. Bicycle and Pedestrian Count Locations (2014) (continued)

Trails								
1. Midtown Greenway E of CSAH 152 (Cedar Ave)	Off-road Trail	Minneapolis	(a) MetroCount	9/11/2014	9/19/2014	Yes	Yes	6
			(b) TimeMark (6' spacing)					6
2. Midtown Greenway W of Hennepin Ave	Off-road Trail	Minneapolis	MetroCount	4/15/2014	4/18/2014	No	Yes	7
3. Midtown Greenway W of Hennepin Ave	Off-road Trail	Minneapolis	(a) MetroCount	9/11/2014	9/19/2014	Yes	Yes	7
			(b) TimeMark (6' spacing)					7

Table 0.7. Summary of measured, non-validated mean volumes, TimeMark (2014)

TIMEMARK										
	15th Ave SE N of CSAH 36 (University Ave SE)	CSAH 35 (Portland Ave S) S of E 28th St *	CSAH 36 (University Ave Se) E of 10th Ave SE (All Lanes)	CSAH 36 (University Ave Se) E of 10th Ave SE (Bike Lane)	CSAH 40 (Glenwood Ave) E of Xerxes Ave N	CSAH 152 (Washington Ave) E of TH 65 (3rd Ave S) **	CSAH 152 (Washington Ave) E of 11th Ave S ***	CSAH 152 (Washington Ave) S of Dowling Ave N ****	Midtown Greenway E of CSAH 152 (Cedar Ave)	Midtown Greenway W of Hennepin Ave
Facility Type	Bike Lane	Protected Bike Lane	Bike Lane	Bike Lane	Bike Lane	None	None	Bike Lane	Trail	Trail
Complete Days	4	8	8	7	3	3	3	3	6	7
Mean Daily Bike Count	1070.00	276.88	186.50	15.71	39.00	85.33	14.67	72.00	1408.50	1703.29
Direction 1 (N or E)	454.50		One-way Eastbound	One-way Eastbound		0.00			Bi-directional	Bi-directional
Direction 2 (S or W)	615.50					85.33				
Daily Bike % Mode Share	78.00%	73.20%	1.39%	11.45%	2.98%	2.27%	0.37%	1.87%	83.93%	83.02%
Mean WD Bike Count	1658.50	304.33	191.50	20.60	40.00	84.00	28.00	72.00	1271.00	1691.40
Direction 1 (N or E)	716.00		One-way Eastbound	One-way Eastbound		0.00			Bi-directional	Bi-directional
Direction 2 (S or W)	942.50					84.00				
WD Bike % Mode Share	77.28%	73.90%	1.34%	11.15%	2.56%	1.23%	0.44%	N/A	88.74%	86.92%
Mean WE Bike Count	481.50	194.50	171.50	3.50	38.50	86.00	8.00	N/A	1683.50	1733.00
Direction 1 (N or E)	193.00		One-way Eastbound	One-way Eastbound		0.00			Bi-directional	Bi-directional
Direction 2 (S or W)	288.50					86.00				
WE Bike % Mode Share	80.59%	70.09%	1.59%	18.92%	3.26%	4.46%	0.29%	1.87%	76.37%	74.83%
WWI	0.29	0.64	0.90	0.17	0.96	1.02	0.29	N/A	1.32	1.02
AMI	0.76	1.05	1.41	2.00	2.33	1.14	5.00	8.33	1.61	1.27
Bike Traffic Classification	Mixed - Utilitarian	Mixed - Utilitarian	Mixed - Utilitarian	Utilitarian	Mixed - Utilitarian	Mixed - Utilitarian	Utilitarian	N/A	Mixed - Utilitarian	Mixed - Utilitarian

* Results from 10ft tube spacing (6ft tube spacing counted about a 1/3 of the bikes and motor vehicles)
** Data is suspect (counting tubes loosened, were removed resulting in suspect data in one direction or both)
*** Computed for westbound traffic only
**** Computed for southbound traffic only

Table 0.8. Summary of MetroCount ARX Scheme Data (2014)

ARX						
	CSAH 33 (Park Ave) S of 3rd Ave S (Downtown)	CSAH 36 (University Ave Se) E of 10th Ave SE (All Lanes)	CSAH 36 (University Ave Se) E of 10th Ave SE (Bike Lane) *	CSAH 152 (Washington Ave) E of 11th Ave S	Midtown Greenway E of CSAH 152 (Cedar Ave)	Midtown Greenway W of Hennepin Ave
Facility Type	Bike Lane	Bike Lane	Bike Lane	None	Trail	Trail
Complete Days	2	6	7	3	6	7
Mean Daily Bike Count	406.5	212.3	9.3	217.0	1700.3	1701.1
Direction 1 (N or E)	Only Northbound	Only Eastbound	Only Eastbound	102.7	Bi-directional	Bi-directional
Direction 2 (S or W)				114.3		
Daily Bike % Mode Share	95.82%	1.52%	1.70%	1.48%	83.35%	84.01%
Mean WD Bike Count	406.5	187.5	13.0	129.0	1672.8	1683.0
Direction 1 (N or E)				117		
Direction 2 (S or W)				12		
WD Bike % Mode Share	95.82%	1.23%	1.88%	0.70%	83.00%	86.25%
Mean WE Bike Count	N/A	262.0	0.0	261.0	1755.5	1746.5
Direction 1 (N or E)				95.5		
Direction 2 (S or W)				165.5		
WE Bike % Mode Share	N/A	2.29%	NA	2.03%	84.02%	79.0%
WWI	N/A	1.40	NA	2.02	1.05	1.04
AMI	4.91	1.54	NA	2.13	1.52	1.28
Bike Traffic Classification	N/A	Mixed - Utilitarian	Not Enough Sampling	Mixed	Mixed - Utilitarian	Mixed - Utilitarian

* Data is suspect (sensor tubes loosened or were removed resulting in suspect data in one direction or both)

Table 0.9. Summary of MetroCount BOCO Scheme Data (2014)

BOCO						
	CSAH 33 (Park Ave) S of 3rd Ave S (Downtown)	CSAH 36 (University Ave Se) E of 10th Ave SE (All Lanes)	CSAH 36 (University Ave Se) E of 10th Ave SE (Bike Lane) *	CSAH 152 (Washington Ave) E of 11th Ave S	Midtown Greenway E of CSAH 152 (Cedar Ave)	Midtown Greenway W of Hennepin Ave
Facility Type	Bike Lane	Bike Lane	Bike Lane	None	Trail	Trail
Complete Days	2	6	7	3	6	7
Mean Daily Bike Count	323.5	372.2	10.4	283.7	1980.7	2170.3
Direction 1 (N or E)	Only Northbound	Only Eastbound	Only Eastbound	161.0	Bi-directional	Bi-directional
Direction 2 (S or W)				122.7		
Daily Bike % Mode Share	95.99%	2.66%	1.51%	1.93%	90.88%	94.80%
Mean WD Bike Count	323.5	379.5	14.6	204.0	1790.3	2036.2
Direction 1 (N or E)				195.0		
Direction 2 (S or W)				9.0		
WD Bike % Mode Share	95.99%	2.48%	1.67%	1.11%	88.52%	95.21%
Mean WE Bike Count	N/A	357.5	0.0	323.5	2361.5	2505.5
Direction 1 (N or E)				144.0		
Direction 2 (S or W)				179.5		
WE Bike % Mode Share	N/A	3.12%	0.0%	2.52%	94.73%	93.96%
WWI	N/A	0.94	0.00	1.59	1.32	1.23
AMI	1.89	1.55	15.50	2.00	1.29	1.16
Bike Traffic Classification	N/A	Mixed - Utilitarian	Not Enough Sampling	Mixed	Mixed	Mixed - Utilitarian

* Data is suspect (sensor tubes loosened or were removed resulting in suspect data in one direction or both)

Table 0.10. MetroCount ARXm and BOCO Summary Table (2014)

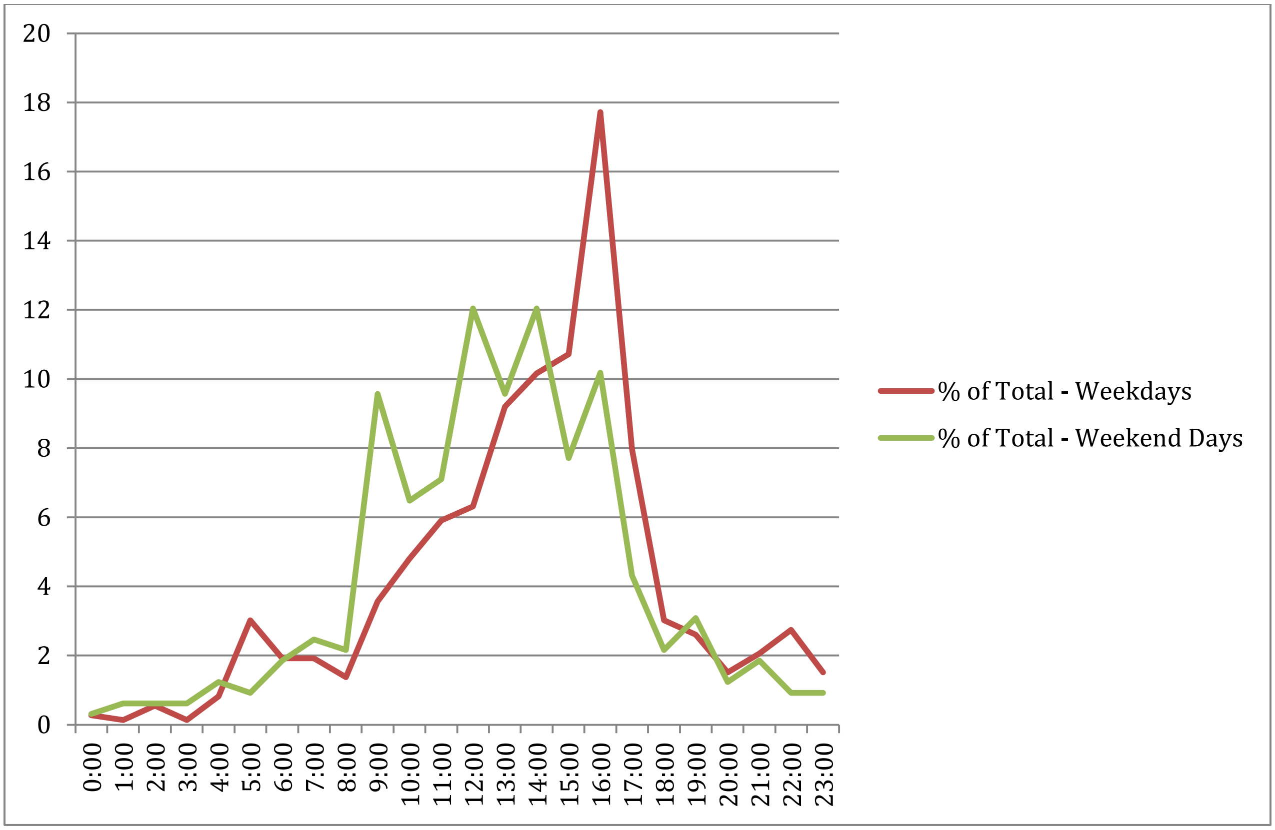
	CSAH 33 (Park Ave) S of 3rd Ave S (Downtown)	CSAH 36 (University Ave Se) E of 10th Ave SE (All Lanes)	CSAH 36 (University Ave Se) E of 10th Ave SE (Bike Lane) *	CSAH 152 (Washington Ave) E of 11th Ave S	Midtown Greenway E of CSAH 152 (Cedar Ave)	Midtown Greenway W of Hennepin Ave
Complete Days	2	6	7	3	6	7
Travel Direction	Only Northbound	Only Eastbound	Only Eastbound	East & West Separately	Bi-directional	Bi-directional
Mean Daily Bike Count	406.5	212.3	9.3	217.0	1700.3	1701.1
Mean Daily Bike Count	323.5	372.2	10.4	283.7	1980.7	2170.3

APPENDIX H:
BEMIDJI MONITORING RESULTS

Table 0.11. Lake Bemidji Trail Bicycle Monitoring Results

Date	Weekday?	Bike Count	Bike Distribution over Sample (%)
10/3/2014	1	16	2.1
10/4/2014	0	39	5.1
10/5/2014	0	26	3.4
10/6/2014	1	56	7.4
10/7/2014	1	36	4.7
10/8/2014	1	0	0.0
10/9/2014	1	44	5.8
10/10/2014	1	59	7.8
10/11/2014	0	73	9.6
10/12/2014	0	53	7.0
10/13/2014	1	52	6.8
10/14/2014	1	100	13.2
10/15/2014	1	104	13.7
10/16/2014	1	102	13.4
10/17/2014	1	35	4.6
10/18/2014	0	60	7.9
10/19/2014	0	73	9.6
10/20/2014	1	67	8.8
10/21/2014	1	57	7.5
	Total	1052	
	WD Total	728	
	WE Total	324	
	Mean	55.4	
	WD Mean	56.0	
	WE Mean	54.0	

Figure 0.12. Percentage of bicycle traffic by hour of day, weekdays and weekend days, Lake Bemidji Trail



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% of Total - Weekdays
% of Total - Weekend Days

Table 0.13. Claussen Avenue, northbound, monitoring results: daily bicycle traffic (ARX Cycle Classification)

Complete Dates (24hrs)	Weekday?	Bike Count	Motor Vehicle Count	Total Count	% Bikes	% Motor Vehicles	Bike Distribution over Sample (%)	Motor Vehicle Distribution over Sample (%)	Total Distribution over Sample (%)
10/3/2014	1	2	163	165	1.2	98.8	2.1	6.3	6.1
10/4/2014	0	4	146	150	2.7	97.3	4.1	5.6	5.5
10/5/2014	0	2	151	153	1.3	98.7	2.1	5.8	5.7
10/6/2014	1	3	193	196	1.5	98.5	3.1	7.4	7.2
10/7/2014	1	2	230	232	0.9	99.1	2.1	8.8	8.6
10/8/2014	1	5	184	189	2.6	97.4	5.2	7.1	7.0
10/9/2014	1	7	167	174	4.0	96.0	7.2	6.4	6.4
10/10/2014	1	9	211	220	4.1	95.9	9.3	8.1	8.1
10/11/2014	0	12	210	222	5.4	94.6	12.4	8.1	8.2
10/12/2014	0	4	184	188	2.1	97.9	4.1	7.1	7.0
10/13/2014	1	12	187	199	6.0	94.0	12.4	7.2	7.4
10/14/2014	1	12	214	226	5.3	94.7	12.4	8.2	8.4
10/15/2014	1	9	181	190	4.7	95.3	9.3	6.9	7.0
10/16/2014	1	14	187	201	7.0	93.0	14.4	7.2	7.4
10/17/2014	1	4	185	189	2.1	97.9	4.1	7.1	7.0
10/18/2014	0	4	165	169	2.4	97.6	4.1	6.3	6.2
10/19/2014	0	10	154	164	6.1	93.9	10.3	5.9	6.1
10/20/2014	1	11	185	196	5.6	94.4	11.3	7.1	7.2
10/21/2014	1	7	184	191	3.7	96.3	7.2	7.1	7.1
	Total	97	2608	2705	3.6	96.4			
	WD Total	75	1917	1992	3.8	96.2			
	WE Total	22	691	713	3.1	96.9			
	Mean	6.9	186.3	193.2					
	WD Mean	7.5	191.7	199.2					
	WE Mean	5.5	172.8	178.3					

Table 0.14. Claussen Avenue, southbound, monitoring results: daily bicycle traffic (ARX Cycle classification)

Complete Dates (24hrs)	Weekday?	Bike Count	Motor Vehicle Count	Total Count	% Bikes	% Motor Vehicles	Bike Distribution over Sample (%)	Motor Vehicle Distribution over Sample (%)	Total Distribution over Sample (%)
10/3/2014	1	3	188	191	1.6	98.4	3.5	6.6	6.5
10/4/2014	0	2	174	176	1.1	98.9	2.4	6.1	6.0
10/5/2014	0	5	182	187	2.7	97.3	5.9	6.4	6.4
10/6/2014	1	2	207	209	1.0	99.0	2.4	7.3	7.1
10/7/2014	1	4	254	258	1.6	98.4	4.7	8.9	8.8
10/8/2014	1	1	205	206	0.5	99.5	1.2	7.2	7.0
10/9/2014	1	5	183	188	2.7	97.3	5.9	6.4	6.4
10/10/2014	1	7	233	240	2.9	97.1	8.2	8.2	8.2
10/11/2014	0	10	242	252	4.0	96.0	11.8	8.5	8.6
10/12/2014	0	6	190	196	3.1	96.9	7.1	6.7	6.7
10/13/2014	1	10	179	189	5.3	94.7	11.8	6.3	6.4
10/14/2014	1	6	197	203	3.0	97.0	7.1	6.9	6.9
10/15/2014	1	12	207	219	5.5	94.5	14.1	7.3	7.5
10/16/2014	1	12	213	225	5.3	94.7	14.1	7.5	7.7
10/17/2014	1	4	206	210	1.9	98.1	4.7	7.2	7.1
10/18/2014	0	9	186	195	4.6	95.4	10.6	6.5	6.6
10/19/2014	0	10	164	174	5.7	94.3	11.8	5.7	5.9
10/20/2014	1	8	202	210	3.8	96.2	9.4	7.1	7.1
10/21/2014	1	4	196	200	2.0	98.0	4.7	6.9	6.8
	Total	85	2854	2939	2.9	97.1			
	WD Total	62	2066	2128	2.9	97.1			
	WE Total	23	788	811	2.8	97.2			
	Mean	6.1	203.9	209.9					
	WD Mean	6.2	206.6	212.8					
	WE Mean	5.8	197.0	202.8					

Figure 0.1. Percentage of bicycle traffic by hour of day, weekdays and weekend days, Claussen Avenue, Southbound

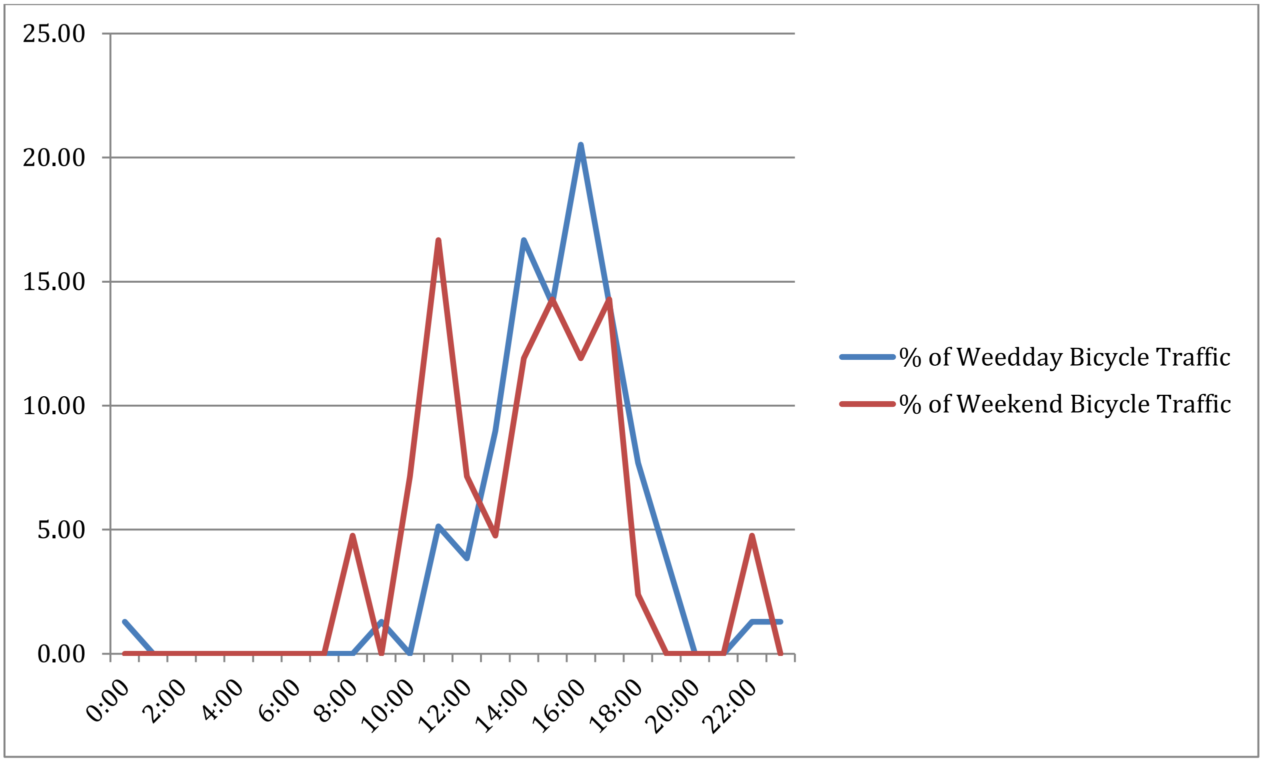

Table 0.15. First Avenue Westbound, bicycle traffic monitoring results

Complete Dates (24hrs)	Weekday?	Bike Count	Motor Vehicle Count	Total Count	% Bikes	% Motor Vehicles	Bike Distribution over Sample (%)	Motor Vehicle Distribution over Sample (%)	Total Distribution over Sample (%)
10/3/2014	1	3	3552	3555	0.1	99.9	20.0	42.3	42.3
10/4/2014	0	5	2675	2680	0.2	99.8	33.3	31.9	31.9
10/5/2014	0	7	2166	2173	0.3	99.7	46.7	25.8	25.8
	Total	15	8393	8408	0.2	99.8			
	WD Total	3	3552	3555	0.1	99.9			
	WE Total	12	4841	4853	0.2	99.8			
	Mean	5.0	2797.7	2802.7					
	WD Mean	3.0	3552.0	3555.0					
	WE Mean	6.0	2420.5	2426.5					