MONITORING TRAIL USE:
Case Study Applications at
San Antonio Missions National Historical Park and
Guadalupe Mountains National Park

Sponsored By
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**Title:** Monitoring Trail Use: Case Study Applications at San Antonio Missions National Historical Park and Guadalupe Mountains National Park

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**Abstract:**
This study evaluated commercially-available trail counters, developed a step-by-step framework for monitoring trails and other non-motorized facilities, and applied the monitoring framework in two unique park settings. The Mission Reach Trail in the San Antonio Missions National Historical Park served as an example of a typical linear urban park. The Guadalupe Mountains National Park served as an example of a rural park with a trail network and a limited number of discrete access points. Trail use was sampled at several locations within these two parks, and overall estimates of trail use were developed from this data collection. The resulting trail use data quantifies how many people use the trails at different times during the day, different days of the week, and months of the year. This trail use data can be used for several purposes, such as managing natural resources, planning or developing new programs and facilities, and quantifying the public health and physical activity benefits to park visitors.
DISCLAIMER

This research was performed in cooperation with the Gulf Coast Cooperative Ecosystem Studies Unit at Texas A&M University and the National Park Service Social Science Branch. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the National Park Service. This report does not constitute a standard, specification, or regulation.

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CHAPTER 1—INTRODUCTION

PROBLEM STATEMENT

The national parks have been called “America’s Best Idea,” “...with a sometimes conflicting two-part mission: to make the parks accessible to all and to preserve them for future generations.”¹ Large numbers of visitors can overwhelm natural resources and visitor experiences at the nation’s busiest parks. Therefore, this two-part mission is a balancing act that requires effective resource management, which in part, requires gathering data about visitor access and circulation within national parks (Figure 1). Similar management challenges exist within other federally-managed lands, like national forests, national wildlife refuges, national monuments, wilderness areas, etc.

Figure 1. Resource Management Requires Gathering Data about Visitation Levels and Use Patterns

Source: http://www.flickr.com/photos/kangaeru/95537621/

Some parks already have programs and procedures for collecting data on automobile traffic. However, collecting data on non-motorized traffic (e.g., pedestrians and bicyclists) remains a challenge in most

areas, even as these modes of transportation take on greater importance in terms of visitor access, circulation, and opportunities for physical activity.

**STUDY OBJECTIVES**

The primary goal of this study was to develop and refine methods to monitor visitor use on trail systems in national parks. The research study had three primary objectives:

1. Evaluate several commercially available trail counters in typical National Park Service (NPS) settings.
2. Develop a generalized process for monitoring year-round trail use, and then apply the monitoring process in different park settings.
3. Summarize the trail use data into example reports that are useful for NPS staff and other decision-makers.

The trail use and count data can then be used to:

- Document the importance and relevance of “alternative transportation” funding programs.
- Quantify the public health and physical activity benefits to visitors.
- Plan or develop new programs and facilities to meet visitor needs.
- Manage natural resources to avoid overuse or degradation.
- Provide a more comprehensive picture of visitor access and circulation.

**USE OF CASE STUDY PARKS**

In this study, the generalized monitoring process was applied to two specific national parks with differing characteristics:

1. **San Antonio Missions National Historical Park**: a linear urban park with several historic sites along the San Antonio River in Texas.
2. **Guadalupe Mountains National Park**: a rural park in west Texas with a limited number of access points and a network of hiking trails.

These case study parks demonstrate the application of the generalized monitoring process to specific parks and trail systems. The generalized monitoring process and underlying concepts can similarly be applied to other national parks or trail systems.

**WHAT IS “NON-MOTORIZED TRAFFIC”?**

Throughout this report, the terms “visitor use,” “trail use,” and “non-motorized traffic” are used interchangeably. In most park settings, non-motorized traffic consists of pedestrians and bicyclists traveling along roads or trails. It can also include people walking through an exhibit or visitors center,
along a pedestrian mall, or on connecting sidewalks. Pedal bikes are the most common form of non-motorized wheeled vehicles, but other forms include wheelchairs, foot scooters, and other electric-assist personal vehicles (e.g., Segway® transporters) (Figure 2).

**Figure 2. Non-Motorized Traffic Can Take Many Forms**

Water-based transportation, such as the use of canoe or kayak, also fits in the definition of non-motorized traffic. However, this mode has unique monitoring challenges that are not fully addressed in this report. Animal-assisted transportation (e.g., horseback or muleback riding, dogsledding) often uses the same hiking trails and can also be considered non-motorized traffic.

The final decision about what gets defined and counted as “non-motorized traffic” is site-specific and depends on how you will use the data. For example, if you intend to use the data to make multiple decisions, the best practice is to, when practical, count different user types separately. This approach provides maximum flexibility to combine user types later, when summarizing the same data.

**OVERVIEW OF REPORT**

Chapter 2 of this report describes the generalized trail monitoring process that was developed for national parks. This chapter also provides detail for the essential process elements related to non-motorized traffic monitoring. Chapter 3 describes the application and testing of the generalized monitoring process at two different national parks. Finally, Chapter 4 summarizes the conclusions from this study on monitoring trail use in three main areas: 1) automated trail counters; 2) generalized trail monitoring process; and, 3) trail usage patterns in the two case study parks.
CHAPTER 2—METHODS: DEVELOPING A MONITORING FRAMEWORK

This chapter describes the generalized trail use monitoring process that was developed for national parks and other federal lands. The chapter also provides detail for the essential process elements related to non-motorized traffic monitoring.

The overall monitoring framework in this chapter is consistent with several other manuals or guides\(^2,3,4,5\) on visitor monitoring in recreational settings. Interested readers are referred to these other sources for more detail on specific topics.

PROCESS MANAGEMENT FUNDAMENTALS APPLIED TO NON-MOTORIZED TRAFFIC MONITORING

The Plan-Do-Check-Act cycle (see Figure 3) is a common approach for improving processes and products. Based on the scientific method, this iterative cycle — also known as the Deming circle/cycle/wheel, Shewhart cycle, control circle/cycle, or plan-do-study-act — has been used by many different industries.

**Figure 3. The Plan-Do-Check-Act Cycle**

The major stages of the cycle are:

---


• **Plan.** Establish the objectives and processes to meet the goal or target. In the traffic monitoring context, this means identifying users and uses (i.e., Who needs traffic data and for what purposes or decisions?), then developing an approach based on those users and uses.

• **Do.** Implement the plan, execute the process, or make the product. In the traffic monitoring context, this is the stage where you’d collect the traffic counts for the users and purposes specified in the “Plan” phase.

• **Check.** Analyze the results. In the traffic monitoring context, you would summarize the traffic data and provide it to users for specified purposes (e.g., to justify funding requests).

• **Act.** Make decisions based on results. Apply lessons learned and quality improvement principles to subsequent iterations of the process cycle to improve efficiency and accountability.

Figure 4 shows that, when applied to non-motorized traffic monitoring, the following steps can be attached to each major element of the Plan-Do-Check-Act cycle.

**Figure 4. The Plan-Do-Check-Act Cycle, Applied to Non-Motorized Traffic Monitoring**

1. Identify Uses & Users
2. Define Required Data
3. Identify Data Collection Tools
4. Develop Data Collection Plan
5. Execute Data Collection Plan
6. Analyze & Summarize Data
7. Report & Communicate Results
8. Make Decisions Based on Results
9. Improve Quality in Future Cycles
The following sections highlight the steps of the monitoring process and involve developing a monitoring plan based on how data will be used and by whom.

**STEP 1. IDENTIFY USES AND USERS**

Trying to define all the data collection details without knowing how you will use the data can feel overwhelming. For example, consider trying to answer these questions if you are told only to count pedestrians and bicyclists:

- Where should we collect data?
- How should we collect data? Can automated equipment be used?
- For how long should we collect data?
- How often throughout the year should we collect data?
- How should we summarize and report data?

The most important step in developing a non-motorized traffic monitoring process is to identify those who will be using the data and for what purposes or decisions. By clearly defining the users and uses, you can logically derive many of the data collection details. Some of the most common uses of non-motorized traffic-count data are listed below. Though not exhaustive, this list is intended to get you thinking about how you could use your own count data. Example data uses include:

- Monitoring usage levels to better manage and protect natural resources.
- Estimating potential demand for new programs and facilities based on existing usage.
- Documenting increases in usage (e.g., before-and-after scenarios) based on new programs and facilities.
- Quantifying the public health and physical activity benefits of visitors.
- Documenting the importance and relevance of “alternative transportation” funding programs.
- Providing a more comprehensive picture of visitor access and circulation.

You might need to monitor traffic in your park for multiple purposes and use the data in several different ways. Make a list of these different needs. The most demanding requirements will determine the controlling data collection parameters. For example, if Use A requires daily counts and Use B requires hourly counts for a specific day, then Use B (the more frequent count) will dictate data-collection details.

**STEP 2. DEFINE REQUIRED DATA**

This study focused solely on one data attribute: counts of non-motorized traffic. However, it is likely that the use requirements identified in Step 1 will require other data attributes besides just counts.
How you might use your data can vary from location to location, but it’s important to think about that since what you want to use the data for directly impacts the resources and procedures applied to gathering it. For example, let’s say you wanted to know the physical activity benefits to park visitors; you need other data besides non-motorized traffic counts at multiple locations. You would also need to know the typical duration of the activity for the persons counted and the typical intensity of the activity.

As a second example, you might count hikers along the middle of a trail but also want to know the origin and destination for a typical hiker passing along this point on the trail (e.g., to calculate distance hiked).

For both of these examples, you could use visitor surveys to gather the additional data. The conduct of visitor surveys should be closely coordinated with non-motorized traffic monitoring. You can find more information on visitor surveys at http://www.nature.nps.gov/socialscience/expedited.cfm and http://www.psu.uidaho.edu/vsp.htm.

STEP 3. IDENTIFY DATA COLLECTION TOOLS

Once you have identified the use requirements (Step 1) and defined the required data for these uses (Step 2), the next step is to identify the necessary tools to collect the data (defined in this study as the required counts). Later sections describe different types of equipment for automatically counting non-motorized traffic. First, we should address two larger questions:

1. Is a one-time effort adequate or is there an ongoing need to monitor counts?
2. Is automated equipment necessary or is it better to manually count visitors?

Completing Step 1 will help answer the first question. For example, resource protection will likely require more regular monitoring, whereas a feasibility study for new programs/facilities might only require a one-time effort. Other factors that you should also consider include:

- **Resource levels.** Available resources often determine the data-collection scope more than use requirements or statistical considerations.

- **Change in usage.** If you expect a minimal change in counts over time, repeatedly counting usage is unnecessary.

- **Data sharing.** Can you estimate or obtain similar data from other sources or agencies? For example, can you estimate trail-hiker counts using vehicle entrance or other visitor counts? Does a local agency count the trail traffic that leads into your park?

Deciding the necessary frequency for counting will answer the question of conducting manual counts versus using automated equipment. Automatic counters are initially more expensive, but that cost can be offset by lower operating costs over time. Staff must be trained to use automatic counters correctly, however. Manual counts by human observers often take much less time to do than counts using automatic counters, which take time to set up and calibrate.

Another alternative is to contract for data collection services from a third party. There are several companies in the United States that specialize in non-motorized traffic counts.
Selecting Automatic Counter Equipment

This section describes the equipment and technologies commonly used to automatically count non-motorized (e.g., bike, pedestrian) traffic volumes. The authors differentiate technologies best suited for counting bicyclists versus those best suited for pedestrians. Technologies appropriate for short-duration (i.e., portable) counting are distinguished from those ideal for continuous (i.e., permanent) counting.

While many of the basic technologies used to count pedestrians and bicyclists are similar to those used to count cars and trucks, their design and configuration are often quite different. Therefore, it is common to use separate and dedicated equipment to monitor non-motorized traffic.

There are a few technological challenges to non-motorized traffic monitoring:

- Pedestrians and bicyclists are less confined to fixed lanes or paths of travel than motor vehicles. Pedestrians and hikers take shortcuts along trails or in open areas. Bicyclists sometimes ride on sidewalks, travel outside designated bikeways, or might stop in front of a sensor to talk, wait, or even examine the sensor itself. These behaviors not only make it challenging to place and aim sensors, they can also cause inaccurate counts.

- Pedestrians and bicyclists sometimes travel in closely spaced groups. Some sensors have difficulty differentiating between individuals within a group. A group with multiple persons might be counted as one person, thereby underestimating actual counts.

Despite these challenges, several technologies exist that accurately count non-motorized traffic. The growing demand for automatic counters has brought about improvements in equipment accuracy. Increased competition in this marketplace and collective experience with existing products should continue to drive technology improvements.

Selecting the most appropriate counter can be daunting. Commercially available counters use a variety of technologies and features that can vary dramatically and affect how, what, where, and how long counts are collected. Cost per data point can also vary greatly between counters. For example, manual data collection (e.g., a person with a clipboard) is relatively inexpensive, but only because that counting method doesn’t collect many data points. In comparison, automatic equipment is more expensive but collects many more data points since you can install and leave it for days or weeks at a time.

Figure 5 presents a simplified flowchart that can help to narrow possible choices based on the two most important aspects of data collection:

1. What are you counting (pedestrians only, pedestrians and bicyclists [separately or combined], or bicyclists only)?

2. For how long are you counting (permanently, temporarily, or somewhere in-between)?

To decide what technology to use, you must first know your equipment budget and the commercial availability of the technology in question. Tables 1 and 2 provide additional information for automatic counter technologies, their strengths and weaknesses, and commercial availability. Tables 1 and 2 are best used after the relevant technologies have been narrowed down using Figure 5. Later sections provide more detailed information on each technology.
Figure 5. Simplified Flowchart for Selecting Automatic Counter Equipment

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<td>○</td>
<td>⬇️</td>
<td>$$</td>
</tr>
<tr>
<td></td>
<td>Magnetometer(^2)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>$$</td>
</tr>
<tr>
<td></td>
<td>Pressure Sensor(^2)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>$$</td>
</tr>
<tr>
<td></td>
<td>Radar Sensor</td>
<td>○</td>
<td>○</td>
<td>○</td>
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<td>$$</td>
</tr>
<tr>
<td></td>
<td>Seismic Sensor</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>$$</td>
</tr>
<tr>
<td></td>
<td>Video Imaging: Automated</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>$$</td>
</tr>
<tr>
<td></td>
<td>Infrared Sensor (Active or Passive)</td>
<td>○(^3)</td>
<td>●</td>
<td>●</td>
<td>⬇️</td>
<td>$-$-$-$</td>
</tr>
<tr>
<td></td>
<td>Pneumatic Tubes</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>⬇️</td>
<td>$-$-$-$</td>
</tr>
<tr>
<td>Temporary/Short Term</td>
<td>Video Imaging: Manual</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>$-$-$-$</td>
</tr>
<tr>
<td></td>
<td>Manual Observers</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>$-$-$-$</td>
</tr>
</tbody>
</table>

○ Indicates what is technologically possible.
● Indicates a common practice.
\(^1\) Indicates a common practice, but must be combined with another technology to classify pedestrians and bicyclists separately.
\(^2\) Indicates relative cost per data point.
\(^3\) Typically requires a unique loop configuration separate from motor vehicle loops, especially in a traffic lane shared by bicyclists and motor vehicles.
Permanent installation is typical for asphalt or concrete pavements; temporary installation is possible for unpaved, natural surface trails.
Requires specific mounting configuration to avoid counting cars in main traffic lanes or counting pedestrians on the sidewalk.
<table>
<thead>
<tr>
<th>Technology</th>
<th>Typical Applications</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual Observer</td>
<td>Short-term counts Bicyclists and pedestrians separately</td>
<td>• Very portable  &lt;br&gt; • Can be used for automated equipment validation</td>
<td>• Expensive and possibly inaccurate for longer duration counts</td>
</tr>
<tr>
<td>Inductance Loop</td>
<td>Permanent counts Bicyclists only</td>
<td>• Accurate when properly installed and configured</td>
<td>• Capable of counting bicyclists only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Uses traditional motor vehicle counting technology</td>
<td>• Requires saw cuts in existing pavement or pre-formed loops in new pavement construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• May have higher error with groups</td>
</tr>
<tr>
<td>Infrared – Active</td>
<td>Short-term or permanent counts Bicyclists and pedestrians combined</td>
<td>• Relatively portable  &lt;br&gt; • Low profile, unobtrusive appearance</td>
<td>• Cannot distinguish between bicyclists and pedestrians unless combined with another bicycle detection technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Very difficult to use for bike lanes and shared lanes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• May have higher error with groups</td>
</tr>
<tr>
<td>Infrared – Passive</td>
<td>Short-term or permanent counts Bicyclists and pedestrians combined</td>
<td>• Very portable with easy setup  &lt;br&gt; • Low profile, unobtrusive appearance</td>
<td>• Cannot distinguish between bicyclists and pedestrians unless combined with another bicycle detector</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Difficult to use for bike lanes and shared lanes, requires careful site selection and configuration</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• May have higher error when ambient air temperature approaches body temperature range</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• May have higher error with groups</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Direct sunlight on sensor may create false counts</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>Permanent counts Bicyclists only</td>
<td>• May be possible to use existing motor vehicle sensors</td>
<td>• Commercially-available, off-the-shelf products for counting bicyclists are limited</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• May have higher error with groups</td>
</tr>
<tr>
<td>Pneumatic Tube</td>
<td>Short-term counts Bicyclists only</td>
<td>• Relatively portable, low-cost</td>
<td>• Capable of counting bicyclists only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• May be possible to use existing motor vehicle counting technology and equipment</td>
<td>• Tubes and nails to attach may pose hazard to users</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Greater risk of vandalism</td>
</tr>
<tr>
<td>Pressure / Acoustic</td>
<td>Permanent counts Bicyclists and pedestrians separately Typically unpaved trails or paths</td>
<td>• Some equipment may be able to distinguish bicyclists and pedestrians</td>
<td>• Expensive/disruptive for installation under asphalt or concrete pavement</td>
</tr>
<tr>
<td>Video Imaging – Automated</td>
<td>Short-term or permanent counts Bicyclists and pedestrians separately</td>
<td>• Potential accuracy in dense, high-traffic areas</td>
<td>• Typically more expensive for exclusive installations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Algorithm development still maturing</td>
</tr>
<tr>
<td>Video Imaging – Manual Reduction</td>
<td>Short-term counts Bicyclists and pedestrians separately</td>
<td>• Can be lower cost when existing video cameras are already installed</td>
<td>• Limited to short-term use</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Manual video reduction is labor-intensive</td>
</tr>
</tbody>
</table>
**Table 2. Listing of Commercially-Available Trail Counters in North America**

<table>
<thead>
<tr>
<th>Company and Product Name</th>
<th>Technology</th>
<th>Contact Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond Traffic: TT-41/Pegasus</td>
<td>Inductance Loop</td>
<td></td>
</tr>
<tr>
<td>EcoCounter ZELT</td>
<td>Inductance Loop</td>
<td></td>
</tr>
<tr>
<td>EcoCounter TUBE</td>
<td>Pneumatic Tube</td>
<td></td>
</tr>
<tr>
<td>TRAFx: Mountain Bike Counter</td>
<td>Geomagnetic</td>
<td></td>
</tr>
</tbody>
</table>

Note: The companies are arranged by alphabetical order and no endorsements of their products are made or implied by their listing in this table.

**Counter Accuracy and Count Validation**

The accuracy of commercially available products can vary significantly based on configuration, installation, and level of use, even within a specific technology (e.g., inductance loops for bicycles). Use calibration/validation procedures (even if conducted on a limited scale) to ensure count data is within the bounds of acceptable accuracy. In fact, some local agencies have developed an “equipment adjustment factor” that adjusts for systematic error (e.g., undercounting) that can occur with some technologies.

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**Technology: Inductance Loop Detectors**

Inductance loop detectors operate by circulating a low alternating electrical current through a formed wire coil embedded in the pavement. The alternating current creates an electromagnetic field above the formed wire coil, and a conductive object (e.g., car, truck, or bike) passing through the electromagnetic field will disrupt the field by a measurable amount. If this disruption meets predetermined criteria, then detection occurs and an object is counted by a data logger or computer controller.

Despite their reliance on an electromagnetic field for detection, loop detectors do not require the presence of ferrous (i.e., iron, steel) bicycle frames. However, large conductive objects (like a car or truck) are more likely to meet the predetermined “disruption” criteria than smaller conductive or non-ferrous objects (like a motorcycle or bicycle). You can adjust the sensitivity of a loop detector to better detect motorcycles or bicycles, but increased sensitivity often results in over-counting cars and trucks. For this reason, most agencies typically use dedicated loop detectors for counting bicycles rather than trying to use existing detectors to count cars, trucks, and bicycles.

Loop detectors are commonly used to detect the presence of motorized vehicles at or near intersections for traffic signal control. In some cases, these loop detectors might detect the presence of bicycles. However, the location and configuration of these intersection-based loop detectors are often not ideal (and therefore rarely used) for counting motor vehicles or bicycles.

The preferred counting area is at mid-block or other locations where bicycles are free-flowing and/or not likely to stop. Ideally, place loop detectors for counting bicycles in lane positions primarily used by bicycles. If you place loop detectors in lanes shared by motorized traffic and bicycles, special algorithms are needed to distinguish the bicycles from motorized traffic.

Loop detectors can measure bicyclist travel direction using at least two different ways:

1. Installing an inductance loop within each directional travel lane — assumes that all, or a high percentage of, bicyclists are traveling in the specified direction (e.g., shared use path or directional bike lane) in each lane.

2. Installing two inductance loops in series such that you can infer travel direction from the timing of when detection occurs for each loop.

The first option is the most commonly used practice to date. For the second option, some data loggers or controller equipment might not be capable of interpreting signals from a paired inductance loop sequence.

The most important variables in accurate bicycle detection via loop detectors are:

- **Loop configuration:** Figure 6 shows several different wire patterns appropriate for counting bicycles.

- **Detector circuit sensitivity:** Set the sensitivity high enough to detect non-ferrous bicycle frames but not so high as to detect motor vehicles in adjacent lanes.
• **Bicycle position over the loop:** Pavement stencils may be used to indicate optimal (i.e., most accurate) bicycle position over the loop detector, which is typically directly over the saw cut for the wire coil.

• **Bicycle size and composition:** A large steel frame is more likely to disrupt the loop detector’s field than a smaller, non-steel frame, but the threshold amount of ferrous metal is not a known quantity and varies based on the other three variables listed above.
Figure 6. Examples of Inductance Loop Detector Shapes for Bicyclist Counting

**Quadrupole Shape**

Source: Adapted from Caltrans Standard Plan ES-5B, 2002

**Diagonal Quadrupole Shape**

Source: Adapted from Caltrans Standard Plan ES-5B, 2002

**Double Chevron Shape**

Source: Adapted from Traffic Detector Handbook, May 2006

Double Chevron Shape: Photo
Figure 6. Examples of Inductance Loop Detector Shapes for Bicyclist Counting (Continued)

**Alternative Double Chevron Shape**

Source: Adapted from J. Bunker, City of Boulder

**Elongated Diamond Shape**

Source: Adapted from Eco-Counter Specifications
Technology: Infrared Sensors

Two types of infrared sensors can easily be distinguished.

- **Active Infrared Sensors.** Uses a signal transmitter on one side of the detection area and a receiver (or target reflector) on the other side. Operates by beaming a series of infrared pulses from a transmitter to a receiver. When the beam is broken for a pre-determined time, then a detection event (or count) is registered.

- **Passive Infrared Sensors.** Uses a signal transmitter only on one side of the detection area, and operates by identifying a changing heat differential in the detection area. If the heat differential and pattern meets pre-defined criteria, then a detection event (or count) is registered.

Active infrared sensors have a narrower cone/zone of detection than passive infrared sensors. However, installation of active infrared sensors can be more challenging than passive infrared sensors. You must align the transmitter and receiver parts of an active infrared sensor properly, which requires a vertical mounting location on both sides of the detection area with a clear line of sight between.

A passive infrared sensor only requires a single vertical mounting location on one side of the detection area. However, accuracy is improved when the passive infrared sensor is pointed toward a wall, building face, dense vegetation, or similar background.

Most infrared sensors perform best in areas where the travel area is narrow (e.g., where the path is constrained by landscaping or a fence, restricting the sensor’s coverage area) and/or the detection area is well defined. Because of the basic operating principle, infrared sensors sometimes cannot distinguish multiple persons in a group (i.e., side-by-side or closely spaced front to back). In addition, infrared sensors cannot differentiate between bicyclists and pedestrians. So, if you need separate counts, pair infrared sensors with another technology able to accurately count bicycles (e.g., pneumatic tubes or loop detectors). For example, Figure 7 shows a permanent monitoring location that combines a passive infrared sensor with loop detectors. Most infrared sensors have a small profile and form factor (see Figure 8 for examples). For portable applications, infrared sensors can be enclosed in a vandal-resistant, lockable box and attached to an existing pole, fence post, or tree. For permanent applications, infrared sensors are often enclosed within wooden fence or other vertical posts.

Because passive infrared sensors look for heat differentials and their patterns, higher error rates might occur when the ambient air temperature approaches normal body temperature (97°-100° Fahrenheit). However, no conclusive evidence of this increased potential for error exists, and the error might vary among different brands of passive infrared counters.
Figure 7. Example of Passive Infrared Sensor Combined with Inductance Loop Detectors

Figure 8. Different Types of Infrared Counters for Non-Motorized Traffic

(Equipment shown in a temporary testing and evaluation configuration)
Figure 9 shows a typical configuration for an active infrared sensor. This example shows an ideal location:

- Primarily used by pedestrians and bicyclists only.
- Travel area is constrained with the detector pointing across the sidewalk away from the street.
- Detection area is well defined in a position where pedestrians and bicyclists travel perpendicular to the sensor.

Figure 9. Typical Configuration for Active Infrared Sensor
**Technology: Magnetometers**

Magnetometers operate by detecting a change in the normal magnetic field of the earth caused by a ferrous metal object (e.g., bicycle frame or components). According to the Third Edition (October 2006) of the Traffic Detector Handbook, “Magnetometers are sensitive enough to detect bicycles passing across a four-foot span when the electronics unit is connected to two sensor probes buried six inches deep and spaced three feet apart.”

However, the installation and configuration for motor vehicles might not be optimal for accurate bicycle counting. The shallow placement of magnetometers will result in more accurate bicycle counts but could cause over-counting of motor vehicles. This occurs as a result of the detector distinguishing between changes in sections of the vehicle — such as the engine block, axles, or transmission — causing the detector to register multiple vehicles.

Magnetometers designed for motorized traffic (see Figure 10) might be capable of detecting bicycle frames made of non-ferrous materials (e.g., aluminum, carbon fiber, titanium) but are not designed or optimized for this purpose. There are few commercially available magnetometers designed for bicycle detection and counting.

*Figure 10. Wireless Magnetometer Being Installed for Motorized Traffic*

Source: Dan Middleton, Texas A&M Transportation Institute
Another drawback to the use of existing magnetometers for the detection of bicycles is the increased equipment needs. For example, a 30-foot detection area for automobiles would require five magnetometers and one electronic data logger. The same 30-foot detection area would require ten magnetometers and four to five data loggers to detect bicycles. So, generally speaking, magnetometers can be adapted for counting bicycles but, with some exceptions, are not as well suited as other technologies.

**Technology: Pneumatic Tubes**

Pneumatic tubes are a low-cost, portable approach for counting bicyclists only (Figure 11). Pneumatic tubes operate by using an air switch to detect short burst(s) of air from a passing motorized or non-motorized vehicle. The data logger then uses pre-defined criteria (e.g., axle spacing) and/or algorithms to determine whether a valid vehicle type has passed over the tubes.

*Figure 11. Example of Pneumatic Tube Configuration for Counting Directional Bicyclist Traffic*

![Example of Pneumatic Tube Configuration for Counting Directional Bicyclist Traffic](image)

*Source: J.F. Rheault, Eco-Counter*

The technology has been used to count cars and trucks for several decades, so most public agencies either have the equipment or are familiar with the technology. You can combine pneumatic tubes with infrared sensors, for example, at locations where both bicyclist and pedestrian counts are desired.

As with other traditional, motorized-traffic monitoring technology, the optimal placement and configuration of pneumatic tubes for counting bicyclists differs from that for cars and trucks. Ideally, the placement of pneumatic tubes for bicycles should adequately cover the bicycle travel path while not being exposed to activation by motor vehicles. When counting bicycles in a bike lane or shared lane,
passage and activation by motorized traffic might be unavoidable. In these cases, the data logger criteria should be capable of ignoring typical motor vehicle axle spacing. If you want to know the direction of bicyclist travel, place a pair of pneumatic tubes (see Figure 11) to determine travel direction using the timing of detection events at each tube.

Take extra care in installing pneumatic tubes, either by placing metal fixtures or pavement nails outside the bicycle facility or by using tape or other adhesive material to ensure fasteners stay down. Bicyclists could possibly dislodge these fasteners from the pavement and puncture a bicycle tire, creating a safety hazard for themselves or others.

Technology: Pressure and Seismic Sensors

Pressure sensors detect changes in force (i.e., weight), much like an electronic bathroom scale. Seismic sensors (also sometimes called acoustic sensors) detect the passage of energy waves through the ground caused by feet, bicycle tires, or other non-motorized wheels. As with other monitoring technologies, pre-defined criteria are used to determine a valid detection and, therefore, a valid user to be counted.

Both pressure and seismic sensors require placement of the sensor element underneath or very near the detection area. Pressure and seismic sensors are most common on unpaved trails or paths (Figure 12), where burial of the sensor element is typically inexpensive and minimally disruptive. However, pressure sensors have been used (more commonly in Western Europe) at curbside pedestrian signal waiting areas, as a supplement to or replacement of a pedestrian crosswalk push button.

Some models of pressure and seismic sensors are capable of detecting the difference between pedestrians and bicyclists. Placement and size of the pressure sensors (also known as pressure mats) can be used to gather directional information. When installed properly, pressure and seismic sensors can serve as permanent continuous counters.
Figure 12. Examples of Pressure Sensors on Natural (a) and Paved (b) Surfaces

(a) Pressure sensor on natural surface trail

(b) Pressure sensor on paved surface

Source: J.F. Rheault, Eco-Counter

Technology: Video Image Processing

Video image processing uses sophisticated visual pattern recognition to identify (and sometimes track) a pedestrian or bicyclist traveling through a video camera’s field-of-view (see Figure 13). The critical elements for accurate bicyclist and pedestrian counting are the pattern recognition algorithms and software. Because of the commercial demand for detecting and counting motorized traffic, manufacturers and vendors have extensively refined this software. Some universities have conducted
research and development for bicyclist and pedestrian-specific algorithms; however, much of this research has not been incorporated into existing commercially available products.

**Figure 13. Example of Video Image Processing for Tracking and Counting Non-Motorized Traffic**

![Example of Video Image Processing](image)

Source: Malinovskiy, Zheng, and Wang, 2009\(^\text{11}\), used with permission

Video image processing has the capability to distinguish pedestrians and/or bicyclists traveling in a group or cluster. The technology also has the capability to distinguish direction of travel and potentially track the non-motorized traffic through the field-of-view. Again, these capabilities depend on the level of algorithm development of the commercial products. Weather and lighting can reduce the accuracy of this technology. Finally, video image processing typically has the highest equipment costs.

In some cities, pedestrian and bicyclist counts are manually reduced by viewing recorded video from intersection control or surveillance cameras. This manual approach is practical and low-cost for periodic short-term counts, but is not sustainable for continuous monitoring purposes (due to required labor and associated costs).

This approach eliminates equipment installation (and corresponding traffic control) but also requires a low-cost labor force to manually review the video. Several companies offer a portable video recording unit as well as data reduction services. This recorded video might be useful to other agencies or departments that wish to study bicyclist and pedestrian behavior (e.g., in response to safety issues or concerns). You can also use this video footage for quality assurance purposes (e.g., for verification/validation of nearby automated counts).

**Emerging Technologies**

The commercial marketplace for non-motorized traffic monitoring is still maturing, and several companies are working to adapt their motorized traffic monitoring technology to accurately count bicyclists and pedestrians. For example, several companies are working to adapt their existing video image processing products to accurately count bicyclists and pedestrians. However, there are several other companies that successfully sold their non-motorized traffic monitoring equipment for more than a decade. An increased demand for non-motorized traffic monitoring data will provide incentives to existing companies that want to develop non-motorized traffic monitoring products.

Mobile devices with GPS and/or Bluetooth capabilities also provide a means to monitor small samples of bicyclist and pedestrian traffic. Several cities and some parks are evaluating or using these technologies to gather route choice, origin-destination, and travel time data (e.g., Banff National Park, Rocky Mountain National Park, San Francisco12, Monterey12, and Austin13). However, these technologies alone cannot directly count the total volumes of bicyclists and pedestrians.

**STEP 4. DEVELOP DATA COLLECTION PLAN**

Developing a data collection plan is the final step in the planning phase. When done properly, Step 4 helps ensure success when collecting quality data. A data collection plan typically includes the following steps:

- **Identifying the overall goal for data collection.** Important when data collectors might have to use their judgment in executing the exact details of data collection.

- **Choosing locations.** Specified using annotated aerial photography, location sketches, or latitude/longitude pairs.

- **Setting the date, time, and duration.** Note when, where, and for how long counts are conducted.

- **Determining the minimum reported time interval.** Are counts collected in shorter time intervals (e.g., count subtotals every 5 or 15 minutes) or longer time intervals (e.g., hourly or daily)?


• **Specifying the equipment specifications and/or instructions.** If used, specify the type of automatic counter equipment and any required configuration parameters or settings (such as sensitivity). This could also include the manufacturer’s recommendations for locating and installing their equipment.

• **Creating a contingency plan.** Failures, malfunctions, minor glitches, and inclement weather occur during data collection. Your data collection plan should address fixes or workarounds for the most likely problems. Make decisions in advance about how to deal with inclement weather that occurs during short-duration counts (Note: inclement weather has been demonstrated to significantly affect non-motorized counts.) Chapter 4 provides additional discussion of how to address the issue of weather in collecting non-motorized traffic counts.

The following paragraphs in this section provide more information for defining these details.

**Defining Goals and Scope of Monitoring**

The first major step in developing a specific monitoring plan is defining the scope of the monitoring activity. That is, you must first answer the question: What is to be monitored? Is it a specific trail/path/location? Is it several designated trails/paths/locations? Or is it all trails/paths/locations within a defined geographic boundary, such as the park’s or federal land’s boundaries? In most cases, you should set the geographic scope of monitoring by the application requirements (i.e., how you plan to use the monitoring data).

**Choosing Collection Locations and Time Frames**

It’s often impractical to count traffic at every location from which you might want data. Extrapolating information from data taken at representative sample locations can prove a cost-effective way of getting what you need. You can minimize the error in these generalized estimates by using statistically-based sampling procedures.

Once a representative geographic sample of all possible locations is chosen, decide on the time duration and frequency of the count. For example, do you want to know how many pedestrians use a particular trail during the peak visitor season (e.g., the summer)? How often should you count and at what times? Is the trail more scenic near dusk and, therefore, likely to have more pedestrians using it at that time? Answering questions like these can help you better scope counting time duration and frequency, which not only helps you gather more reliable data, but also helps you manage resources more efficiently.

In established traffic monitoring programs, personnel designate a limited number of permanent locations to collect continuous data and many more short-duration locations to sample count data in time (for several hours to several days) every one or more years. Figure 14 illustrates this concept in a city setting.
Figure 14. Illustration of Permanent and Short-Duration Count Locations for Non-Motorized Traffic
Using Permanent Counts to Improve Short-Duration Counts

With the sampling strategy shown in Figure 14, the short duration counts provide the geographic coverage needed to understand traffic characteristics on individual roads, paths/trails, and areas without requiring a permanent presence at each location. However, short-duration counts only represent the short time period during which they were collected. Non-motorized traffic is known to vary considerably over time (see Figures 15, 16, and 17). Permanent data collection sites provide data on seasonal and day-of-week variation. So the continuous data from permanent locations are used to adjust short duration traffic counts to create more representative daily, monthly, seasonal, or annual averages.

To adjust short-duration samples, combine the permanent monitoring locations into traffic pattern groups, such that locations with similar traffic patterns are grouped together into a single adjustment group or factor group. A typical traffic profile (how traffic varies by month, day of week, and time of day) is calculated for each traffic pattern group (see Figures 15 through 17 for example traffic profiles from one location). Each of the short-duration locations is then assigned to a traffic pattern group, based upon location criteria and best available fit of collected data. After assigning the short-duration data to a traffic pattern group, you can expand it to represent longer periods of time, such as daily average, monthly average, or annual average of traffic counts.

Figure 15. Example of Non-Motorized Traffic Patterns by Time of Day
Figure 16. Example of Non-Motorized Traffic Patterns by Day of Week

Figure 17. Example of Non-Motorized Traffic Patterns by Month of Year
In some cases, permanent counter locations might not be feasible or practical for a variety of reasons (e.g., budget restrictions or weather conditions). Sometimes you may be able to use other continuously collected data (such as park entrance counts or nearby motorized traffic counts) to adjust the short-duration counts.

You can find extensive detail on the use of sampling procedures, permanent and short-duration monitoring locations, and designation of traffic pattern groups can be found in the resources shown here:


**Determining the Number of Permanent Locations**

The statistical sampling of traffic counts is theoretically based on their variability. That is, if traffic counts are similar among all locations of interest, then you need fewer samples than if traffic varies greatly among different locations. However, little information is known about how non-motorized traffic varies by time and location, and what is known is very location-specific and difficult to generalize nationwide. In most cases (where no non-motorized counting currently exists), the number of count locations will be based on what is feasible given existing data collection resources.

If equipment budgets are not constrained, then a rule of thumb is to install two or three continuous count locations per distinct traffic pattern group (determined based on trip purpose and seasonality). The number of permanent count locations can be refined and/or increased as more data is collected on non-motorized traffic.

**Identifying Permanent Locations**

After you’ve determined the number of permanent locations within each traffic pattern group, identify specific permanent monitoring locations. Several considerations should be addressed in this step.

- **Differentiating pedestrian and bicyclist traffic:** Will you monitor pedestrian and bicyclist traffic at each permanent count location? In the case of shared-use paths, pedestrians and bicyclists will share the same travel space. You must use specialized equipment to differentiate these user types. In other situations, you might want to monitor bicyclists separately from pedestrians. You can outfit exclusive bicycle lanes or separated bicycle paths with permanent inductance loops or short-term pneumatic tubes that will not count larger, heavier motorized vehicles. You can instrument pedestrian malls, sidewalks or walkways with a single-purpose infrared counter if bicyclists are not typically present.
• **Selecting representative permanent count locations:** Although you might be tempted to select the most heavily used locations for permanent monitoring, focus primarily on selecting those locations that best represent prevailing non-motorized traffic patterns. Remember: the primary purpose of these permanent monitoring locations is to help seasonally adjust (i.e., annualize) the other short-duration counts. Continuous counts at a high-pedestrian or high-bicyclist location may look impressive, but might not yield accurate results when adjusting short-duration counts.

*Optimizing Locations and Monitor Positions*

The following recommended location criteria have been adapted from other national guidance on selecting permanent locations:

- Pedestrian and bicyclist activity areas or corridors that connect major access points or areas of interest.
- Trails or paths that serve the highest levels of recreational activity.
- Key routes or paths you can use to gauge the impacts of future improvements.
- Locations where counts have been conducted historically.
- Gaps, “pinch points,” and locations that are operationally difficult for bicyclists and pedestrians (potential improvement areas).
- Locations with a high number of bicyclist and/or pedestrian collisions.
- Selected locations that meet as many of the criteria as possible.

After identifying a general location site, choose the optimal installation location based on the strengths and requirements of the specific monitoring technology and equipment you’ve chosen. In most cases, the optimal location is:

- On straight sections of road or trail, not on curves.
- On smooth pavement or other compacted surface.
- Where the traveled way is clearly delineated and deviation by trail users is not common.
- Not near water or in direct sunlight (for infrared sensors).
- Not directly facing a roadway unless a vertical barrier exists (for infrared sensors).
- Not near high-power utility lines that could disrupt or distort the detection capability (for inductance loop detectors).

*Identifying Short-Duration Locations*

For motorized traffic, state transportation departments have a short-duration data program that provides traffic data for all roads on their state highway systems. The same goal for non-motorized traffic data might not be feasible, especially since most non-motorized travel occurs off the highway system on trails, shared use paths, and pedestrian walkways.
The prevailing practice for collecting short-duration non-motorized traffic data has focused on targeted locations where activity levels and professional interest are the highest. Although this non-random site selection may not yield a statistically representative overall estimate, it provides a more efficient use of limited data collection resources (e.g., random samples could possibly result in many locations with low or very low non-motorized use).

Optimizing Locations and Number of Short-Duration Counts

The locations for short-duration counts should use similar criteria as the permanent locations:

- Pedestrian and bicyclist activity areas or corridors that connect major areas of interest.
- Trails or paths that serve the highest levels of recreational activity.
- Key routes or paths you can use to gauge the impacts of future improvements.
- Locations where counts have been conducted historically.
- Gaps, “pinch points,” and locations that are operationally difficult for bicyclists and pedestrians (potential improvement areas).
- Locations with a high number of bicyclist and/or pedestrian collisions.
- Selected locations that meet as many of the criteria as possible.

The number of short-duration count locations depends on your available budget and how you plan to use the count data. At the time this report is being written, there exists no definitive analysis, or guidance for, determining the required number of short-duration count locations.

For most parks or agencies getting started with counting non-motorized travel, the short-count program is best developed by working with other key stakeholders interested in collecting and using these data. By discussing needs and budgets, this group can identify and prioritize the special needs short count locations that the available data collection budget can afford to collect. The special needs counts will then provide the data needed to guide the development of a more statistically valid sample of short-count locations. These more statistically rigorous sample designs will become possible in the future as you collect more data and perform more research.

Time Length of Short-Duration Counts

There currently exists no definitive guidance on the minimum required duration of short-duration non-motorized counts. The prevailing practice on city streets has been to collect two consecutive hours’ worth of data on a single day, but that practice is evolving as more public agencies use automatic counters and become aware of the inherent variability of non-motorized traffic. The authors discuss several factors below that agencies should consider when determining the duration of their short-duration counts.
Manual versus Automated Collection

The use of automatic counter equipment can dramatically extend the duration of short-duration counts. If using automatic counters, the minimum suggested duration is 7 days (such that the collected data represents all weekday and weekend days). Depending on several other factors (e.g., day-to-day count variability, the total number of short-duration monitoring sites, and the number of automatic counters), the preferred duration of automatic counts could be as long as 14 to 21 days at each location.

The use of manual observers limits the duration of short-duration counts. However, the minimum suggested duration for manual observers is 4 to 6 hours. Schedule counts to coincide with the heaviest non-motorized use (typically mid-day for weekend/recreational trips and morning/evening commute times for other trips).

Manual observers’ counting accuracy declines after 2 hours, so give observers short breaks or replace them with other observers. The preferred length for short-duration counts is 12 hours, which permits calculation of time-of-day use profiles. However, available resources might limit the viability of 12-hour counts.

The prevailing practice for short-duration manual counts has been 2 hours, largely because of resource and manual observer limitations. There are pros and cons to only collecting 2 hours’ worth of data, which is, after all, better than no data. However, 2 hours of count data may lead to high error rates when annualizing counts, which in turn could lead to erroneous conclusions. If manual observers are the only possibility for short-duration counts, then consider counting for longer periods at fewer locations. Alternatively, the NBPD project\textsuperscript{14} has encouraged agencies to count multi-hour periods on several different days.

“We suggest that between 1 and 3 counts be conducted at every location on sequential days and weeks, based on the approximate levels of activity. Areas with high volumes (over 100 people per hour during mid-day periods) can usually be counted once on a weekday and weekend day, unless there is some unusual activity that day or land use nearby.”

“Areas with lower activity levels and/or with unusual nearby land uses (with any irregular activity, such as a ball park) or activity (such as a special event) should be counted on sequential days or weeks at least one more and possibly two more times.”

Count Magnitude and Variability

If non-motorized traffic levels are high and consistent from day-to-day, then consider shorter periods and/or fewer days. However, you’ll need longer-duration count periods to determine how variable the non-motorized traffic is by time-of-day and day-of-week. Unfortunately, little quantitative guidance or consensus exists in this area. Ongoing research will improve future guidance.

Weather

Weather can play a significant role in the level and variability of non-motorized traffic. Consider its impact when developing a short-duration monitoring program. Pedestrians and bicyclists expect seasonal weather patterns (such as cold winters or hot/humid summers), so you should see relatively consistent patterns from year to year. However, heavy precipitation or unexpectedly hot or cold weather may introduce variations for a given day. These variations can both generate unusually high levels of activity (e.g., on a very nice day) or depress otherwise expected levels of activity (on days with inclement weather, for example).

If using automatic counters for short-duration counts in typical weather, the minimum suggested duration is 7 days (to account for weekday and weekend traffic). This duration provides an average of 5 weekdays and 2 weekend days. However, if atypical heavy precipitation or inclement weather occurs during this entire 7-day period, consider extending the duration to 14 days.

When heavy precipitation or inclement weather occurs with manual observers, extend the counts over multiple days at the same time. Use your own judgment based on local conditions to determine whether to include inclement-weather days into a multi-day average.

Because of inclement weather’s influence on non-motorized traffic, record weather conditions in a non-motorized traffic monitoring program. The three most important weather-related attributes are:

1. Precipitation (yes/no): Did measurable precipitation fall at some time during data collection?
2. High temperature: Approximate high temperature for either the day (if a day or longer count), or the high temperature during the duration of the count, if the count is less than a day in duration.
3. Low temperature: Approximate low temperature for either the day (if a day or longer count), or the high temperature during the duration of the count, if the count is less than a day in duration.

You can obtain historical weather data from several different sources. Weather data does not necessarily have to be collected at the exact count location.

Months/Seasons of the Year for Collecting Data

Choose the specific months/seasons of the year for short-duration counts that represent average or typical use levels. You can readily determine these levels from permanent continuous counters (thereby underscoring the importance of these automatic continuous counters). In most climates in the United States, spring and fall are considered representative of average annual non-motorized traffic levels. Areas with high-elevation trails or shorter visitor seasons may have different patterns of representative use.


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You can collect short-duration counts during other months/seasons of the year not considered average or typical. However, you’ll need a factoring process to adjust these counts to best represent an annualized estimate of non-motorized traffic. For example, if trail traffic is counted during an off-peak month, then those counts should be increased to better reflect an annual average that includes both peak and off-peak months.

**STEP 5. EXECUTE DATA COLLECTION PLAN**

A well-prepared data-collection plan can help ensure the smooth and efficient collection of high-quality data. There are several other practices that can also help:

- **Regular progress monitoring and reporting.** This is more important for larger data-collection efforts that occur over longer periods of time or involve multiple data-collection personnel.

- **Clear lines of communication.** Data collection personnel must often make decisions and adapt to changing conditions in the field. Clear lines of communication with a data-collection manager or office personnel helps field personnel make well-informed decisions. Also, good communication between data users and data collectors helps with the quality improvement cycle, such that data collectors can improve upon issues noted by data users.

- **Early data verification.** If using automatic counters for the first time, ensure early verification and validation of the count data. The worst-case scenario is installing automatic counters and then coming back in two weeks to find that no data or incorrect data were collected due to mechanical error. Confirming proper operation and valid data within the first few days of data collection will save time in the long run.

**STEP 6. ANALYZE, ADJUST, AND SUMMARIZE DATA**

Even after you have collected non-motorized count data, you still have work to do:

1. Perform quality assurance and review of the collected data.
2. Estimate missing count data values (if necessary).
3. Adjust raw count data for better estimates of actual trail counts and visitor use.
4. Summarize the data to desired time intervals (e.g., 15-minute or 60-minute subtotals) and locations (e.g., individual locations, for the entire trail length, etc.).

Many state transportation departments have data warehouse tools that already perform this analysis and summarization process for motorized traffic counts. You can use some of these same tools and analysis/summarization processes for non-motorized traffic counts. The amount of non-motorized data collected will influence decisions about whether to use data warehouse tools as opposed to doing manual analysis and summary using personal spreadsheet or database software. In short, crunching large amounts of data is usually much more efficient using data warehouse tools; manually analyzing and summarizing can prove more cost effective for smaller data sets.
Quality Assurance of Non-Motorized Traffic Count Data

Assuring Data Quality Prior to Collection

Remember: effective quality assurance starts before you collect data. In some cases, quality assurance is limited to reviewing and removing suspect or erroneous data already collected. Limiting quality-assurance steps to the post-data gathering phase, however, is ineffective in the long-term because doing so addresses only the symptom, not the root cause, of poor data quality.16

Effective quality assurance is an ongoing process that occurs before, during, and after data gathering and includes the following:

• Regular staff training and professional development.
• Effective equipment procurement procedures.
• Bench testing new field equipment.
• Thorough inspection and acceptance testing of new equipment installations.
• Regular equipment testing and calibration.
• Scheduled maintenance activities.
• Feedback from data users through various channels.

For example, consider a portable automated trail counter that gets rotated among various shared-use path locations. At a few of these locations, the counter reports unreasonably high trail usage. Upon review, the data analyst identifies the high trail counts and removes them from the data set. However, unless the analyst determines the root cause of these unreasonably high trail counts, the sensor will continue to collect inaccurate data. Removing inaccurate data after the fact is really only applying a Band-Aid to the problem.

In this example, an effective quality assurance process should:

1. Determine why the trail counter is reporting high volumes at certain locations.
2. Revise the procedures for identifying count locations and/or installing equipment.
3. Train data collection personnel in revised procedures.
4. Monitor future occurrences of unreasonably high trail counts and repeat above steps as necessary.

Automated Quality Checking Criteria

Manually reviewing traffic count data can be time consuming and tedious, especially when large amounts of data are involved.

Some database applications offer automated quality-checking criteria. These features provide a first line of defense in reviewing data, since they can automatically direct your attention to portions of the data set that deviate the most from expected patterns. This flagging of suspect data enables you to focus your visual review. Whether or not to ultimately accept this data as reliable is up to you.

However, current practice for relying on automated quality criteria for non-motorized traffic counts is fairly limited. As you might expect, many motorized traffic database applications that use automated quality criteria rely on thresholds and parameter values developed and refined for typical motorized traffic patterns. Because non-motorized traffic patterns vary greatly over time, there still exists a need to develop appropriate deviation thresholds and other parameters for using this technology when generating non-motorized traffic count data. At this time, targeted visual review of traffic counts is the recommended approach for quality control purposes.

Use of Targeted Manual Visual Review

Targeted visual review by trained staff can identify suspect data that might pass undetected by the automated processes. Don’t try to review all the collected data. Instead, visually review random data samples to ensure that any automated quality control processes are functioning properly.

Consider an analogy with a factory — you can’t test all widgets rolling off an assembly line for quality standards. Quality control managers will randomly pull a small sample of widgets for more in-depth testing or visual inspection to double-check the automated processes in place.

Several chart graphics can help you visually review the non-motorized traffic count data. Keep in mind, though, a balanced approach is desirable when visually inspecting data. You must review the information at a detailed enough level to identify erroneous data before it becomes averaged and “washed out” in summary statistics. Reviewing data in extreme detail, however, limits the number of locations you can visually inspect. Balancing volume of data with level of detail of data inspected is key to effective quality control. Several graphic types have proven useful in visually reviewing the quality of non-motorized traffic counts (see Figures 18 and 19).

These chart types are effective because you can compare anecdotal observations to the actual data. For example, in Figure 18, we expect to see a peak in trail usage every day, and this peak typically occurs at mid-day or in the evening after work hours. If the trail use is mostly recreational, we would also expect to see higher counts on the weekend days rather than the weekdays.

Similarly, in Figure 19, we can see how consistent the daily counts are across days. If the counts are much higher or lower for a particular day with no logical explanation, that could indicate inaccurate data. For example, lower counts on a rainy or cold day might be expected, but not on a day with pleasant weather. Higher-than-normal counts can be explained by special events or activities (e.g., charity bike rides or walks, school field trips, etc.).
Figure 18. Example 1, Chart Graphic Used to Visually Review Non-Motorized Traffic Counts

Mission Reach Trail Counts: Average Daily Bicycle Usage by Hour
Trail counter located just south of E. Theo Avenue, San Antonio, Texas

Figure 19. Example 2, Chart Graphic Used to Visually Review Non-Motorized Traffic Counts.

Mission Reach Trail Counts: Total Daily Bicycle Counts
Trail counter located just south of E. Theo Avenue, San Antonio, Texas
Estimate Missing Count Data

Most data collection activities involving automated counter equipment are likely to include periods of missing data. A number of things — from temporary hardware or software malfunction to equipment vandalism to quality control actions — can cause missing data. Once you’ve collected raw count data for a site and performed your due diligence for quality control, assess the extent of missing data.

The decision to estimate or replace missing data values depends on a number of factors:

- For what applications or decisions will the data be used?
- Will the missing data dramatically affect the final results?
- How much data is missing?
- If missing data is minor, can the missing data be easily estimated?
- If missing data is major, can additional data collection be performed?

There are a number of methods, ranging from simple to complex, to estimate missing data values. The choice of methods will depend on some of the factors described above, but also on the skill sets of the data analysts. The simplest methods (aside from removing days with incomplete data) involve using average or interpolated count values from similar days and time periods. The more complex methods are statistical approaches such as bootstrapping. The authors advise you to conduct further research on your own regarding these more complex methods if you think you need them.17, 18

Adjusting Raw Count Data

In most cases, you’ll need to adjust raw count data to accurately represent overall trail use and visitor counts. Depending on the equipment, duration of data collection, and summary information produced, you might need to make one or more of the following adjustments:

1. **Equipment Counting Error**: This factor adjusts for systematic undercounting that occurs when pedestrians or bicyclists pass the detection zone at the same time (e.g., side-by-side, closely following, or passing from different directions). Applies only to certain types of automatic counter equipment.

2. **Trail Counts vs. Unique Visitor Counts**: Automatic counters simply count the number of times someone passes in front of the sensor, not necessarily the unique number of visitors. For example, the same park visitor could hike out and back past the same counter (counting as “two” toward the trail count). If you need to know the number of unique visitors, then adjust the raw data using calibration factors.

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3. **Short-Duration Collection (Seasonal Adjustment):** If collecting count data for short periods of time (less than a full week), then adjust the raw data to account for varying use between weekdays and weekends. If you need annual estimates, use a monthly adjustment factor to calculate total or average annual use.

*Equipment Counting Error*

This adjustment factor accounts for systematic counting error that occurs during automatic data collection. Equipment counting errors occur most commonly with certain types of technology (such as infrared sensors) unable to detect multiple individuals passing near the sensor at the same time (e.g., side-by-side, closely following, or passing from different directions). However, you can use the equipment adjustment for any equipment type that routinely counts less or more than the actual number of trail users.

Manually counting trail traffic simultaneously with the automatic counter collecting data is the preferred method to calculate an equipment adjustment factor. The manual counts provide a reference point you can use to determine if the automatic counter is routinely under- or over-counting. You can then use the average error generated by the equipment adjustment factor to alter your count accordingly. For example, if an infrared counter consistently undercounts trail users by 20 percent, then the raw counts should be increased by 20 percent.

The equipment adjustment factor is likely to vary for different levels of trail traffic. For example, during peak hours, when a trail is very crowded, the degree of undercounting will likely be higher than times with low trail traffic. Therefore, you should manually collect a minimum of 4 to 6 hours of reference count data for each type of equipment. Schedule these hours to include a range of usage levels (if possible, light, moderate, and heavy use).

Develop an equipment adjustment factor for each installation location, if possible. However, if it’s not possible to conduct manual data collection at each location, use adjustment factors for trails with similar traffic levels. When using this strategy, it’s important to ensure the consistency of installation (e.g., mounting height, equipment settings, etc.) across locations.

*Trail Counts vs. Unique Visitor Counts*

As mentioned, automatic counters do not differentiate unique visitors. To determine the number of unique visitors, adjust the raw counts (i.e., divide by 1+n, where n is the decimal fraction of people passing the counter twice). For example, on a typical out-and-back trail, all hikers will pass a given counter twice: once on the way out and once on the way back. To determine the actual number of hikers (rather than the number of counts), divide the trail count by 2 (i.e., divide by 1 + 1, assuming 100 percent of trail users pass the counter twice).

On a loop trail where users are most likely to pass the counter only once, no user adjustment factor is needed (i.e., divide by 1 + 0, assuming 0% of trail users pass the counter twice). For trails in a network with out-and-back and loop travel, the denominator should be between 1 and 2, depending on how
many trail users are estimated to be passing the counter twice. If 50 percent of the trail users pass the counter twice, then divide the raw trail count by 1.5 (or 1 + 0.5).

You can determine the percentage of trail users passing the counter in several ways. Previous or ongoing visitor surveys might ask about typical trail origins and destinations. If you’re installing multiple counters on a trail network, you can infer certain information about most likely paths. Or, in some cases, GPS tracking data may be available. Finally, you can use limited/informal sampling and/or local knowledge to estimate typical trail use patterns.

*Short-Duration Collection (Seasonal Adjustment)*

If you need average annual statistics from short-duration counts, adjust these counts to account for variation in non-motorized traffic in different seasons. For example, if conducting short-duration counts during a busy month of the year, don’t simply assume that this busy month accurately represents an annual average.

In motorized vehicle monitoring, personnel install permanent monitoring locations to capture the seasonal variation, and then provide seasonal adjustments to short-duration counts using traffic ratios from permanent locations in a traffic pattern group. Depending on the count duration, you might need one or more of these traffic ratios:

1. **Day-of-week:** If collecting data on a single weekday or weekend day, the day-of-week ratio adjusts a single or multiple day-of-week count to an average daily count (weekday or weekend).
2. **Month-of-year:** If collecting less than a full year of data, the month-of-year ratio adjusts an average daily count to an average annual daily count.

Calculate these traffic ratios for each distinct traffic pattern group (groups of permanent counters with similar traffic patterns). The permanent counters in each pattern group provide year-round non-motorized traffic counts and permit these short-duration counts to be annualized in a way that minimizes error.

**Equation 1:** Average Annual Daily Traffic = (Average Daily Count Month M / (Traffic Ratio Month M)

The calculation of traffic ratios is fairly straightforward based on continuous data from permanent counter locations (Equation 2). Adjust short-duration counts using the following equation:

**Equation 2:** Traffic Ratio for Month M = Month M average daily traffic / Annual average daily traffic

For example, consider that we collect an average daily count of 370 trail user during the month of April from a short-duration location. From a permanent counter location, we used Equation 2 to calculate an April traffic ratio of 1.05. The average annual daily traffic estimate (from Equation 1) is 370 / 1.05, or 352 average annual daily users.
**Base Time Intervals for Data Collection and Storage**

Many different ways to summarize and report non-motorized traffic count data exist (Step 7 covers this topic). However, you must be able to calculate all these different data reports and summaries from the base time interval used to collect and store the non-motorized traffic data.

For example, you can’t report 5-minute traffic counts if the raw data is stored in 60-minute time intervals. It’s important, whenever possible, to think through all possible uses of the count data before designating a base time interval for data collection and storage.

Most automatic trail counters can store and summarize data in several different time intervals (e.g., 15-minutes, 60-minutes, daily, etc.). For many situations, 60-minute summaries (that is, count subtotals for every hour) are sufficient to capture daily use patterns. Average daily traffic counts (hourly counts combined for each day, then averaged across multiple days) are commonly used to indicate overall use level. Even though average daily traffic counts are a popular summary interval, you should store the raw traffic count data at more detailed time intervals to allow more flexibility when summarizing.

Some trail counter equipment manufacturers can store traffic counts on an event basis. That is, they can store the exact time when each pedestrian or bicyclist passed through the sensor. This detailed, event-based data is useful in certain types of detailed analysis and research. And, if disk storage space is not an issue, it provides the most flexibility for summarizing data for different time intervals.

Some automatic counter equipment can distinguish pedestrians from bicyclists and count them separately. When possible, subtotal the pedestrian and bicyclist counts separately; you can easily combine traffic counts from the two modes later. However, if you combine pedestrian and bicyclist counts before data storage, there is no easy way to recreate the separate counts later.

After selecting the base time interval for data storage, a number of tools and software exist to use in summarizing the count data. Several equipment manufacturers provide proprietary analysis software with pre-programmed report and chart templates. Other equipment manufactures provide text-delimited data files for importing into spreadsheet and database applications (like Microsoft Excel or Access) for customized summary and analysis.

**Step 6 Summary**

To produce understandable results from your monitoring activities, you first have to accurately analyze and summarize the data. To do that, your data must be reliable and complete. Data quality assurance is an ongoing process that starts before you ever begin counting. For example, regular staff training and equipment testing, inspection, and calibration are essential to producing consistent data.

Although tools exist to automate counts, current software and equipment limitations still require significant manual review of random data samples to ensure the consistency of information produced for non-motorized traffic counts. Using visual representation of automated vs. manual counts can help you identify counting anomalies that require further attention to correct.

Generally speaking, you’ll need to perform some kind of data adjustment to accurately represent your non-motorized traffic volumes (e.g., to account for sensors that can’t discretely identify a single person
counted multiple times by the same sensor). Methods and equations presented in this chapter can help you adjust your counts for accuracy.

Perhaps the single most important consideration when determining how to collect and store raw data is choosing the base time interval. Always choose the smallest base time interval for which you need reportable data.

**STEP 7. REPORT AND COMMUNICATE RESULTS**

Once traffic count data have passed quality assurance and been summarized and seasonally adjusted (if necessary), it's time to communicate the results of your monitoring. Too often, big-picture results are drowned in an endless sea of data tables, charts, and numbers. Some technical staff are content to simply “report the numbers.” Effective reporting, however, means:

- Making the information understandable and accessible to non-technical audiences.
- Interpreting the results correctly and putting them into context.
- Being proactive about communicating both good and bad news.

This section illustrates effective ways to report non-motorized traffic count information to a wide variety of audiences. The three levels of detail for reporting non-motorized traffic counts addressed in this chapter are:

- Regional/area-wide or multiple trails/corridors.
- Individual trail/corridor (possibly multiple locations).
- Individual location.

Differentiating these three levels of detail is not always easy. For our purposes, these levels are used as a way to organize the many examples contained within this chapter.

**High-Level Reporting: Regional/Area-wide or Multiple Corridors**

This is the least-detailed (i.e., biggest picture) reporting level, and includes traffic count and facility usage data from two or more unique trails, corridors, or facilities. The thing to remember when reporting on regional/area-wide or multiple corridors is that you’re including multiple trails and/or facilities that could have very different levels and patterns of use. So, making accurate generalizations that apply to all facilities can be tricky.

The most effective reporting at this level typically shows change in usage over time (commonly year to year). Figure 20 shows a sample three-year chart illustrating growth in usage on the Intertwine trail network in Portland, Oregon. Note how easy it is to see the growth. Even without numbers attached to each of the bars, growth is evident across years. (Having said that, showing precise numbers always supports the perception that findings are statistically sound, providing that the numbers themselves don’t confuse the viewer.)
Table 3 shows percentage growth in bicycle use in different parts of the city of Portland, Oregon. With enough effort, the viewer might be able to see the trends highlighted here, but often large tables with lots of numbers can confuse readers, particularly when it’s not clear what information you’re trying to highlight.

**Figure 20. Example Chart Showing Growth in Regional Trail Traffic**

![Bar chart showing growth in Intertwine use](image)


**Table 3. Example Table Showing Growth in Bicycle Use by District/Location within Portland**

<table>
<thead>
<tr>
<th>DISTRICT/LOCATION</th>
<th>% CHANGE SINCE 2000/01</th>
<th>BASED ON # LOCATIONS</th>
<th>% CHANGE SINCE 2009</th>
<th>BASED ON # LOCATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citywide Total</td>
<td>189%</td>
<td>32</td>
<td>6.8%</td>
<td>109</td>
</tr>
<tr>
<td>Central City (west side)</td>
<td>243%</td>
<td>6</td>
<td>6.3%</td>
<td>13</td>
</tr>
<tr>
<td>North</td>
<td>367%</td>
<td>2</td>
<td>7.0%</td>
<td>7</td>
</tr>
<tr>
<td>Northeast</td>
<td>80%</td>
<td>5</td>
<td>7.5%</td>
<td>15</td>
</tr>
<tr>
<td>Southeast</td>
<td>234%</td>
<td>7</td>
<td>2.9%</td>
<td>24</td>
</tr>
<tr>
<td>East</td>
<td>Na</td>
<td>Na</td>
<td>9.5%</td>
<td>17</td>
</tr>
<tr>
<td>Northwest</td>
<td>93%</td>
<td>4</td>
<td>2.0%</td>
<td>10</td>
</tr>
<tr>
<td>Southwest (excluding Central City)</td>
<td>133%</td>
<td>8</td>
<td>19.0%</td>
<td>24</td>
</tr>
</tbody>
</table>

Other reports at this level might include user characteristics, such as mode of travel, trip purpose, gender, helmet use, etc. For example, Figure 21 shows overall mode share on the Intertwine trail network, and Figure 22 illustrates trip purpose for each travel mode. Note again the simplicity of the information presented and how easily accessible it is to the lay reader compared to Table 3.

**Figure 21. Example Chart Showing Mode of Travel on Regional Trail Network**

![Pie chart showing mode share](chart1)


**Figure 22. Example Chart Showing Trip Purpose by Travel Mode**

![Bar chart showing trip purpose](chart2)

MID-LEVEL REPORTING: SINGLE TRAIL OR CORRIDOR (POSSIBLY MULTIPLE LOCATIONS)

Intermediate reporting level includes traffic count and usage data at the trail or corridor level. For longer trails or corridors, you might collect data at multiple locations. If you’ve only collected count data at a single location, your reports should explicitly state whether that location represents the entire length of the trail or corridor.

Like regional or area-wide reporting, this level of detail typically illustrates growth over time. Another common theme is reporting most heavily used trails or corridors in a region or park. Figure 23 shows the five busiest trails in Portland, Oregon, and illustrates the types of trail users on each (i.e., bicyclists, pedestrians, and other users). Figure 24 combines both elements (growth and individual corridor traffic) and shows bicyclist counts at four different bridge crossings over a 20-year period.

Annotated maps, like that shown in Figure 25, are effective at showing the location and relative use levels in a larger geographic region. This more detailed level of reporting can also include user characteristics such as mode of travel, trip purpose, gender, helmet use, etc.

Figure 23. Example Chart Showing Busiest Trails in the Region

Figure 24. Example Chart Showing Bicycle Traffic Growth on Four Bridges

Source: City of Portland, Oregon
Figure 25. Example Map Showing Trail Locations and Relative Use Levels

LOW-LEVEL REPORTING: INDIVIDUAL LOCATIONS

Individual locations are the basic unit of data collection and do not require combining data from multiple data collection sites. Non-motorized traffic count and usage data at individual locations is the most detailed reporting level and the most commonly seen since most automatic counter equipment software can easily create individual location reports.

You can report the same types of information at individual locations or the more aggregated levels. Examples of this information include:

- Change in use over time.
- User characteristics (travel mode, trip purpose, etc.).
- Locations with highest use levels.

With individual locations, more detailed information about traffic patterns becomes relevant and useful for decision-making. For example, you can develop charts showing use by time of day (Figure 26), day of week (Figure 27), and month of year (Figure 28) to understand how traffic patterns at a specific location vary.

Figure 26. Example Chart Showing Traffic Patterns by Time of Day

When compiling data from numerous individual locations, it’s easy to become overwhelmed with the amount of information available to you. To convey just the basic facts for each location, dashboard graphics are a simple and effective communications tool. One example of the dashboard principle is shown in Figure 29 and includes two prominent elements:

- Number of bicyclists/pedestrian counted thus far today.
- Number of bicyclists/pedestrian counted thus far this year.
This Internet-based dashboard display also includes a clickable interface that shows more detailed charts of:

- Daily total counts for the most recent 30 days.
- Daily total counts since installation (or other preferred start date).
- Weekly total counts.
- Monthly total counts.
- Average and maximum weekday, weekly, and monthly count.

Map-based displays (Figure 30) are also effective for quickly identifying locations that have the highest use levels.
Figure 30. Example Map Graphic Showing Relative Pedestrian Traffic Levels at Selected Locations

STEP 8. MAKE DECISIONS BASED ON RESULTS

Once you have reported the results, it’s time to make better-informed decisions using them. Although these decision-making processes are not addressed in this report, there is one aspect that should be mentioned here:

- **Ensuring that data collection goals have been met.** Data users should assess whether the collected data meets their needs. If not, you should clearly communicate required improvements to data-collection personnel, who should then consider rolling these quality improvements into future data-collection cycles.

STEP 9. IMPROVE QUALITY IN FUTURE CYCLES

A fundamental principle of the Plan-Do-Check-Act cycle (and quality management cycles in general) is the iterative nature — or continuous improvement — inherent in the process. That is, once the cycle has been completed, seek feedback and incorporate quality improvements (based on the collected data) into future process cycles.

Continued repetition of this process cycle — with continuous quality improvements rolled back into the cycle itself — will result in data that consistently meets or exceeds the needs of data users (even when data needs evolve, as is often the case). Important elements of this step include:

- Commitment and dedication to quality improvement.
- Clear and honest communication between data users and data collectors.
- Resources available to effect quality improvement.

CHAPTER SUMMARY

This chapter described a generalized trail use monitoring process, and provided detail for the essential process elements. The following sections summarize the most important points.

**Step 1. Identify Uses and Users & Step 2. Define Required Data**

The first two steps to monitoring traffic is to determine what you want to monitor and for what purpose(s). Determining these parameters will help you frame the scope of the overall monitoring effort.

**Step 3. Identify Data Collection Tools**

Choosing the right automatic counting equipment depends on:

1. Determining what you need the data for,
2. Understanding the equipment options available, and
3. Knowing the budget and personnel you can afford to devote to the task.
Figure 5 in this chapter can help you do all three.

Technology options available for counting non-motorized traffic include inductance loop detectors, active- and passive-infrared sensors, magnetometers, pneumatic tubes, pressure and seismic sensors, and video image processing. However, not all technologies are created equal. You must balance cost effectiveness with data accuracy and hands-on requirements (e.g., training personnel on equipment). For example, monitoring personnel who review video imaging equipment can easily distinguish pedestrians from bicyclists, but doing so requires dedicating personnel to the task. More traditional, proven technologies – like pneumatic tubes – are low cost and portable for counting bicyclists but don’t count pedestrians. By combining your determination of what you’re counting and why (using Figure 5) and your assessment of technology capabilities and limitations (Table 1), you can pick the solution that suits your agency best.

Whatever technology you choose, determine first what is acceptable in terms of accuracy, and then create calibration/validation procedures to ensure it. Talking to peer agencies that have made similar efforts at counting non-motorized traffic can benefit you with their lessons learned.

By the time this report is published, new (or refined older) technologies might have already emerged to meet the growing market for counting non-motorized traffic. So don’t hesitate to research some options on your own using the Internet. Searching on key words like “non-motorized, traffic, count, bicycle, pedestrian,” etc., are an excellent way to find the latest technologies available. Just remember to try and independently evaluate (e.g., via independent research) vendor claims of performance or capability.

Step 4. Develop Data Collection Plan

Choose representative geographic locations within your federal land and appropriate time durations and frequencies for counting. Since you can’t always monitor every location for which you want count data, combining permanent and short-duration monitoring techniques can help you maximize resources while still obtaining the necessary data. Permanent sites provide continuous data that, once properly analyzed, you can use to generalize findings from short-duration counts (normally only relevant to their limited geographic areas). Assigning traffic pattern groups to count sites and generating a traffic pattern profile from each group will create reliable, representative data.

Select permanent and short-duration monitoring sites carefully. Consider, for example, whether you intend to differentiate between pedestrian and bicycle traffic when choosing permanent sites. Follow this chapter’s criteria to optimize permanent site locations and properly position monitors, based on equipment limitations, to achieve the most accurate results.

When selecting short-duration sites, choose targeted locations where activity levels and professional interest is highest. How many short-duration sites you choose depends on your available budget and how you intend to use the data you gather. Working with other stakeholders who need the data can help you prioritize short-duration count locations.

Conduct automated counts for 7 to 14 days. How long you scope your automated counts depends on variable factors including weather. Though many agencies conduct manual counts for 2-hour periods,
the authors recommend you schedule them for 4 to 12 hours, offering short breaks (or assigning personnel in 2-hour shifts) to offset declines in count accuracy resulting from human fatigue.

**Step 5. Execute Data Collection Plan**

A well-prepared data-collection plan can help ensure the smooth and efficient collection of high-quality data. There are several other practices that can also help:

- Regular progress monitoring and reporting
- Clear lines of communication
- Early data verification

**Step 6. Analyze, Adjust, and Summarize Data**

To produce understandable results from your monitoring activities, you first have to accurately analyze and summarize the data. To do that, your data must be reliable and complete. Data quality assurance is an ongoing process that starts before you ever begin counting. For example, regular staff training and equipment testing, inspection, and calibration are essential to producing consistent data.

Although tools exist to automate counts, current software and equipment limitations still require significant manual review of random data samples to ensure the consistency of information produced for non-motorized traffic counts. Using visual representation of automated vs. manual counts can help you identify counting anomalies that require further attention to correct.

Generally speaking, you’ll need to perform some kind of data adjustment to accurately represent your non-motorized traffic volumes (e.g., to account for sensors that can’t discretely identify a single person counted multiple times by the same sensor). Methods and equations presented in this chapter can help you adjust your counts for accuracy.

Perhaps the single most important consideration when determining how to collect and store raw data is choosing the base time interval. Always choose the smallest base time interval (e.g., 5 minutes) for which you need reportable data.

**Step 7. Report and Communicate Results**

Once traffic count data have passed quality assurance and been summarized and seasonally adjusted (if necessary), it’s time to communicate the results of your monitoring. Too often, big-picture results are drowning in an endless sea of data tables, charts, and numbers. Some technical practitioners are content to simply “report the numbers.” Effective reporting, however, means:

- Making the information understandable and accessible to non-technical audiences.
- Interpreting the results correctly and putting them into context.
- Being proactive about communicating both good and bad news.

The three levels of detail for reporting non-motorized traffic counts addressed in this chapter are:
• Regional/area-wide or multiple trails/corridors.
• Individual trail/corridor (possibly multiple locations).
• Individual location.

Step 8. Make Decisions Based on Results

Once you have reported the results, it’s time to make better-informed decisions using them. Also, data users should assess whether the collected data meets their needs. If not, you should clearly communicate required improvements to data-collection personnel, who should then consider rolling these quality improvements into future data-collection cycles.

Step 9. Improve Quality in Future Cycles

A fundamental principle of the Plan-Do-Check-Act cycle (and quality management cycles in general) is the iterative nature – or continuous improvement — inherent in the process. That is, once the cycle has been completed, seek feedback and incorporate quality improvements (based on the collected data) into future process cycles.
CHAPTER 3—RESULTS & DISCUSSION

This chapter describes the application and testing of the generalized monitoring process described in Chapter 2. The generalized process was applied at two different national parks, which are also introduced and described in this chapter.

INTRODUCTION OF CASE STUDY EXAMPLES

San Antonio Missions National Historical Park

This park includes four historical Spanish missions along the San Antonio River, extending from 3 miles south to 9 miles south of downtown San Antonio (Figure 31).

A shared-use path (i.e., hike-and-bike trail) within existing park boundaries has connected the southernmost missions for some time. More recently, the Mission Reach Ecosystem Restoration and Recreation Project is restoring the river habitat and adding various amenities, including 15 miles of paved concrete shared-use path.

Totaling $245.7 million, the Mission Reach improvements are expected to significantly increase recreational activity along the river and non-motorized traffic between the project area and into the National Historical Park. The Mission Reach improvements also involve multiple federal and local agencies in the planning, design, construction, operation, and maintenance of the facility.

Guadalupe Mountains National Park

This park in rural West Texas includes the southern portion of the Guadalupe Mountains, an exposed fossil reef that was formed about 250 million years ago.

The park encompasses 135 square miles of rugged desert terrain (Figure 32), including high-elevation forests and the highest point in Texas, Guadalupe Peak at 8,751 feet. Large portions of the park have been designated as a wilderness area (per the Wilderness Act of 1964), and there are about 80 miles of hiking trails, many of which traverse the wilderness area.
Figure 31. Overview Map of Mission Reach Trail and San Antonio Missions National Historical Park

Source: Adapted from San Antonio River Authority graphic file
Figure 32. Overview Map of Guadalupe Mountains National Park

Source: Adapted from National Park Service graphic file
STEP 1. IDENTIFY USES AND USERS

San Antonio Missions National Historical Park

Because of the level of investment and involvement, multiple stakeholders (including the National Park Service, San Antonio River Authority, and the City of San Antonio) decided to document the number of people using the Mission Reach trail system. The first step involved compiling a list of how these stakeholder agencies would use the count data (Step 1. Identify Uses and Users). The following list of data-use purposes resulted:

- Monitor overall usage levels to justify the capital investment.
- Monitor before-and-after usage levels on different trail sections as they are opened to the public.
- Determine how usage levels (considering walking and biking separately) varied along the trail and between the missions.
- Estimate demand and plan locations for bike sharing kiosks.
- Measure and report usage for special (e.g., education, interpretative, and recreational) events.
- Measure non-motorized visitor access to the National Historical Park for possible inclusion in NPS-required monthly visitor statistics.

Guadalupe Mountains National Park

Park staff wanted to measure the level of use on the trail network, since existing information was mostly anecdotal. Because the park is in a remote area, the National Park Service was the primary stakeholder and data user. The following list of uses was developed:

- Monitor overall usage levels on the most popular front-country trails for multiple purposes, including trail maintenance.
- Monitor maximum usage levels on trails in the wilderness area to ensure “opportunities for solitude” exist (as required by the Wilderness Act of 1964).
- Measure trail use to determine compliance with hiker self-registration and honor-based fee collection at trailheads.

Park staff indicated that there was not a need to separately count different types of trail users. Bicycles are prohibited on trails within the park, and equestrians accounted for only a small portion of trail users as compared to hikers. The 80-mile trail network includes out-and-back trails, loop trails, and point-to-point trails that connect the three different park entrances.
STEP 2. DEFINE REQUIRED DATA

Step 2 was simplified in these case studies, as park staff at both locations was focused solely on one data attribute: counts of trail traffic at both parks. Therefore, the required data was defined to be trail traffic counts.

STEP 3. IDENTIFY DATA COLLECTION TOOLS

San Antonio Missions National Historical Park

Based on stakeholder discussions about data uses in San Antonio, park personnel established the following criteria for selecting counter equipment for the Mission Reach Trail:

- The equipment should count pedestrians and bicyclists separately.
- The equipment should distinguish between travel directions.
- Counts were needed at several different locations along the trail, and potentially at several locations between the trail and individual mission entrances.
- The equipment must be compatible with a paved concrete trail surface.
- At least one location should be permanent to provide continuous data year round.

With these considerations as context, park personnel used Figure 5 and Table 1 to narrow the list of technology options as follows:

- Video imaging is the only “all-in-one” technology capable of distinguishing pedestrians and bicyclists. However, it is the most expensive solution, and commercial products are limited.
- To count bicyclists separately and inexpensively, inductance loops or magnetometers are the most viable options at permanent locations. Personnel can use pneumatic tubes on a temporary basis.
- To count pedestrians separately, infrared sensors are the most cost-effective technology option. Infrared sensors can be installed on a permanent or temporary basis.

Therefore, based on the equipment budget and commercial product availability, the following counter equipment was obtained for monitoring the Mission Reach trail (circled in Figure 33):

- For permanent installation, a combined infrared-inductance loop counter capable of counting pedestrians and bicyclists separately, as well as determining direction of travel. The specific brand and model selected was the Eco-Counter Eco-MULTI system.
- A portable infrared counter for collecting data several weeks at a time, then rotated among several different monitoring locations. The portable infrared counter can determine travel direction but cannot differentiate between pedestrians and bicyclists. The specific brand and model selected was the Eco-Counter Eco-PYRO counter.
**Guadalupe Mountains National Park**

Based on stakeholder discussions of data use, park personnel established the following criteria for selecting counter equipment for the hiking and equestrian trails in Guadalupe Mountains National Park:

- The equipment should count persons using the trail. Differentiating hikers from equestrians is not required, but would be helpful.
- The equipment must be compatible with natural surface trails used by both hikers and horseback riders.
- Distinguishing the direction of trail travel is not required.
- The equipment should support permanent installation but should also be portable among monitoring locations on numerous different hiking trails.

With these considerations as context, park personnel used Figure 5 and Table 1 to narrow the list of technology options as follows:

- Pressure/seismic sensors are a viable option, as are both active and passive infrared sensors.
- Pressure/seismic sensors are a more permanent solution than infrared sensors.

---

### Figure 33. Selecting Counter Equipment for Mission Reach Trail, San Antonio

<table>
<thead>
<tr>
<th>Technology</th>
<th>Bicyclists Only</th>
<th>Pedestrians Only</th>
<th>Pedestrians &amp; Bicyclist Combined</th>
<th>Pedestrians &amp; Bicyclist Separately</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inductance Loops(^1)</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>$$$</td>
</tr>
<tr>
<td>Magnetometer(^2)</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td></td>
<td>$-$$</td>
</tr>
<tr>
<td>Pressure Sensor(^2)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
<td>$-$$</td>
</tr>
<tr>
<td>Radar Sensor</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
<td>$-$$</td>
</tr>
<tr>
<td>Seismic Sensor</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td></td>
<td>$-$$</td>
</tr>
<tr>
<td>Video Imaging: Automated</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
<td>$-$$</td>
</tr>
<tr>
<td>Infrared Sensor (Active or Passive)</td>
<td>○(^3)</td>
<td>●</td>
<td>●</td>
<td></td>
<td>$-$$</td>
</tr>
<tr>
<td>Pneumatic Tubes</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td></td>
<td>$-$$</td>
</tr>
<tr>
<td>Video Imaging: Manual</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
<td>$-$$</td>
</tr>
<tr>
<td>Manual Observers</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td>$-$-$$</td>
</tr>
</tbody>
</table>

\(^1\) Indicates what is technologically possible.
\(^2\) Indicates a common practice, but must be combined with another technology to classify pedestrians and bicyclists separately.
\(^3\) Typically requires a unique loop configuration separate from motor vehicle loops, especially in a traffic lane shared by bicyclists and motor vehicles.

Based on stakeholder discussions of data use, park personnel established the following criteria for selecting counter equipment for the hiking and equestrian trails in Guadalupe Mountains National Park:

- The equipment should count persons using the trail. Differentiating hikers from equestrians is not required, but would be helpful.
- The equipment must be compatible with natural surface trails used by both hikers and horseback riders.
- Distinguishing the direction of trail travel is not required.
- The equipment should support permanent installation but should also be portable among monitoring locations on numerous different hiking trails.

With these considerations as context, park personnel used Figure 5 and Table 1 to narrow the list of technology options as follows:

- Pressure/seismic sensors are a viable option, as are both active and passive infrared sensors.
- Pressure/seismic sensors are a more permanent solution than infrared sensors.
Depending upon pricing and availability, pressure/seismic sensors could be more expensive than low-cost infrared sensors. Therefore, based on the equipment budget and commercial product availability, personnel obtained the following counter equipment for monitoring the park’s hiking trails (circled in Figure 34):

- Multiple, low-cost passive infrared trail counters. Each trail counter was outfitted in a vandal-resistant metal enclosure that could be used for temporary or permanent installations. The specific brand and model selected was the TRAFx infrared counter.
- The infrared counters are incapable of reporting trail traffic by direction. For out-and-back trails, personnel will need to adjust the raw counts to estimate the number of unique visitors.
- If desired, personnel can use two infrared counters (the first one mounted at hiker height, the second mounted at horseback height) to separately count hikers and horseback riders.

**Figure 34. Selecting Counter Equipment for Guadalupe Mountains National Park**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>Inductance Loops¹</td>
<td>●</td>
<td></td>
<td></td>
<td>◼</td>
<td>$5</td>
</tr>
<tr>
<td></td>
<td>Magnetometer²</td>
<td>○</td>
<td>○</td>
<td></td>
<td>●</td>
<td>$-$ $5</td>
</tr>
<tr>
<td></td>
<td>Pressure Sensor²</td>
<td>○</td>
<td>○</td>
<td></td>
<td>●</td>
<td>$5</td>
</tr>
<tr>
<td></td>
<td>Radar Sensor</td>
<td>○</td>
<td>○</td>
<td></td>
<td>●</td>
<td>$-$ $5</td>
</tr>
<tr>
<td></td>
<td>Seismic Sensor</td>
<td>○</td>
<td>○</td>
<td></td>
<td>●</td>
<td>$5</td>
</tr>
<tr>
<td></td>
<td>Video Imaging: Automated</td>
<td>○</td>
<td>○</td>
<td></td>
<td>●</td>
<td>$-$ $5</td>
</tr>
<tr>
<td></td>
<td>Infrared Sensor (Active or Passive)</td>
<td>○³</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>$-$ $5</td>
</tr>
<tr>
<td></td>
<td>Pneumatic Tubes</td>
<td>●</td>
<td></td>
<td></td>
<td>●</td>
<td>$-$ $5</td>
</tr>
<tr>
<td></td>
<td>Video Imaging: Manual</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>$-$ $5</td>
</tr>
<tr>
<td></td>
<td>Manual Observers</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>$-$ $5</td>
</tr>
</tbody>
</table>

- ○ Indicates what is technologically possible.
- ● Indicates a common practice.
- ◼ Indicates a common practice, but must be combined with another technology to classify pedestrians and bicyclists separately.
- $, $-$, $-$-$-$: Indicates relative cost per data point.

¹ Typically requires a unique loop configuration separate from motor vehicle loops, especially in a traffic lane shared by bicyclists and motor vehicles.
² Permanent installation is typical for asphalt or concrete pavements; temporary installation is possible for unpaved, natural surface trails.
³ Requires specific mounting configuration to avoid counting cars in main traffic lanes or counting pedestrians on the sidewalks.
STEP 4. DEVELOP DATA COLLECTION PLAN

San Antonio Missions National Historical Park

Based on the guidance in Chapter 2, one permanent monitoring location and five short-duration monitoring locations were designated along the Mission Reach trail (Figure 35).

Permanent Monitoring Location

We designated a permanent monitoring location because of the stakeholders’ strong interest in monitoring trail traffic on a year-round basis. One permanent location was deemed adequate for the entire length of Mission Reach trail. We expect overall usage levels to change along the trail (based on nearby attractions). However, the relative use patterns (how traffic varies by day-of-week and month-of-year) should be consistent along the entire trail length, and these initial expectations were verified using the ongoing data collection along Mission Reach.

The location of the single permanent monitoring location is in the northern portion of the Mission Reach trail, just south of the northernmost Mission Concepción (Figure 35). Ideally, we would have located the permanent location on central portions of the trail (near Mission San José); however, trail construction and counter equipment installation schedules did not match, so choosing a more northern permanent location was necessary.

Short-Duration Monitoring Locations

We chose five trail locations for short-duration monitoring (see Figure 35), at which we placed a portable automatic counter for multiple days on a periodic basis (Table 4). We chose the five locations based on major attractions along the trail (e.g., the historic Spanish missions). In most cases, these monitoring sites were situated about midway between the missions to capture primarily those people biking or walking between the missions along the trail. People who don’t venture far from the missions will likely not be captured at these midway locations. However, other attractions (e.g., city parks and other historical sites) in the vicinity will attract some, so the counts should capture some of these travelers.

Since we used portable automatic counters, we scoped these short-duration counts for at least 14 days. At a bare minimum, 7 days’ worth of data should be collected to account for traffic occurring each day of the week. However, only having five monitoring locations enabled us to collect more days of data at each location. Had we chosen 10 or more short-duration locations for an extensive trail network, we would have reduced these short-duration counts to 5 to 7 days.

To determine the frequency of short-duration counts, one should consider the uses and users of the data as well as the growth rate of trail traffic. Agencies typically perform short-duration monitoring for non-motorized traffic annually. However, when building new facilities, agencies might collect short-duration counts several times per year during the initial phases of construction.
Figure 35. Selected Monitoring Locations Along Mission Reach Trail, San Antonio
Table 4. Planned Mission Trail Count Locations near San Antonio Missions NHP

<table>
<thead>
<tr>
<th>Point of Interest/Access</th>
<th>Counter Location</th>
<th>Dates of Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roosevelt Park/Lone Star Boulevard (start of trail)</td>
<td>Between Steves Avenue and Mitchell Street</td>
<td>March 8-21, 2012</td>
</tr>
<tr>
<td>Mission Concepción/Concepción Portal</td>
<td>Between Theo Avenue and Mission Road</td>
<td>Continuous counter, since February 3, 2012</td>
</tr>
<tr>
<td>Mission Road trail access</td>
<td>Trail under construction</td>
<td>Trail under construction, no data collection</td>
</tr>
<tr>
<td>Mission San José/Mission County Park/Padre Park</td>
<td>Between Napier Ave and SE Military Drive</td>
<td>March 23-April 4, 2012</td>
</tr>
<tr>
<td>Espada Park</td>
<td>Trail under construction</td>
<td>Trail under construction, no data collection</td>
</tr>
<tr>
<td>Espada Aqueduct/Mission San Juan Capistrano</td>
<td>Between Espada Road access point and IH-410</td>
<td>April 6-19, 2012</td>
</tr>
<tr>
<td>Mission Espada/Mission Reach Trail terminus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Guadalupe Mountains National Park**

Based on the guidance in Chapter 2, we designated eight short-duration monitoring locations along Guadalupe Mountain National Park hiking trails (see Figure 36). This approach is more appropriate for the moderate visitation and data collection resources of more remote national parks.
Figure 36. Selected Monitoring Locations in Guadalupe Mountains National Park

Permanent Monitoring Location

We didn’t designate a permanent non-motorized monitoring location here. Instead, we used year-round visitor counts collected at the three main park entrances (i.e., Pine Springs, McKittrick Canyon, and Dog Canyon) to seasonally adjust the short-duration trail counts.

Short-Duration Monitoring Locations

We chose eight different hiking trails for short-duration trail counts (see Figure 36), at which we placed a portable automatic counter for multiple days on a periodic basis (Table 5). The eight hiking trails were chosen based on several factors:
• Front-country access with moderate to high expected trail use.
• Trails highlighted in park brochures.
• Park staff interest.
• Trails that may be nearing wilderness thresholds.

Because of relatively low use levels, no monitoring locations were designated on back-country trails (e.g., Bush Mountain Trail, Tejas Trail) or trails near the Dog Canyon park entrance.

Table 5. Planned Trail Count Locations in Guadalupe Mountains National Park

<table>
<thead>
<tr>
<th>Trail</th>
<th>Counter Location</th>
<th>Dates of Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guadalupe Peak Trail</td>
<td>15-minute hike past junction with steep ascent of Guadalupe Peak Trail</td>
<td>March 10-21, 2012</td>
</tr>
<tr>
<td>Devil’s Hall Trail</td>
<td>15-minute hike past junction with gentler ascent of Guadalupe Peak Trail</td>
<td>March 10-21, 2012</td>
</tr>
<tr>
<td>Smith Spring Trail</td>
<td>Eastern side of loop in wooded area just prior to Smith Spring</td>
<td>March 10-21, 2012</td>
</tr>
</tbody>
</table>

--- Reposition counters on March 22 ---

<table>
<thead>
<tr>
<th>Trail</th>
<th>Counter Location</th>
<th>Dates of Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mckittrick Canyon Trail</td>
<td>First suitable mounting location after a 15-minute hike from trailhead</td>
<td>March 23-April 4, 2012</td>
</tr>
<tr>
<td>Permian Reef Trail</td>
<td>First suitable mounting location after a 15-minute hike from trailhead</td>
<td>March 23-April 4, 2012</td>
</tr>
<tr>
<td>Mckittrick Canyon Nature Loop</td>
<td>First suitable mounting location after a 15-minute hike from trailhead</td>
<td>March 23-April 4, 2012</td>
</tr>
</tbody>
</table>

--- Reposition counters on April 5 ---

<table>
<thead>
<tr>
<th>Trail</th>
<th>Counter Location</th>
<th>Dates of Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Capitan Trail</td>
<td>First suitable mounting location after a 15-minute hike from trailhead</td>
<td>April 6-19, 2012</td>
</tr>
<tr>
<td>Tejas Trail (Bowl Loop)</td>
<td>First suitable mounting location after a 15-minute hike from trailhead</td>
<td>April 6-19, 2012</td>
</tr>
<tr>
<td>Guadalupe Peak Trail</td>
<td>15-minute hike past junction with steep ascent of Guadalupe Peak Trail</td>
<td>April 6-19, 2012</td>
</tr>
</tbody>
</table>

Note: Trails shown in Bold were categorized as “high use” trails.

We selected specific count locations along these eight trails at distances that were at least a 15-minute hike past a trailhead or trail junction. This eliminates counting hikers who might mistakenly enter a trail and then quickly turn around. Also, because access is rather limited along the trails between trailheads and other trail junctions, use level was deemed fairly consistent along the length of each trail. For longer trails, some hikers might not complete the full length of the trail because they turn around and head back to where they came from. These kinds of exceptions are much less likely to occur when a
destination exists at the end of the trail. However, if you mount trail counters at the destination of a trail, then some hikers might be missed. A trail midpoint (e.g., halfway to a destination) presents one possible compromise. You should also consider trail length and its effect on staff time to place counters. For longer backcountry trails where a through-hike is most likely, a trail midpoint might not offer the ideal counter location (because of time to reach that trail midpoint to place a counter).

STEP 5. EXECUTE DATA COLLECTION PLAN

As expected, several issues (i.e., equipment malfunction, trail construction) arose during the data collection phase that required adjustments to the data collection plan. We modified the data collection plan as appropriate to still meet the primary objectives. The actual data collection schedules for which valid trail count data was gathered is shown in Tables 6 and 7.

Table 6. Actual Data Collection Schedule on Mission Trail near San Antonio Missions NHP

<table>
<thead>
<tr>
<th>Point of Interest/Access</th>
<th>Counter Location</th>
<th>Dates of Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roosevelt Park/Lone Star Boulevard (start of trail)</td>
<td>Between Steves Avenue and Mitchell Street</td>
<td>March 8-21, April 9-June 25</td>
</tr>
<tr>
<td>Mission Concepción/Concepción Portal</td>
<td>Between Theo Avenue and Mission Road</td>
<td>Continuous data collection starting February 2</td>
</tr>
<tr>
<td>Mission Road trail access</td>
<td>South of Southcross Blvd</td>
<td>July 9-August 20</td>
</tr>
<tr>
<td>Mission San José/Mission County Park/Padre Park</td>
<td>Between Napier Ave and SE Military Drive</td>
<td>March 23-April 4</td>
</tr>
<tr>
<td>Espada Park</td>
<td>Trail under construction</td>
<td>Trail under construction, no data collection</td>
</tr>
<tr>
<td>Espada Aqueduct/Mission San Juan Capistrano</td>
<td>Between Espada Road access point and IH-410</td>
<td>Trail under construction, no data collection</td>
</tr>
<tr>
<td>Mission Espada/Mission Reach Trail terminus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 7. Actual Data Collection Schedule in Guadalupe Mountains National Park

<table>
<thead>
<tr>
<th>Trail</th>
<th>Counter Location</th>
<th>Dates of Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guadalupe Peak Trail</td>
<td>15-minute hike past junction with steep ascent of Guadalupe Peak Trail</td>
<td>March 10-21, April 6-May 31</td>
</tr>
<tr>
<td>Devil’s Hall Trail</td>
<td>15-minute hike past junction with gentler ascent of Guadalupe Peak Trail</td>
<td>March 10-21</td>
</tr>
<tr>
<td>Smith Spring Trail</td>
<td>Eastern side of loop in wooded area just prior to Smith Spring</td>
<td>March 10-21</td>
</tr>
</tbody>
</table>

--- Reposition counters on March 22 ---

<table>
<thead>
<tr>
<th>Trail</th>
<th>Counter Location</th>
<th>Dates of Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>McKittrick Canyon Trail</td>
<td>First suitable mounting location after a 15-minute hike from trailhead</td>
<td>March 23-June 24</td>
</tr>
<tr>
<td>Permian Reef Trail</td>
<td>First suitable mounting location after a 15-minute hike from trailhead</td>
<td>March 23-April 4</td>
</tr>
<tr>
<td>McKittrick Canyon Nature Loop</td>
<td>First suitable mounting location after a 15-minute hike from trailhead</td>
<td>Counter malfunction</td>
</tr>
</tbody>
</table>

--- Reposition counters on April 5 ---

<table>
<thead>
<tr>
<th>Trail</th>
<th>Counter Location</th>
<th>Dates of Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Capitan Trail</td>
<td>First suitable mounting location after a 15-minute hike from trailhead</td>
<td>April 6-19</td>
</tr>
<tr>
<td>Tejas Trail (Bowl Loop)</td>
<td>First suitable mounting location after a 15-minute hike from trailhead</td>
<td>April 6-19</td>
</tr>
<tr>
<td>Guadalupe Peak Trail</td>
<td>15-minute hike past junction with steep ascent of Guadalupe Peak Trail</td>
<td>April 6-19</td>
</tr>
</tbody>
</table>

STEP 6. ANALYZE, ADJUST, AND SUMMARIZE DATA

San Antonio Missions National Historical Park

We pulled data from each location using either Bluetooth or the permanent counter’s GSM modem and Eco-Counter’s online platform, Eco-Visio, and then compiled and assessed the data using Microsoft Excel instead of Eco-Visio. When compiling the data for the permanent site, we noticed several unusual data readings for pedestrians in the northbound direction (the permanent pedestrian and bicycle counter located just south of E. Theo Avenue measures usages and provides directionality data for each mode). Because of the location of the passive infrared pedestrian sensor, the afternoon sun appears to have tripped the sensor, giving hundreds or even thousands of erroneous counts. If no directionality is measured, the counter’s software will assign all unknown counts to the northbound direction. We pushed the lens further into its shaded housing, but the error still occasionally occurred until we affixed a shade hood over the housing. With the root of the problem solved, we still needed to address issues in the data.
Assumptions

The counter error greatly skewed the counting data, making it difficult to glean any meaningful statistics. Therefore, we made an effort to implement quality control checks to identify bad data points and reasonably estimate new data points that can be used to create trail use statistics. To do this, we made certain assumptions about the trail, the counter, and the data:

- The southbound pedestrian data are correct.
- Weekday and weekend trail usage differ greatly from one another and cannot be combined.
- Extremely high counts in the northbound direction for multiple hours are not the result of a special event occurring in the area (though we made an effort to identify dates and times of special events).

Identifying and Isolating Bad Data

Identifying bad data involved finding outliers that did not fit reasonable trail usage patterns. Because the southbound data were assumed to be correct, they were subtracted from the northbound data. The difference is believed to be a more accurate identifier of bad data because it accounts for variation in counts on different days (i.e., if counts are particularly high for one day in both directions, since the southbound data is assumed to be correct, then it would be reasonable to believe the northbound counts should also be relatively high. Otherwise, the analysis would think high-traffic days are errors). The difference was then separated by weekdays and weekends since trail usage differs greatly on the weekend. Any hour that had a zero count was excluded from the analysis (too many zero counts would skew processes later in the analysis).

Once separated, the minimum value, first quartile, median, third quartile, and maximum value were calculated for both weekends and weekdays. The first and third quartiles were used to calculate the interquartile range (IQR), represented by the following equation:

\[
IQR = 0.5(Q_3 - Q_1) + Q_3
\]

The coefficient of 0.5 was used rather than the standard coefficient of 1.5 for both weekday and weekend analyses to provide a more conservative cutoff point for outliers.

The IQR produced a cutoff point for both weekdays and weekends: any difference found to be higher than this cutoff number was flagged as an error and isolated. These numbers would be excluded from any other data aggregations until a substitute number was calculated. Currently, the cutoff points for identifying outliers are weekday hourly counts over 9 and weekend hourly counts over 11. As more data are collected, these cutoff points could change.

Establishing New Data Points

We aggregated the data points that were below the cutoff points from hourly to daily counts in north and southbound directions. Note that a corresponding southbound count to a northbound count that fell above the cutoff point was also excluded for this segment. The northbound daily counts were then divided by the southbound counts to find a ratio of northbound to southbound traffic. These ratios
were split between weekdays and weekends. In each category, the median ratio was found and used as a multiplier to establish a new data point. Currently, weekday and weekend northbound counts are set equal to southbound counts. This ratio was then multiplied with the southbound data for all bad data points to establish new estimated counts for northbound traffic.

Once the new data were integrated, we set up a series of pivot tables based on different sets of information that we would eventually use to create charts and a dashboard that would easily communicate relevant trail information.

**Guadalupe Mountains National Park**

Because the counters used on the trails in Guadalupe Mountains did not collect direction data, the quality assurance and control process for these counts is much simpler. The number of counts on each trail also eased the process since the temporary counts lasted for approximately two weeks at a time in each location. Less data points makes the data easier to handle.

We retrieved the data from the individual counters using TRAFx’s specialized software called TRAFx Communicator (v3.1) which returned the data in a text file. We then converted the data to an excel format and summarized the data by hour (counts are time stamped as they occur instead of summarized by hour). Since there were many hours of the day that a count did not occur, we had to fill in those hours with a zero value to ensure that when the data is summarized, days and hours are not compressed, giving the false impression of consistent counts during each time period.

We performed spot-check quality assurance with this data by charting the hourly counts by day. Since each trail had two weeks of data, visual inspection of trends was relatively simple. Spikes in trail usage were compared to the time of day and hour of the week to make sure they reasonably made sense. Daily traffic patterns were also examined and compared across each time period and with other similar trails. We did note that three high daily counts occurred during spring break for local universities, which explained the higher-than-usual trail use.

**STEP 7. REPORT AND COMMUNICATE RESULTS**

**San Antonio Missions National Historical Park**

Reporting trail use statistics in a meaningful and useful manner can be extremely difficult. We considered what metrics would be useful for both the National Park Service and the San Antonio River Authority and integrated summary statistics into a dashboard that mapped the specific count locations, dates, and trail segment lengths. Data concerning total counts, estimated usage and daily statistics were integrated and separated by mode split.

Additionally, we provided more detailed charts illustrating average hourly, daily, weekly, and monthly usage broken down to individual count locations, direction, and mode.
Mission Reach Trail Counts: Average Hourly Trail Usage
Trail counter located just south of E. Theo Avenue

Mission Reach Trail Counts: Average Weekly Trail Usage
Trail counter located just south of E. Theo Avenue
Guadalupe Mountains National Park

Reporting trail usage for Guadalupe Mountains National Park followed a similar thought process as previously mentioned, however, the needs of the park differed greatly because of the context differences between the two parks. We created a simpler dashboard that illustrated counter locations and average trail usage. However, in this park, we included data that converted raw count data into an average daily hiker metric (based upon the likelihood that a hiker would make a roundtrip hike or only pass the counter location once). This metric was then also divided by weekday and weekend to illustrate the dramatic difference in usage.

Additional charts were created for daily trail usage, trail use comparison, vehicle entrance counts, and detailed daily and hourly usage by each individual trail. In these charts, note the discernible spikes in usage each weekend and the dramatic increase in usage over spring break.
# Guadalupe Mountains National Park Trail Count Summary

![Map of Guadalupe Mountains National Park with trail count summary]

<table>
<thead>
<tr>
<th>Trail</th>
<th>Length (Mi.)</th>
<th>Daily Count Profile</th>
<th>Avg Daily Traffic (ADT)</th>
<th>% of Round Trips on Trail</th>
<th>Avg Daily Hikers</th>
<th>Avg Weekday Hikers</th>
<th>Avg Weekend Hikers</th>
<th>Daily Hiker Miles of Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Guadalupe Peak Trail</td>
<td>4.2</td>
<td><img src="profile1.png" alt="Profile" /></td>
<td>86</td>
<td>100%</td>
<td>43</td>
<td>31</td>
<td>71</td>
<td>723</td>
</tr>
<tr>
<td>2. Devil's Hall Trail</td>
<td>2.1</td>
<td><img src="profile2.png" alt="Profile" /></td>
<td>59</td>
<td>100%</td>
<td>29</td>
<td>27</td>
<td>34</td>
<td>247</td>
</tr>
<tr>
<td>3. Tejas Trail</td>
<td>11.7</td>
<td><img src="profile3.png" alt="Profile" /></td>
<td>57</td>
<td>50%</td>
<td>38</td>
<td>12</td>
<td>101</td>
<td>992</td>
</tr>
<tr>
<td>4. McKittrick Canyon Trail</td>
<td>2.4</td>
<td><img src="profile4.png" alt="Profile" /></td>
<td>47</td>
<td>75%</td>
<td>27</td>
<td>22</td>
<td>38</td>
<td>195</td>
</tr>
<tr>
<td>5. Smith Springs Trail</td>
<td>2.3</td>
<td><img src="profile5.png" alt="Profile" /></td>
<td>34</td>
<td>0%</td>
<td>34</td>
<td>39</td>
<td>24</td>
<td>78</td>
</tr>
<tr>
<td>6. El Capitan Trail</td>
<td>5.2</td>
<td><img src="profile6.png" alt="Profile" /></td>
<td>18</td>
<td>100%</td>
<td>9</td>
<td>6</td>
<td>15</td>
<td>183</td>
</tr>
<tr>
<td>7. Permian Reef Trail</td>
<td>4.2</td>
<td><img src="profile7.png" alt="Profile" /></td>
<td>11</td>
<td>100%</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>94</td>
</tr>
</tbody>
</table>
Guadalupe Peak Trail: Daily Trail Counts

Guadalupe Peak Trail: Average Hourly Trail Use
Devil's Hall Trail: Daily Trail Counts

Devil's Hall: Average Hourly Trail Use
Smith Spring Trail: Daily Trail Counts

Smith Spring Trail: Average Hourly Trail Use
El Capitan Trail: Daily Trail Counts

El Capitan Trail: Average Hourly Trail Use
CHAPTER 4—CONCLUSIONS

This chapter summarizes the conclusions from this study on monitoring trail use. The conclusions are organized around the three study objectives:

1. **Automated Trail Counters**: Evaluate several commercially available trail counters in typical park settings.

2. **Monitoring Process for Parks**: Develop a generalized process for monitoring year-round trail use, and then apply the monitoring process in different park settings.

3. **Usage in Case Study Parks**: Summarize the trail use data into example reports that are useful for NPS staff and other decision-makers.

AUTOMATED TRAIL COUNTERS

In this study, we identified numerous commercially-available automated trail counters. The technologies used in these counters varied, as did the available features and most likely applications. A matrix (Figure 5) was developed to help practitioners identify the relevant technologies for monitoring pedestrians, bicyclists, and/or both. Accompanying tables identified the strengths and weakness of these counter technologies (Table 1) and their commercial availability (Table 2). In Chapter 2, each technology was described in more detail.

Based on this assessment of existing trail counters, two different products were selected and used in the case study parks for collecting trail use data:

- **San Antonio Missions National Historical Park**: Eco-Counter MULTI to separately count bicyclist and pedestrian traffic, and Eco-Counter PYRO to count overall trail traffic (bicyclists and pedestrians combined).
- **Guadalupe Mountains National Park**: TRAFx Infrared Trail Counter in a lockable enclosure.

Through field evaluations of each counter, it was determined that both counters had a tendency to undercount actual trail use, most likely due to multiple people passing through the counter zone at the same time. Because of this consistent undercounting, we adjusted the raw counts from our data collection.

Although there were a few minor glitches, the automatic trail counters in this project performed satisfactorily. When properly installed and maintained, these trail counters can substantially reduce the long-term costs associated with monitoring trails in park settings using other methods, such as human observers.
MONITORING PROCESS FOR PARKS

In this study, we developed a generalized monitoring process (Figure 4) that was then applied to our two case study parks. In Chapter 2, we also developed extensive details and guidance for each of these nine monitoring steps:

1. Identify uses and users
2. Define required data
3. Identify data collection tools
4. Develop data collection plan
5. Execute data collection plan
6. Analyze, adjust & summarize data
7. Report & communicate results
8. Make decisions based on results
9. Improve quality in future cycles

USAGE IN CASE STUDY PARKS

In this study, we collected trail use data in two case study parks. Chapter 3 provides detailed information on the results of this data collection. Tables 8 and 9 provide a tabular summary.

Table 8. Summary of Trail Counts along the San Antonio Mission Reach Trail

<table>
<thead>
<tr>
<th>Trail Segment (north to south)</th>
<th>Average Daily Trail Users</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total of Both Directions</td>
</tr>
<tr>
<td>1. Roosevelt Park to Concepción Park</td>
<td>353</td>
</tr>
<tr>
<td>2. Concepción Park to Mission Road</td>
<td>214</td>
</tr>
<tr>
<td>3. Mission Road to VFW Blvd.</td>
<td>276</td>
</tr>
<tr>
<td>4. VFW Blvd to Military Drive</td>
<td>94</td>
</tr>
</tbody>
</table>

* The ratio of pedestrians to bicyclists is estimated at these locations, based on the permanent counter at Mission Concepción. The ratio of northbound to southbound trail counts was directly measured at all locations.
Table 9. Summary of Trail Counts in Guadalupe Mountains National Park

<table>
<thead>
<tr>
<th>Trail</th>
<th>Length (mi)</th>
<th>Average Daily Trail Count</th>
<th>% of Round Trips on Trail</th>
<th>Avg. Daily Hikers</th>
<th>Avg. Weekday Hikers</th>
<th>Avg. Weekend Hikers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guadalupe Peak</td>
<td>4.2</td>
<td>86</td>
<td>100%</td>
<td>43</td>
<td>31</td>
<td>71</td>
</tr>
<tr>
<td>Devil’s Hall</td>
<td>2.1</td>
<td>59</td>
<td>100%</td>
<td>29</td>
<td>27</td>
<td>34</td>
</tr>
<tr>
<td>Tejas</td>
<td>11.7</td>
<td>57</td>
<td>50%</td>
<td>38</td>
<td>12</td>
<td>101</td>
</tr>
<tr>
<td>McKittrick Canyon</td>
<td>2.4</td>
<td>47</td>
<td>75%</td>
<td>27</td>
<td>22</td>
<td>38</td>
</tr>
<tr>
<td>Smith Springs</td>
<td>2.3</td>
<td>34</td>
<td>0%</td>
<td>34</td>
<td>39</td>
<td>24</td>
</tr>
<tr>
<td>El Capitan</td>
<td>5.2</td>
<td>18</td>
<td>100%</td>
<td>9</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>Permian Reef</td>
<td>4.2</td>
<td>11</td>
<td>100%</td>
<td>6</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>
REFERENCES

The following documents were referenced as footnotes in this report.


