Traffic Signal Management Plans

An Objectives- and Performance-based Approach for Improving the Design, Operations, and Maintenance of Traffic Signal Systems

November 2015

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SI* (MODERN METRIC) CONVERSION				
FACTORS APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
^oC	Celsius	1.8C+32	Fahrenheit	^oF
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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EXECUTIVE SUMMARY

The Federal Highway Administration (FHWA) has prepared this guidebook to assist transportation agencies across the country in better managing their traffic signal systems through systematic alignment of maintenance, design, and operations activities and resources. It provides step-by-step instructions for documenting current activities, relating them to the agency's goals and transportation objectives, and offers a structure that shows how the activities of all staff involved in traffic signal management support those objectives.

Research has shown that in effective traffic signal programs there is a strong connection between doing what's most important in the context of limited resources and the extent to which a department's activities are planned ahead to achieve specific, objectives (FHWA, 2009).
The idea for this guidebook grew out of the findings of the *National Traffic Signal Report Card* (NTOC, 2012). One finding from the analysis of responses by agencies to this self-assessment of their traffic signal operation and management was that almost no agencies in the United States have a formal traffic signal management plan (TSMP). The majority of agencies have master plans for pedestrians, bicycles, local specific plans, city-wide general plans, and regional and statewide transportation plans, while fewer have ITS master plans. These are almost entirely aimed at supporting capital improvement programs, and most are required by various Federal and State regulations. Surprisingly few have comprehensive plans of similar quality to guide maintenance, design, and operations of their traffic signal systems.

Based on FHWA's broad experience with agencies across the country, it has become clear that agencies with some form of strategic plan that covers their traffic signal systems tend to have better organized operations and management of their traffic signal systems.

A well-organized traffic signal management plan will provide multiple benefits to an agency. It will also:

- Document what traffic signal maintenance, operations, and design staff do, why they do it, and how their activities support the agency's goals and objectives.
- Provide a firm basis to support maintenance and operations as well as capital budgets.
- Facilitate succession planning and integration of new staff into the organization.
- Specify a logical framework within which staff training can be planned and organized.
- Help agencies become less dependent on key individuals, reduce ad hoc procedures and provide organization and structure for the agency's activities.

CHAPTER 1. PURPOSE OF THIS GUIDEBOOK

INTRODUCTION

Overview

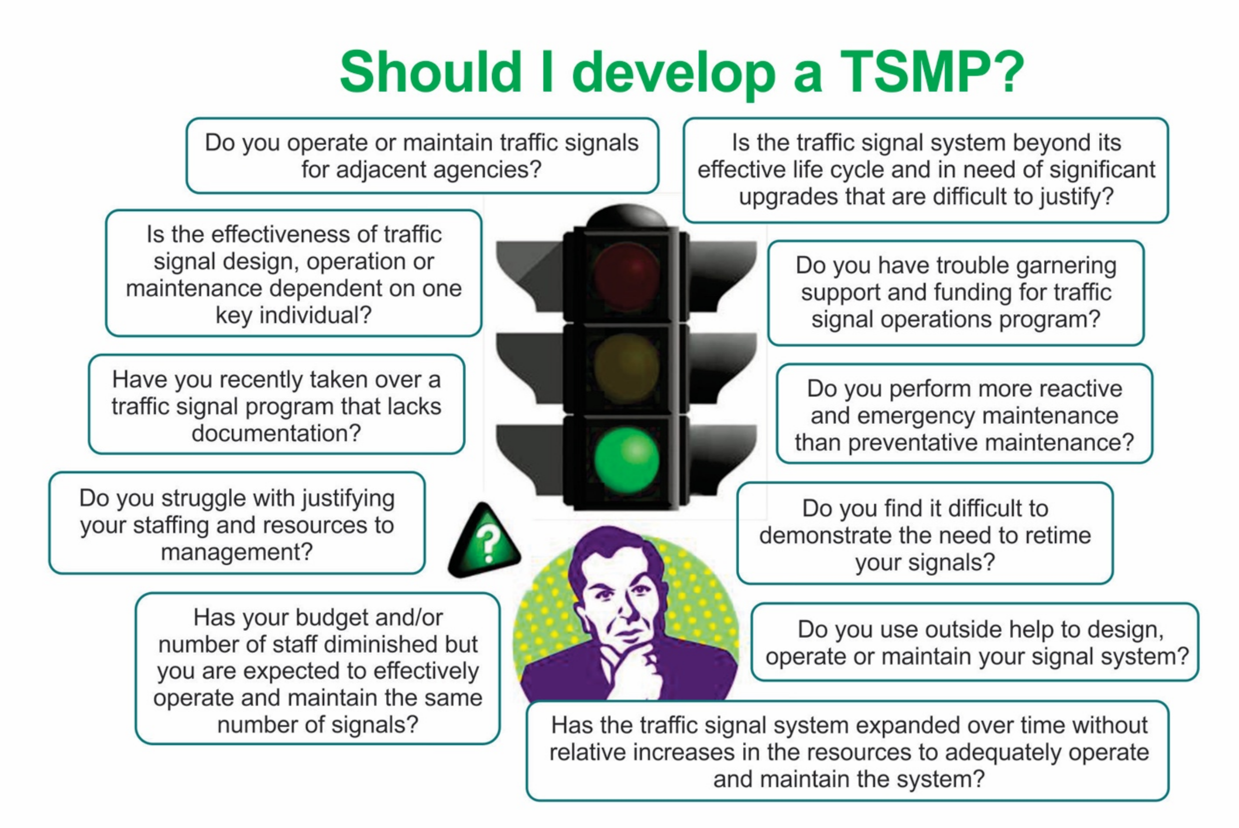
Research has shown that in effective traffic signal programs there is a strong connection between doing what's most important in the context of limited resources and the extent to which its activities are planned ahead to achieve specific objectives (FHWA, 2009). This research has shown that the extent to which an agency provides good service to its community is not necessarily directly related to the prevalence of resources. Some well-funded agencies are not high performers, while some agencies that are not well funded provide a high standard of service within their acknowledged constraints and in accordance with their plan. A common thread that exists amongst high performing agencies is a demonstrated ability to align and plan the design, operations, management and maintenance activities, and the ultimate replacement of traffic signals (NTOC, 2012).

This guidance establishes a framework for developing traffic signal management plans (TSMP) based on knowledge transferred from a number of archetypical traffic signal programs. A TSMP is intended to document and connect, at a high level, the goals, objectives, strategies and performance measures that an agency uses to achieve outcomes consistent with doing what's most important given a limited set of resources. This guidance will help practitioners strategically connect their activities related to traffic signal design, operations, maintenance, and management with the goals and objectives of their agency. The result will be an objectives-driven TSMP that:

- Provides a succinct description of all activities required for agency staff to manage the traffic signal program.
- Offers a basis for introducing new staff to the processes relevant to their roles, both inside and outside the program or agency.
- Illustrates to management and outside funding agencies the structured approach to traffic signal management.
- Specifies an approach to strategically shift maintenance, operation, and design from reactionary to proactive and to effectively plan for needed capital improvements.
- Outlines an approach for identifying how to deliver good basic service (defined below).
- Helps to provide direction to a large and complex program (in the presence of plentiful resources).
- Identifies programmatic objectives supported by existing activities.
- Improves support for the traffic signal program both within and external to one's agency.
- Aids in mitigating the risks of the program underperforming and not meeting one's objectives.
- Supports succession planning.

Should You Invest Time in Developing a Traffic Signal Management Plan (TSMP)?

Ask yourself the questions in Figure 1. If you answer yes to any of them, your agency is a candidate for a TSMP.



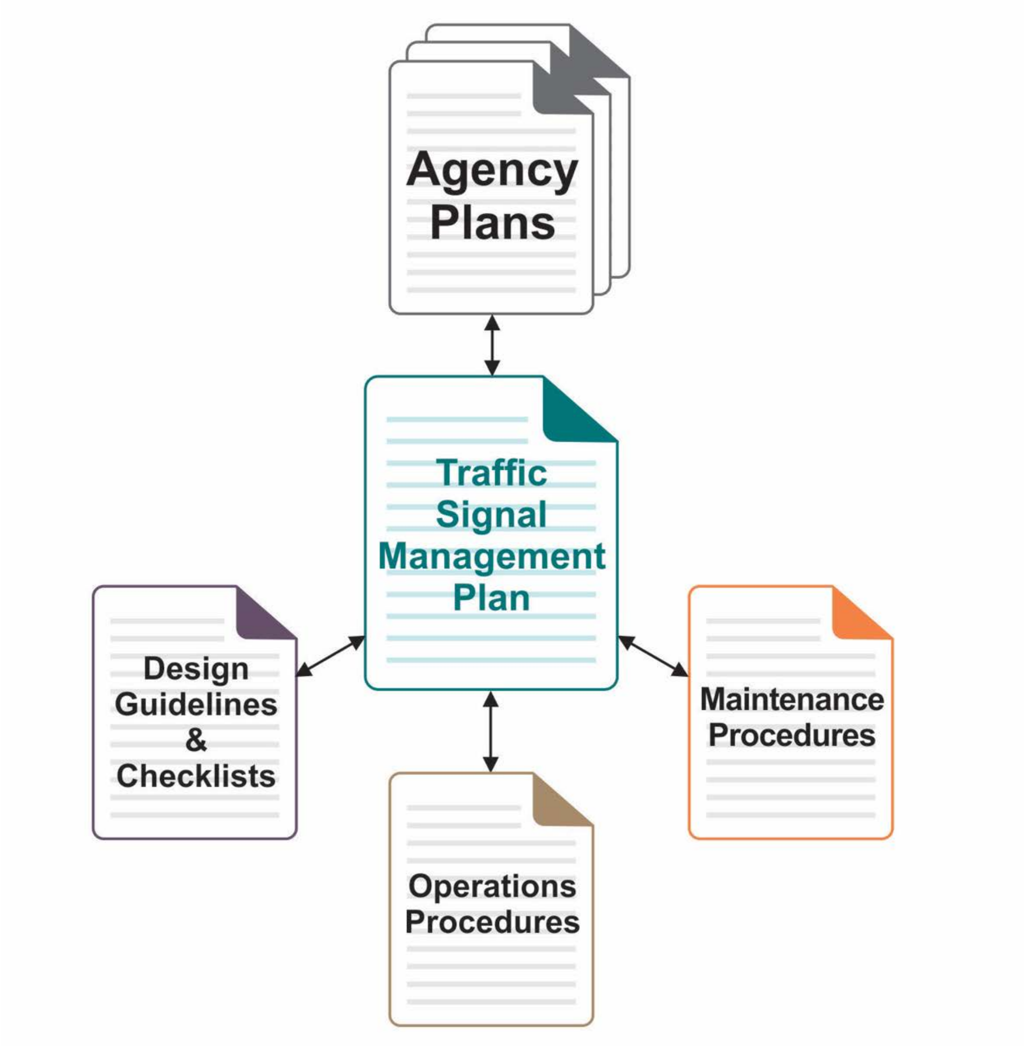
Source: DKS

Figure 1. Graphic. Would a traffic signal management plan be helpful for my agency?

It is clear from the results of the national traffic signal report card survey (NTOC, 2012) and other research that very few agencies have a comprehensive plan covering the full lifecycle of design, operations, management, maintenance and ultimate replacement of traffic signals. Moreover, those agencies that do have operating and management plans very often have not clearly linked their objectives to the livability and mobility goals and objectives of their agency or regional planning authority. A strategic approach is needed in order to effectively garner support for and resources to improve the state of traffic signal systems.

Based on FHWA’s broad experience with agencies across the country, it has also become clear that agencies that have some form of strategic plan that covers their traffic signal system also have a high level of performance in the management of their traffic signal system. Moreover, this seems to apply regardless of the level of resources available for traffic signal management. Many resource-rich agencies do not provide great service, while other relatively under-resourced agencies provide very good service within their constraints.

The TSMP connects the goals that appear in agency and regional plans with objectives and strategies that support day to day traffic signal design, operations maintenance, and administrative activities. The TSMP supports an agency's general plan or strategic plan, in a manner similar to an ITS plan, pedestrian master plan or a bicycle master plan, and lays the foundation for development of traffic signal capital improvement plans. Many agencies have existing procedures and policies that feed into the information in the TSMP. Figure 2 shows the relationship between the different documents an agency may have.



Source: DKS

Figure 2. Graphic. Relationships among agency documents.

GOOD BASIC SERVICE AND PROGRAM RELIABILITY

The mission of a traffic signal program is to provide good basic service that satisfies the goals of the agency and regional partners involved in transportation systems management and operations (TSM&O). Good basic service is defined as doing the most important things given a set of resources. The definition of "important" is up to the agency to determine, but should match closely with user expectations. Traffic signal programs that do not align their objectives with agency and regional goals may encounter difficulty in attracting and sustaining resources to adequately design, operate and maintain traffic signal systems. Achieving good basic service requires implementation of strategies (operations, maintenance, and design) that work together to optimize the program, along with a clear understanding of their objectives. Figure 3 illustrates how the different aspects of managing a signal system all need to work together. If an agency is weak in one area, the stool will be unbalanced, meaning the other two areas need to compensate to remain balanced. For example, if detection is not maintained well, the signal will continue to operate, but the signal timing will need to be adjusted in order to serve the users. If an agency is not performing well in all three areas, the stool will collapse and good basic service will not be provided.

Good Basic Service is doing the most important things given a finite set of resources.

Source: FHWA

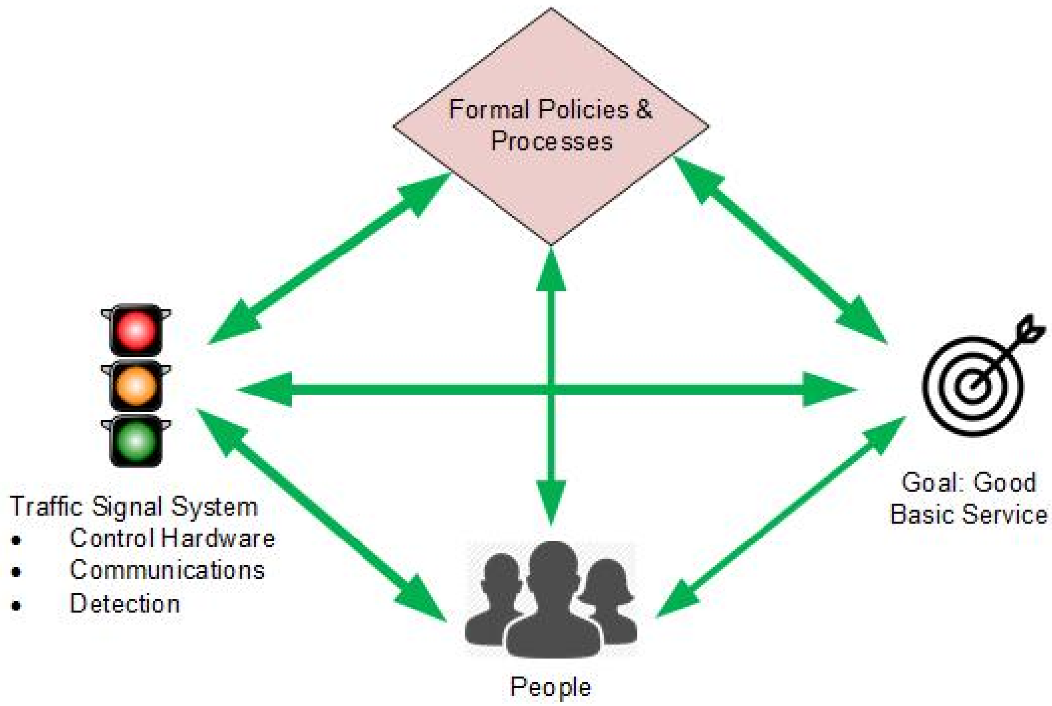
Figure 3. Graphic. Good basic service components.

Program reliability is a measure of an organization's ability to sustain good basic service. Sustaining good basic service is dependent on:

- Articulating objectives clearly.
- Having expert, committed staff.
- Documenting processes.
- Optimizing process effectiveness.
- Applying systematic processes to inform hardware and software procurement.
- Having predictable resources (capital and operating funds).
- Measuring performance in a meaningful way.

The TSMP connects the activities related to traffic signal design, operations, maintenance, and management with the goals and objectives of your agency. This will guard against the impacts of losing key staff, reductions in critical funding, or both.

Achieving good basic service will involve recognizing the interactions between the different actors, systems, and policies and procedures of your organization. Recognizing those interactions will help generate the appropriate mix of operational, maintenance, design and enabling strategies that agencies will need to keep the stool balanced. This concept is illustrated in Figure 4.



Source: FHWA

Figure 4. Graphic. Notable interactions needed to achieve good basic service.

THE OBJECTIVES-DRIVEN PROCESS

The TSMP is based on an objectives-driven, performance-based approach. This type of approach focuses on system performance to measure success rather than the number of activities implemented. The basis of this approach is the development of goals, context, objectives, strategies, and tactics (G-COST). The relationships between goals, objectives, strategies, and tactics are illustrated in Figure 5.

Source: FHWA

Figure 5. Graphic. Goals, context, objectives, strategies, and tactics (GOST) pyramid.

Goals

A goal is a broad statement that describes a desired end state. It is the "what" an agency is trying to achieve. Goals can address different aspects of the transportation system: reliability, efficiency, quality of service, preservation, etc. In many cases, the goal statements for a TSMP can be directly extracted from existing agency policy documents, such as a regional transportation system plan, related master plans such as bicycle and pedestrian master plans, and the transportation element of a city's general plan or master plan.

Here are some examples of agency goals:

- Maintain the transportation system in the most efficient manner.
- Provide mobility for all ages and abilities and for all areas of the community.
- Facilitate efficient transit operation on arterial roads.
- Preserve infrastructure.
- Optimize mobility.

While goals describe a desirable end state, they are not directly "actionable." That is the role of objectives.

Context

While a goal can lead to many different objectives that may apply to a variety of activities (e.g., "livability" may be supported by transportation, libraries, parks, urban design and architecture, sports facilities, and landscaping), the administrative context of the plan and the physical context of the signal operation define the types of objectives that are appropriate in several ways:

- Only objectives that will lead to activities associated with the traffic signal system need to be considered.

- The selected management objectives need to acknowledge the geographical, social, and institutional context within which the plan will operate.
- The operational objectives that define how the signal system controls traffic and other road users need to be consistent with traffic patterns, mobility demands, road network topology, and adjacent land uses.

Objectives

An objective is more specific and measurable and is defined as "what" needs to be done in order to achieve a goal. Although in transportation planning, developing such aims has often been discussed together with goals (e.g., "developing goals and objectives"), it is important to make a critical distinction between goals and objectives within a performance-based planning and programming approach. Whereas goals relate to the "big picture" or desired end-result, objectives should be specific and measurable and support the achievement of a goal.

The most important aspect of identifying these overarching targets is that they be absolutely clear and "actionable." All objectives should include or lead to development of a performance measure that is able to validate achievement of the result, and to support decisions necessary to help achieve each goal. The aims of the TSMP may relate to multiple strategies within the traffic signal program in the areas of maintenance, design, management and operations.
Example TSMP objectives, extracted from some recent TSMPs include:

- Provide facilities at traffic signals to safely and efficiently accommodate all road users (including transit, pedestrians and bicycles in addition to other vehicles).
- Support signal operations that are appropriate for the current traffic conditions and consistent with current operational policies.
- Operate traffic signal system at its maximum efficiency within the context of a balanced, multimodal operation, as described in current operational policies.
- Undertake maintenance in a cost-effective manner.
- Coordinate cooperatively with neighbor agencies to develop and implement regional solutions to traffic problems related to regional issues.
- Design traffic signal system elements that are sustainable in a fiscally responsible manner.
- Preserve the traffic signal system so it always operates as intended.
- Sustain a traffic signal infrastructure that is appropriate for accommodating current mobility goals.
- Inform and educate all stakeholders of the challenge to maintain a modal balance and superior service.
- Keep the community fully informed about the development and operation of the traffic signal system so they understand what we do and why we do what we do, so they can judge for themselves how well we are satisfying their needs.
- Increase traffic flows.
- Improve capacity allocation.
- Advance pedestrian service.

- Enhance bicycle service.
- Create a high level of reliability of detection.
- Maintain fully functional preemption.
- Minimize pollution and noise.
- Retain a complete history of traffic volumes for use in planning, design and operations analysis.
- Develop origin-destination data.
- Further safety-related objectives.
- Reduce time to return intersection to full operation after incident or fault.

It is also important to clearly state the operational strategies one intends to employ in various situations, such as:

- Smooth the flow of traffic along coordinated routes when the system is below saturation.
- Maximize the throughput of vehicles along coordinated routes when conditions are at or above saturation.
- Equitably serve adjacent land uses when throughput is not the objective.
- Manage queues to prevent excessive queuing from reducing efficiency.
- Maximize intersection efficiency at critical isolated (non-coordinated) intersections.

Strategies

A strategy is defined as a capability put in place to achieve an objective. This is where you have the opportunity to be innovative, and also identify strategies that are achievable and sustained within your agency’s existing level of capability. Example strategies found in some recent TSMPs include:

- Undertake proactive maintenance.
- Undertake reactive maintenance.
- Administer maintenance to provide all required capabilities.
- Design signals to support maintenance.
- Design signals to support operations.
- Design signals to accommodate all modes.
- Operate signals to maximize system efficiency.
- Provide signal coordination where suitable.
- Operate signals to safely and efficiently accommodate all users.
- Operate signals to optimize intersection efficiency.
- Operate signals in coordination with regional partners.
- Automate traffic counts.

Each of these strategies has a different effect on one or more of the following:

- Quantity and allocation of resources.
- Documentation of processes.

- Capability of staff.
- Systems and technology.
- Procurement processes.
- Performance measurement.
- Leadership.
- Collaboration, both internal and external.

Tactics

A tactic is the specific method to implement a strategy. It is an action taken (activities) or tool used to help implement the strategies in order to achieve objectives and attain goals.
For example, in response to the objective of maintaining a high level of reliability in detection, these may be some appropriate strategies:

- Provide proactive maintenance, to minimize the risk of detector failure.
- Provide reactive maintenance, to quickly repair failed detectors.
- Design signals with types of detectors that are less prone to damage.
- Design signals with fewer detectors to reduce the total number of failures.

To implement these strategies, several entirely different tactics could be considered, which may include the following:

- Strengthen the pavement when loops are installed to minimize the risk of loop failure due to pavement deterioration.
- Use loops protected by conduit and buried deeper than regular, saw-cut loops.
- Use alternative technologies to inductive loops that are not affected by pavement condition.
- Limit the use of detectors to left turn phases.
- Provide equipment and training so staff can quickly repair failed loops.
- Retain an on-call contractor capable of quickly repairing failed loops.

Each selected tactic has a different effect on one or more of the following and needs to be considered and either accepted or discarded:

- The quantity and allocation of maintenance resources.
- The efficiency of traffic signal operation.
- The level of service provided to the road users.
- The cost of installation of traffic signals.
- The accuracy of vehicle detection.

It may be that each of these tactics will be applicable for an agency to use in one or other situations. For example, if an agency has a preference for standardization (often driven by a belief that maintenance will be more efficient if there is less variation in equipment and procedures), the real and perceived benefits of that standardization should be first weighed against foregone opportunities that would result from not picking the tactic that would most effectively address each situation.

Documentation

At the end of the day, all your activities need to be documented so all relevant staff know exactly what they should do and when they should do it. Documenting activities encourages close examination of changes to procedures, ensuring changes represent improvements when they do occur. Ad hoc activities should eventually be formalized and documented, so for the purposes of the TSMP they should be included in an action plan to ensure they are enshrined in your agency's procedures, are consistently implemented, and will not be lost or abandoned as key staff change.

CHAPTER 2. OPERATIONAL OBJECTIVES AND PERFORMANCE

Meaningful performance measurement is a key tenet of achieving good basic service and is imperative to evaluating the achievement of objectives, the appropriateness of strategies, and enables the optimization of tactics. Performance measures link objectives, strategies, and tactics and are central to implementing performance-based planning and management processes. See FHWA's extensive resources for its Operations Performance Measurement Program at:

http://www.ops.fhwa.dot.gov/perf_measurement

How you define and measure performance will significantly affect the types of strategies and tactics implemented and capital projects advanced to achieve them. Moreover, performance results inform agencies if the types of projects and strategies that have been implemented are, in fact, helping them achieve their goals and objectives.[1]

The National Performance Review (cited in FHWA, 2015) provides the following definition of performance measurement:

> *A process of assessing progress toward achieving predetermined goals, including information on the efficiency with which resources are transformed into goods and services (outputs), the quality of those outputs (how well they are delivered to clients and the extent to which clients are satisfied) and outcomes (the results of a program activity compared to its intended purpose), and the effectiveness of government operations in terms of their specific contributions to program objectives.*

Output may measure the appropriateness of a strategy or the effectiveness of an activity, and is of direct interest to the agency. Outcome may measure the quality of an activity, and is of primary interest to the customer. Both may help to decide on resource needs, and the need for improvement in systems and technology via capital investments.

Examples of measures of effectiveness that describe outcomes are included in Table 1.

[1] This document uses the following definitions for measure and metric; a measure quantifies actual performance (e.g., average speed is X mph), while a metric assesses the quality of performance (e.g., average speed is Y% of the uncongested free flow speed). See, for example, CIO.gov, 2015.

Table 1. Typical outcome performance measures.

Operational Objective	Strategy	Measure
Smooth flow	Provide pipeline	Percent arrivals on green
Throughput	Provide pipeline	Volume passing a critical points
Equitable access to adjacent land uses	Equitably distribute green time	Delay on all movements; Number of phase failures for each movement
Equitable access to adjacent land uses	Operate signals to optimize intersection efficiency	Percentage of "max outs" on each phase
Queue management	Prevent queue overflow	Queue lengths at locations where queue length is critical

ROLES OF PERFORMANCE MEASURES

Performance measures serve five critical purposes within traffic signal management – they are used as follows:

- To clarify the definition of objectives – Metrics assist in conversion of broad goals into measurable objectives.
- To monitor or track performance over time – Metrics are used to track performance on a regular or on-going basis (e.g., yearly, monthly, continual).
- As a reference for target setting – Metrics are used as the basis for selecting a target that is intended to be achieved.
- As a basis for supporting policy and investment decisions by comparing alternative options – Metrics are used as a basis for comparing alternative investments or policies in order to make decisions.
- To assess the effectiveness of projects and strategies – Metrics are what enable measurement to assess whether projects and strategies have worked to further goals.

Two well-known challenges associated with defining performance measures are difficulties associated with data availability and difficulties in developing quantitative measures for goals such as economic vitality and livability. That is why performance measures identified for a TSMP should concentrate on objectives and strategies. See, for example, Gettman, et al. (2013) and Bullock, et al. (2014).

FACTORS TO CONSIDER IN SELECTING MEASURES

Selecting performance measures requires considering what specific metric will be used and how measurements will be taken. For more detailed discussion of performance measures, see the FHWA performance measurement website (FHWA, 2015), and discussion in Day, et al. (2014), Bullock, et al. (2014) and Gettman, et al. (2013). The operational performance objectives are selected within the context of location, traffic congestion, etc. In selecting a performance measure, several factors should be considered:

- **Does it represent a key concern?** The selected performance measure should play a role in decision-making within planning and management and relate clearly to goals established in a performance-based planning process. The selected measure will have important implications on strategies that are selected.
- **Is it clear?** Is the measure understandable to managers, policy makers, and the public? Avoid technical terms if not necessary.
- **Are data available?** Consider the feasibility and practicality to collect, store, and analyze data and report performance information for the selected measures. While data availability is important, it is important to also remember to not simply define the measure based on what data are readily available.
- **Is the measure something the agency and its investments can influence?** A good measure does not need to be something that an agency controls. However, it will be important to select measures that can be influenced through policy and investment decisions in order for the measure to be useful in supporting investment decisionmaking.
- **Is the measure meaningful for the types of services or area?** While consistency in metrics can be valuable, it is also important to make sure that a measure is meaningful to the area or system to which it is applied. Care must be taken to keep the focus on customers (such as on people rather than facilities and vehicles) to avoid unintended consequences.
- **Improvement direction is clear.** In some cases, agencies choose measures but do not state clearly whether they desire the measure to increase or decrease, which is particularly problematic when the measure could be interpreted differently depending on one's perspective.

There often can be value in using multiple measures to address multiple dimensions of a problem. At the same time, it is advisable to start with a limited number of measures since it can be overwhelming to address hundreds of different measures. Experience suggests the importance of keeping the measures simple. It has been noted in many places: "Measure what is important; do not measure everything." Avoid measures that may provide useful information but may not be key considerations in relation to identified goals, making an agency "data rich but information poor."

Appendix A. A contains four case studies, each of which shows very effective use of one measure of performance to assess how well a traffic signal management objective (or strategy) is being met. The four cases described are summarized inTable 2.

Table 2. Summary of performance measure case studies.

Objective or Strategy	Performance Measure	Data Collection Method	Agency
Provide smooth flow on arterial	Percentage arrivals on green in corridor	Automatic high resolution data and Purdue Coordination Diagram	Utah Department of Transportation
Maintain stable travel times over time	End-to-end travel time on specified corridors	Annual floating car surveys Automatic using Bluetooth readers	City of Mesa
Provide travel time commensurate with level of demand	Corridor segment travel time	Automatic using Bluetooth readers	City of Walnut Creek
Maintain signals in good state of repair and operating in a manner for which they were designed (Strategy: proactively maintain detection reliability)	Signal timing complaints	Automated high performance controller data analysis and reporting	Utah Department of Transportation

There are several different layers of performance measures, each of which are essential to effective management of a traffic signal system. At the decision-maker level, measurement of the effect of traffic signal operation on the various road users will quantify how well the objectives are being met (measuring the outcomes). These measures will all be directly observable by the users, such as trip times, fuel consumption, air quality and quality of service measures.

At the strategic and tactical levels, it is the signal manager's responsibility to measure the implementation of activities against established standards, to ensure they are being done effectively and efficiently. These measures generally relate directly to the performance of staff (outputs). Examples of measurements of the performance of a strategy of providing proactive maintenance are shown in

Table 3. Examples of measures that quantify the outcome of the implementation of the same strategy are shown in Table 4.

Table 3. Output performance measures.

Objective	Strategy	Tactic	Measure
Maintain the traffic signal system so it always operates as intended	Undertake proactive maintenance	Test pedestrian detectors	Number of detectors tested Number of failed detectors reported
		Clean and realign signal heads and lenses	Number of heads cleaned Number of heads requiring realignment

Table 4. Outcome performance measures.

Objective	Strategy	Measure
Maintain the traffic signal system so it always operates as intended	Undertake proactive maintenance	Number of emergency maintenance callouts per unit (e.g., per signal, per month) Number of reported malfunctions per unit
Undertake maintenance in a cost-effective manner	Undertake proactive maintenance	Ratio of emergency maintenance to total maintenance expenditure

CHAPTER 3. HOW TO CREATE THE TRAFFIC SIGNAL MANAGEMENT PLAN

INVOLVE THE APPROPRIATE STAKEHOLDERS OR STAFF

The most appropriate staff to have input to the development of a traffic signal management plan (TSMP) will vary depending on the size of the organization and the manner in which its activities are structured. Typically staff with responsibility for the design, operations, or maintenance of the traffic signal system will be involved in developing the TSMP. This may include the following:

- Agency traffic engineer.
- Traffic operations engineer.
- TMC manager.
- Traffic signal timing supervisor.
- Lead technician.
- Maintenance supervisor.
- Signal designers.
- Transportation planners.

The champion of the TSMP should be the senior person responsible for successful operation of the traffic signal system. This person has an interest in the performance of the traffic system as it is impacted by traffic signal timing, an interest in the standard of maintenance, and an interest in good signal design, modification or replacement at an appropriate time.

The champion within the agency may be supported by internal staff and/or by a qualified consultant with experience in strategic planning, operations, maintenance and/or systems engineering in order to develop the document.

SCALE AND SCOPE OF THE DOCUMENT

Deciding on the appropriate scale of the activity and scope of the document will depend on its intended use and on the current state of your signal program. Research suggests that in the majority of agencies, operations capability tends to be immature (largely relying on individuals using ad hoc procedures to time signals), while design and maintenance tend to be more advanced (with more formalized procedures and checklists). Overall the design, operation, and maintenance activities often occur in silos, with the result that needs, resources, and capabilities often do not align satisfactorily. An agency with many ad hoc processes might initially use the TSMP to develop, or identify the need for, documented processes.

If an agency currently operates on a largely ad hoc basis that is intended to initially concentrate on formalizing the planning, execution, and performance measurement of maintenance activities, the initial plan can be relatively small. However, if an agency is well organized and the purpose of the plan is largely to formalize current practices and to facilitate and provide a training and succession plan that will continue successful operation beyond the tenure of existing staff, then it is likely that all sections will be required. For succession planning in an agency with well documented processes, the TSMP might document connections of regional and agency goals to traffic signal program objectives.

Within a State agency, it may be appropriate to have a statewide TSMP, or a separate one for each district. In a smaller agency in which signal timing is handled by the maintenance organization, then the senior technician may be the most appropriate "owner" of the TSMP. Based on experience with several test groups, development of the TSMP typically requires one or two half-day meetings to develop a consensus on the issues, goals, and objectives, followed by several months of activity by a staff member(s) and/or consultant. These case studies have also shown that an agency should set its expectations for the TSMP at a realistic level that initially represents an improvement over its current situation, and not try to develop a fully comprehensive TSMP at the outset. The starting point should begin at the existing level of capability, so that plans and processes move gradually from ad hoc to documented, documented to measured, and measured to optimized.

Support is also available from FHWA's Resource Center. Staff can provide resource materials, such as an annotated outline for a TSMP, can review draft TSMP's and provide content advice, and may also be able to facilitate training workshops for groups that are sufficiently large. Useful materials may also be found on FHWA's website at:

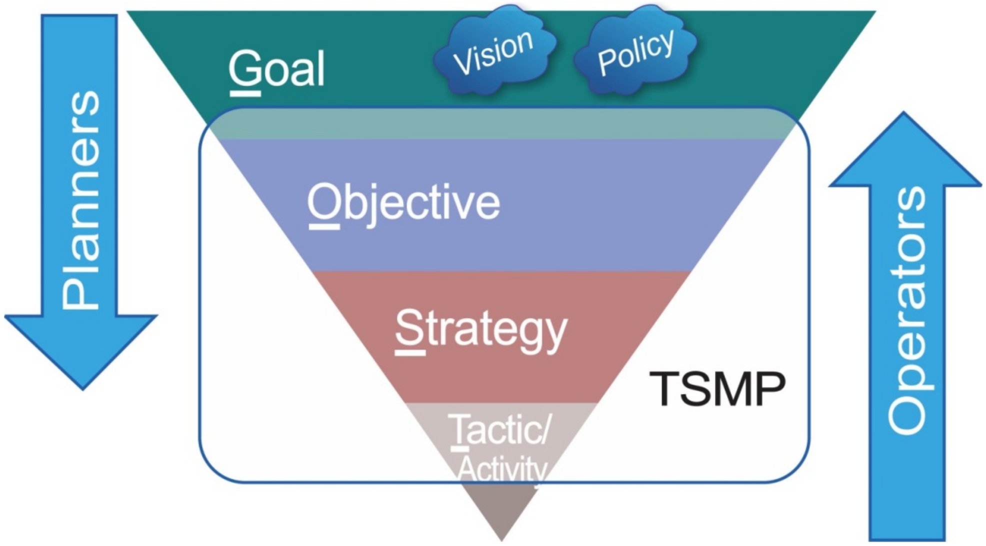
http://www.fhwa.dot.gov/resourcecenter/teams/operations/

OBTAIN APPROPRIATE LEVELS OF APPROVAL

A TSMP should be approved and/or endorsed by the chief executive of an agency. This ensures the support of decision-makers and budget approvers for the activities covered by the TSMP. It also ensures that those activities will be consistent with the plans and programs of other units of the agency.

APPROACH

There are two different but completely acceptable approaches to developing a TSMP, illustrated in Figure 6. The classic ***planner*** approach is top down, which involves progressively developing the GOST statements, starting with goals, which are informed by the agency's vision and policy, and working down to tactics. Within agencies that do not have well-documented processes, it is likely that a top-down approach will be necessary to formulate objectives, strategies and tactics that are consistent with agency goals. The second approach, often more understandable to traffic signal ***operators***, is bottom up. It involves describing the strategies and day-to-day tactics that are used and then describing in turn the objectives that are being achieved by using those tactics and mapping them to the agency goals that are satisfied by those objectives.



Source: DKS

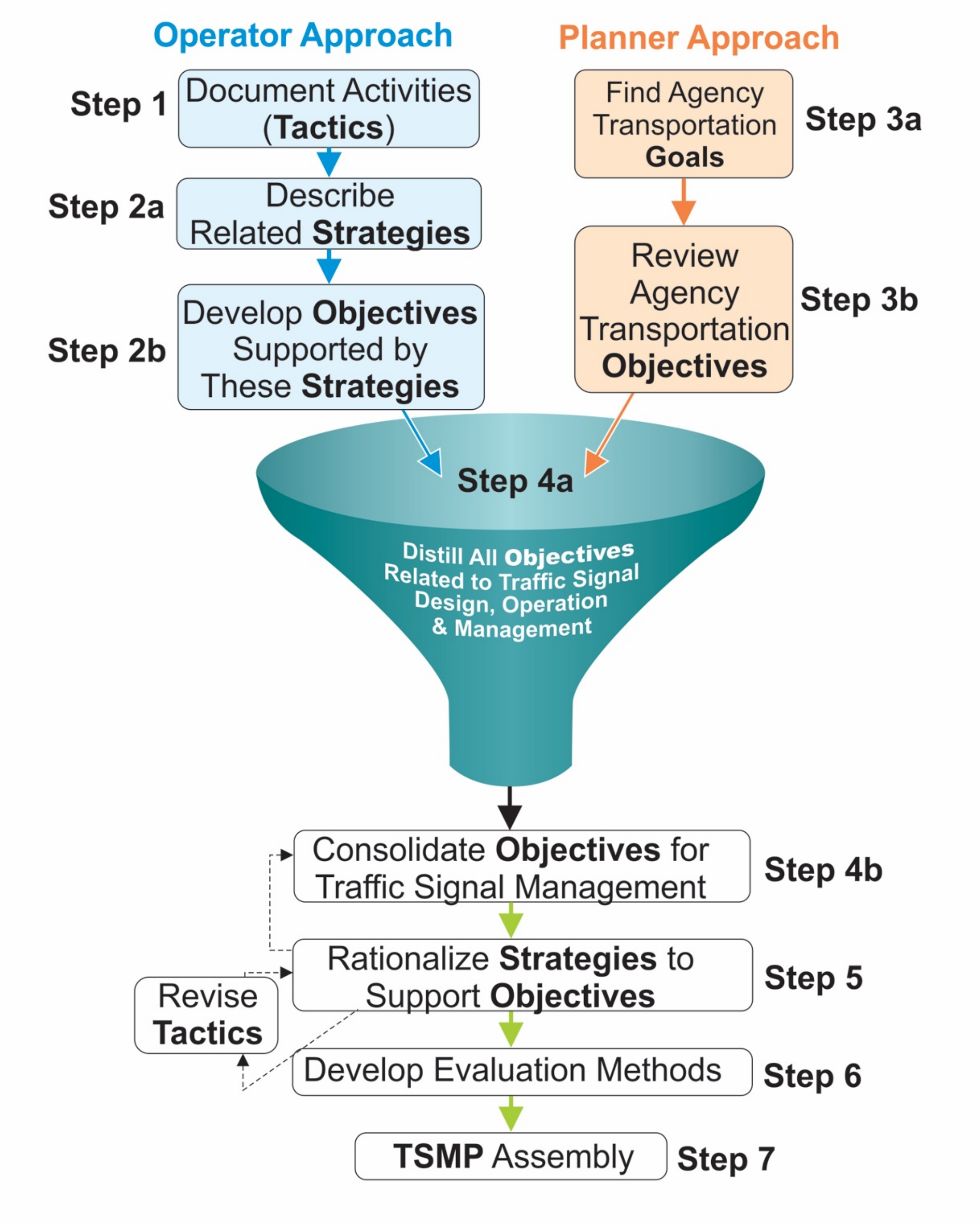
Figure 6. Diagram. Planner and operator approaches to traffic signal management planning.

Often, the most difficult part of the process is to elicit objectives that are stated in a way that is meaningful to traffic signal management, yet clearly consistent with the agency's overall goals and transportation objectives. You must be careful to avoid stating objectives for which the performance measures are not associated with traffic signal management or operation.

For example, an agency's objective related to bicycle safety and mobility may be to "…provide safe and efficient bicycle facilities to and from all major activity generators." However, this could be addressed through many avenues that do not specifically involve traffic signals, such as bike paths, exclusive bike lanes on arterials or parallel roads, shared facilities away from arterials, as well as specific treatments for bicycles at traffic signals. A more focused objective suitable for traffic signal management could be to "…safely and efficiently accommodate all bicycles at all traffic signals." This could lead to specific strategies to be applied at traffic signals (such as detecting bicycles and providing appropriate safety timing when bikes are present) and specific metrics that will determine the extent to which that specific objective is being met through traffic signal management.

Both approaches may be necessary for the assembly of a TSMP. It is easiest for practitioners to start from the bottom by documenting the day-to-day activities (tactics) and work up to the strategies and objectives. It helps to put context around what an agency does. Then go to the top and find the goals and objectives of the agency and work down to the strategies.

The hardest part of this process tends to be developing clear and concise objectives that are actionable and measurable. An agency's planning documents often have statements about vision, goals, objectives, guiding principles and policies that begin at a lofty level and the action plans developed in those documents often sound like statements of objectives to traffic signal operators. An agency should expect that the objectives it creates based on current strategies and activities will likely not match the level of the objectives statements often found in planning documents, as illustrated in Figure 7.



Source: DKS

Figure 7. Diagram. Planner vs. operator goals, context, objectives, strategies, and tactics (GOST) perspective.

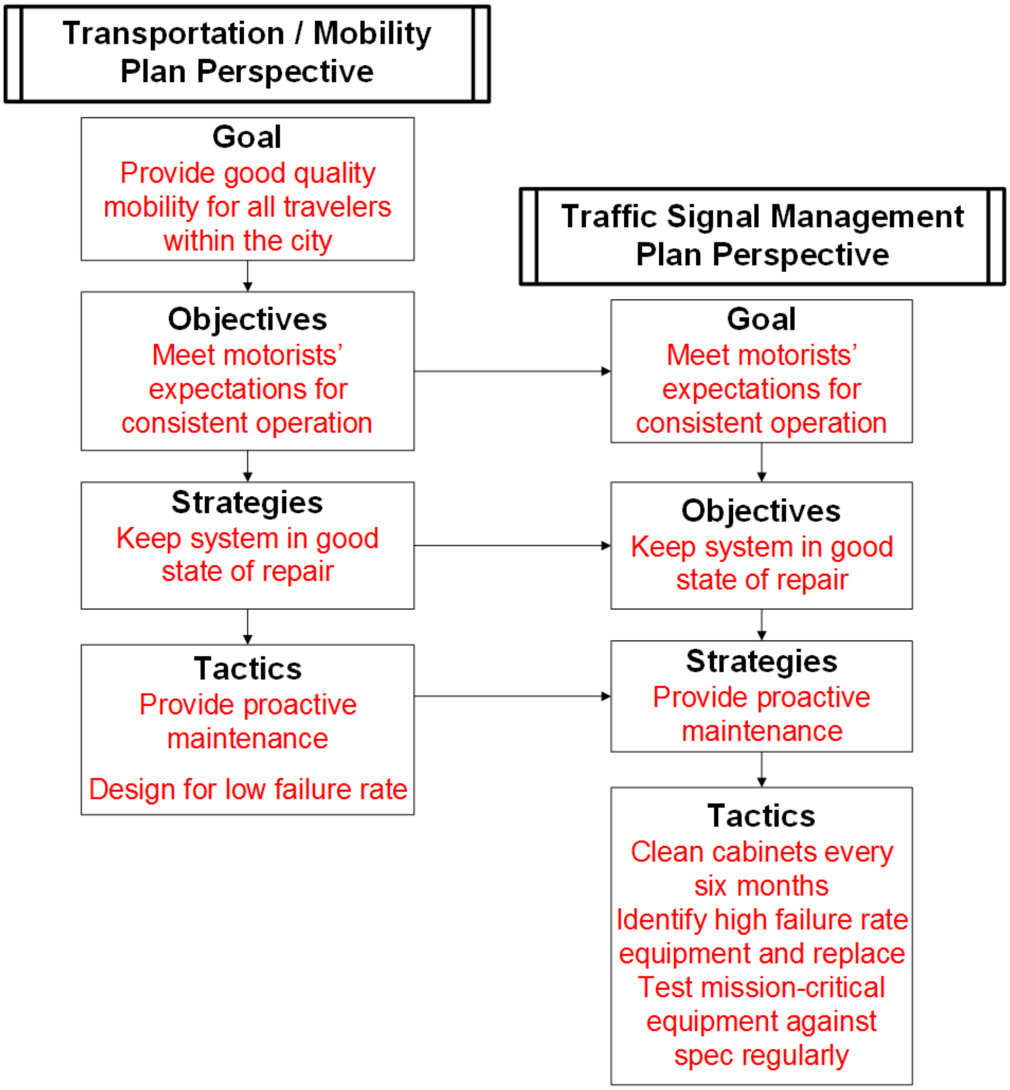
At some point the objectives will be consolidated into those relevant to the traffic signal system and then the strategies need to be reviewed. Working both from the bottom up and the top down helps to identify if there are any holes in the strategies and tactics. You will able to identify if there are goals not being supported by strategies or if there are activities that don't support the goals and objectives, as illustrated in Figure 7.

The following steps provide an outline of the process that may be used to create and adopt a TSMP. The actual process you use should be tailored to suit the size of your organization, the extent to which other agencies will participate in the development process and eventual implementation of the plan, and the key people who are championing the plan. A very important early step is to set out the proposed process and have as many stakeholders as possible commit to following the process before you embark on it.

PROCESS

The intent of the TSMP is to align the activities that are being done to operate and maintain the traffic signal system with objectives and the overarching goals of your agency. As shown in Figure 7, instead of starting with the goals and objectives and working down to the strategies and tactics, the process begins by documenting the activities currently performed by the traffic signal staff (step 1) in each area of the traffic signal program (maintenance, design, operations and management and administration. These activities represent tactics, and it is often easiest to begin by documenting maintenance activities, followed by design and then operations, management, and administration. The process then work its way up to strategies by requiring planners first to ask themselves why each activity is performed (step 2a), then to create an initial set of objectives that could be supported by those strategies. Rather than developing goals at this point, these will be extracted from existing sources (step 3a and 3b).

The initial strategies will be revised (step 5) and expressed in a way that clearly supports the objectives. This may also involve revising the tactics to add new tactics to fill apparent gaps or removing tactics that (while perhaps being of some use) are not necessarily supporting any defined strategy. Some iteration may be necessary between steps 2, 4 and 5. In step 6, evaluation methods and strategies will be selected, and the full TSMP will then be compiled (step 7). Figure 8 depicts a flow chart of the process. As can be seen, the ***operator*** approach and ***planner*** approach run parallel to each other.



Source: DKS

Figure 8. Diagram. Traffic signal management plan development flow chart.

Step 1 – Document Activities

Step 1 starts with the ***operator*** in mind and begins with the tactics. Write down the activities that staff currently do related to the maintenance, design or operation of the traffic signal system. The list of activities should include any activity performed on some recurring basis. An activity could occur annually, be a daily function, or be something that is only done when a specific event or situation occurs. This list will result in your system strategies and tactics. Use this as the basis for a brainstorming session in order to identify all activities. It is also critical to list activities that are contracted out. This list can also include a reference to existing policy documents and procedures you follow (maintenance checklist, signal timings guidelines, etc.), instead of repeating the detailed tasks within each procedure.

It may be helpful to group the activities into three groups: maintenance, operations, and design. By doing this, the staff involved in each of the categories can provide input on their specialty. There may be overlap between the different groups—this is okay. The duplications will be condensed later. The list will most likely contain a mixture of strategies and tactics—this is okay also. Tactics are "what" you do and strategies are "how" you do it, and at times it is difficult to draw the line between them.

The following questions are meant to help you document your activities, by organizing them around the typical categories associated with traffic signal system management. The questions are not all encompassing and your agency may do things not listed here. You can also review job descriptions for your staff to ensure all activities are captured.

Traffic Signal Maintenance

Preventive Maintenance

- Do you perform preventive maintenance of traffic signal hardware? What is included in maintenance list?
- How do you keep track of the condition of signal equipment?
- Do you provide locate services for underground conduit/wire associated with signal system?
- Do you maintain other agency's signal hardware? Do they have preventive maintenance guidelines different than yours?

Routine Maintenance

- How do you know when a detector is not working? (citizen call, central system alarm, routine maintenance).
- Do you maintain log of maintenance issues?
- How do you verify communications is operating as it should?
- What do you do in case of damaged vehicle detectors? (adjust timing, coordinate with signal operator, fix loop)

Emergency Maintenance

- What are your emergency maintenance procedures?
- What do you do in case of traffic signal power outage? (stop signs, generator)

Operations

System Efficiency

- How do you keep track of the signal timings/phasing at each intersection?
- When do timings need to be updated? (What are the triggers? Time, land use developments, etc.)
- Are you measuring performance? What kind?
- Who updates the signal timing? Agency staff or consultant staff?

- How do you monitor the signal operations? (Remote or in field)
- How do you quantify success?
- Do you modify signal operations during construction?

Intersection Efficiency

- How do you determine (calculate) local signal timings? Do you have a standard? Do you review timing routinely?
  - Minimum green, Maximum green
  - Walk, Flashing Don't Walk
  - Yellow, Red
  - Detector settings
- Do you review split logs for phase failures? What do you do about it?

Coordination

- What are your intended outcomes from signal timing? For example, to maximize throughput during peak hours, provide smooth flow during business hours, equitably distribute green time during off-peak times?
- How do you decide when to coordinate signals? (What factors do you consider?)
- How do you develop coordinated timings? Do you have documented policy or guidelines for selecting the following or other parameters?
  - Cycle length
  - Split
  - Offset
  - Advanced features
- How do you determine coordination timing patterns?
- What software program do you use to develop coordinated timings?
- Do you use the results of software analysis directly, or modify the software results to accommodate your objectives that are not adequately reflected in the software models?
- What do you do when traffic conditions are oversaturated, heavy or light? (briefly discuss general operations strategies in each case)
- Do you program special event timings?
- How do you prevent or accommodate queue overflow through use of signal timings?
- How do you coordinate during congestion?
- How do you accommodate various land uses in your coordination timings?
- Do you use a different philosophy to time signals on a corridor with transit?
- Do you time signals differently in a heavy pedestrian environment?

Multimodal safety and efficiency

- How do you time signals to accommodate pedestrians?
- How do you time signals to accommodate bikes?
- How do you time signals to accommodate transit (buses or Light Rail Transit)?
- How do you time signals to accommodate emergency vehicles?
- How do you time signals to accommodate freight (trucks)?
- How do you time signals to accommodate heavy rail?

Regional collaboration

- Do you coordinate signals with those of another agency?

Design

Miscellaneous

- Who designs new or modified traffic signal designs? (agency staff, consultant)
- Who reviews traffic signal design submittals?
- Do you have design standards or guidelines?
- What type of vehicle detection do you use? (inductive, video, radar) – does it depend on context? Why do you use X type of detection?
- What kind of communications infrastructure do you design/maintain?
- Do you share communications infrastructure with other agencies?

Operations Support

- What elements of design do you use specifically to support the operations you need? For example, where do you locate detection zones; do you use EV preemption; do you have transit signal priority (TSP); what communications bandwidth do you need?

Maintenance Support

- What elements of design do you use specifically to support the maintenance? For example, do you have standard specifications for equipment, such as controller, cabinet, detectors, communications equipment, cables or separate conductors, external finish such as paint or galvanized steel?

Multimodal Support

- What elements of design do you use specifically to support multimodal operations?
- How do you design to accommodate pedestrians at traffic signals?
- How do you design to accommodate bikes at traffic signals?
- How do you design to accommodate transit (buses or Light Rail Transit) at traffic signals?
- How do you design to accommodate emergency vehicles at traffic signals?

- How do you design to accommodate freight (trucks) at traffic signals?
- How do you design to accommodate heavy rail at traffic signals?

Management and Administration

Personnel

- What type of training does staff receive?
- How do you retain staff?

Coordination

- Do you coordinate/communicate with adjacent agencies? If so, who does this?

Budgeting and programming

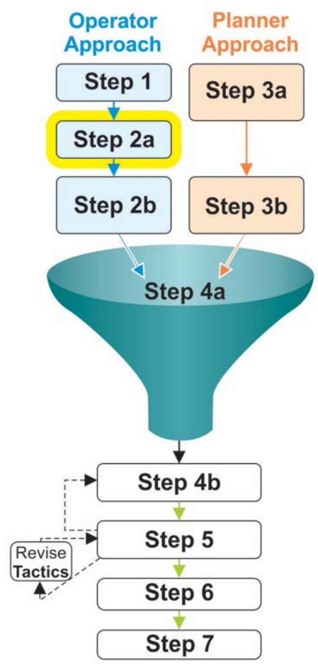
- Do you have on-going signal maintenance and operations specifically identified in your annual budget?
- Does your CIP or RTIP include replacement of signal equipment based on the estimate life cycle of each element?

Customer service

- Who responds to citizen calls?
- Who responds to Mayor's/Director's/ Manager's requests?
- Do you provide outreach to media, stakeholders on signal operations?

Step 2a – Describe Related Strategies

Based on the items listed in Step 1, think of the reasons **why** the agency conducts these particular activities. The answer will typically give you the *strategy* you are implementing through this activity. For example:



What do you do?

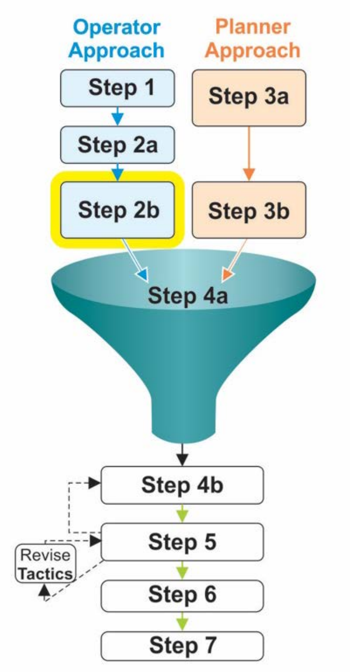
Tactic: Modify signal timing temporarily to compensate for equipment failures (e.g., stuck detector)

Why do this?

Strategy: Respond to citizen complaints

Strategy: Minimize impact of failures on traffic operations

Step 2b – Develop Objectives



For each strategy described in Step 2B pose the question: **what** are we trying to achieve by implementing that strategy? This will identify the *objectives* that you have for all the activities you undertake. For example:

What do you do?

Tactic: Modify signal timing (stuck detector)

Why do this?

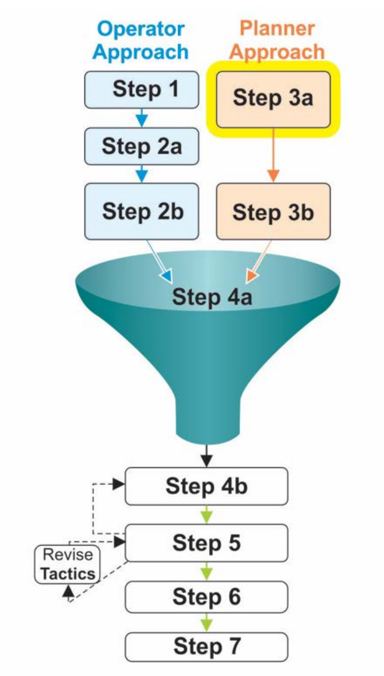
Strategy: Respond to citizen complaint

What are you achieving?

Objective: Maintain operational efficiency of signal system or ensure that traffic signals provide equitable service to all users.

Step 3a – Identify and Link to Agency Goals

Step 3 starts with the ***planner*** in mind by reviewing your agency's planning documents as shown in step 3a. Identify the goals listed in a transportation system plan, transportation chapter of a comprehensive plan, area plan, congestion management plan, etc. Goals from the transportation system plan or the goals of the transportation division of an agency work well since they directly relate to the transportation system. Goals from an agency general plan (for example) tend to be broader or high level and relate more to the overall function of the agency. It may be more challenging to pull out transportation related goals. If your agency doesn't have documented goals from planning documents, then you will need to develop your own goals for the signal system.

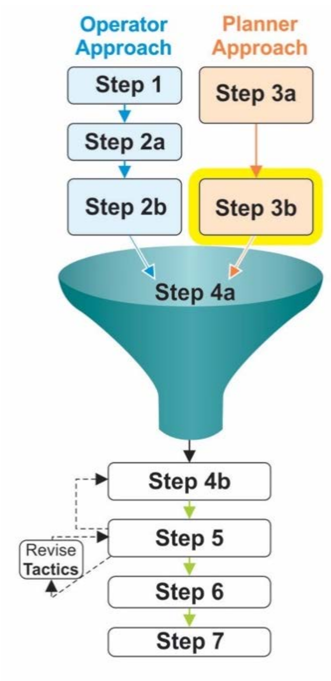


Transportation goals extracted from the City of Walnut Creek General Plan 2025 (Walnut Creek, 2006) are listed in Table 5. Each of the transportation goals is reviewed to determine whether or not it is relevant to traffic signal management. Those that are relevant are then carried forward, along with any related objectives that are documented.

Table 5. Example agency transportation goals.

Description of Agency Transportation Goal	Relevant to Traffic Signal Management?
Minimize future increases in congestion on regional transportation facilities	Yes
Expand and improve regional trail facilities.	No
Maintain a transportation network that provides mobility for all ages and abilities and for all areas of the community.	Yes
Protect residential neighborhoods from through-traffic, speeding, and nonresidential parking.	Yes
Provide a safe and attractive environment for bicycle travel throughout the community.	Yes
Provide a safe and attractive walking environment accessible to all.	Yes
Increase transit ridership and service to employment, schools, shopping, and recreation.	Yes
Serve as a model for other cities by providing a comprehensive TDM program that strives to decrease the use of the automobile and reduce peak-period traffic congestion.	No
Promote a pedestrian friendly downtown.	Yes
Promote safe bicycling to and through downtown.	Yes
Develop a comprehensive shuttle system serving downtown residents, shoppers, day and overnight visitors, and employees.	Yes
Provide convenient and adequate parking.	No
Provide convenient and adequate loading facilities in the Core Area.	No

Source: City of Walnut Creek



Step 3b – Review Transportation Objectives

Some agencies adopt guiding principles or policies to explain the context within which their objectives are framed. In one agency's General Plan, numerous policies were described, intended to support each goal, and at the same time providing a mixture of objectives and contextual guidance. Each of these can then be assessed to determine whether or not they are relevant to traffic signal management.

The transportation policies established in the example General Plan, and an assessment of their relevance to traffic signal management, are contained in Table 6. These can be used to guide the description of traffic signal management objective in the next step.

Some agencies have adopted objectives for the different departments (including public works, engineering, transportation, etc.). If this is the case, review and compile the Objectives that relate to the traffic signal system. If your agency doesn't have documented objectives from planning documents, then you will need to develop your own objectives for the signal system.

Table 6. Example agency transportation plan policies.

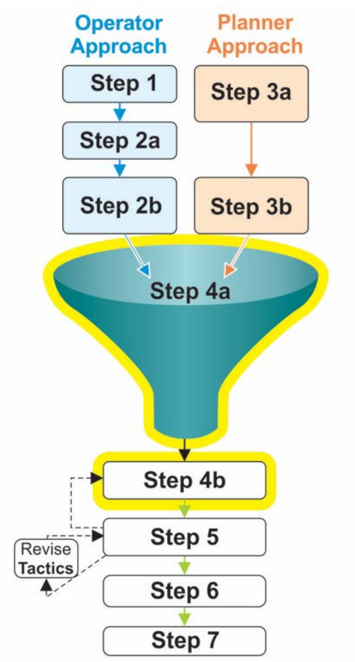
Policy	Description of Guiding Policies	Relevant to Traffic Signal Management?
	Goal 1:Minimize future increases in congestion on regional transportation facilities	
1.1.	In cooperation with State and regional agencies and other jurisdictions, develop and implement regional solutions to local traffic problems created by growth outside the city.	Yes
1.2.	Support efforts to obtain funding for improvements to Highway 4 and other roads that provide a bypass for traffic passing through Walnut Creek.	No
1.3.	Promote off-peak start times for special events that generate traffic passing through Walnut Creek.	No
	Goal 3: Maintain a transportation network that provides mobility for all ages and abilities and for all areas of the community.	
3.1.	Maintain the level of service standards for designated roadways within the City's transportation network.	Yes
3.2.	Make safety, circulation, and congestion-reduction improvements without excessive community disruption.	Yes
3.3.	Promote maximum operational capacity and efficiency on arterials and collectors.	Yes
	Goal 4: Protect residential neighborhoods from through-traffic, speeding, and nonresidential parking.	
4.1.	Manage arterial and collector traffic to minimize adverse effects on neighborhoods.	Yes
4.2.	Discourage through-traffic on local streets and collectors.	Yes
4.3.	Prevent encroachment of nonresidential parking in existing neighborhoods.	No
	Goal 5: Provide a safe and attractive environment for bicycle travel throughout the community.	
5.1.	Promote bicycle use as an alternative way to get to work, school, shopping, recreational facilities, and transit stops.	No
5.2.	Provide facilities that encourage and support bicycle travel.	Yes
5.3.	Oppose the use of motorized transportation (trains, buses, autos, motorcycles) on the Iron Horse Corridor between the Pleasant Hill BART Station and Newell Avenue.	No

Table 6. Example agency transportation plan policies (cont'd).

Policy	Description of Guiding Policies	Relevant to Traffic Signal Management?
	Goal 6: Provide a safe and attractive walking environment accessible to all.	
6.1.	Provide safe and attractive pedestrian routes along arterials and collectors leading to schools, along arterials or collectors that carry high traffic volumes, on all downtown streets, along major streets leading to the downtown, and on all streets leading to transit facilities.	Yes
6.2.	Require full-frontage curb and sidewalk improvements in all commercial areas.	No
6.3.	When utility rights-of-way, drainage, or other corridors are established, obtain dedications of land or easements, where appropriate, for paths that would enhance the pedestrian system.	No
6.4.	Facilitate use of public sidewalks and walkways throughout the city.	Yes
	Goal 7: Increase transit ridership and service to employment, schools, shopping, and recreation.	
7.1	Encourage coordination among transit agencies in facilitating connections and transfers while minimizing delay and inconvenience.	Yes
7.2.	Encourage improvements to transit systems that connect Walnut Creek residents to regional locations.	Yes
7.3.	Link high-density residential developments, schools, employment centers, and shopping areas via transit.	No
7.4.	Offer support and funding for effective transit alternatives such as trolleys and improved shuttle services.	No
7.5.	Develop a comprehensive plan with CCCTA to install public transit amenities such as benches, passenger shelters, and walkways.	No
7.6.	Encourage provision of a variety of transportation services for seniors and members of the public unable to use conventional transit.	No
	Goal 9: Promote a pedestrian friendly downtown.	
9.1.	Balance the needs of drivers with downtown's pedestrian scale and existing and proposed transit and bicycle access.	Yes
9.2.	Favor pedestrian travel over vehicular travel in the Pedestrian Retail District.	Yes
9.3.	Promote pedestrian safety in the downtown area.	Yes
	Goal 10: Promote safe bicycling to and through downtown.	
10.1.	Link existing and planned bikeways in and through downtown.	Yes

Source: City of Walnut Creek

Step 4 – Consolidate Objectives for Traffic Signal Management



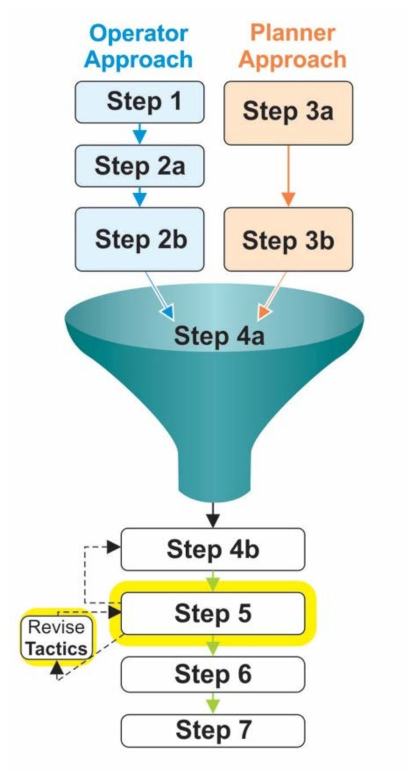
Combine, review, and distill the Objectives developed in Step 2 and the Objectives from Step 3b. Now that you have described objectives that could be supported by your strategies, you should modify them and define them in a manner that is consistent with the transportation objectives identified in Step 3. These should be expressed in terms that would work for both the operator and the planner. Example TSMP objectives that have been derived using this process are contained in Table 7. For example, the TSMP objective of "operate traffic signal system at its maximum efficiency within the context of a balanced, multimodal operation, as described in current operational policies" was established to accommodate several of the agency's transportation objectives, namely:

- Maintain the level of service standards for designated roadways within the City's transportation network.
- Promote maximum operational capacity and efficiency on arterials and collectors.
- Manage arterial and collector traffic to minimize adverse effects on neighborhoods.

Table 7. Example traffic signal management objectives.

	Description
1	Provide facilities at traffic signals to safely and efficiently accommodate all road users (including transit, pedestrians and bicycles in addition to other vehicles)
2	Keep the signal operation appropriate for the current traffic conditions and consistent with current operational policies
3	Operate traffic signal system at its maximum efficiency within the context of a balanced, multimodal operation, as described in current operational policies
4	Undertake maintenance in a cost-effective manner
5	Cooperatively coordinate with neighbor agencies to develop and implement regional solutions to traffic problems related to regional issues
6	Design traffic signal system elements that are sustainable in a fiscally responsible manner
7	Maintain the traffic signal system so it always operates as intended
8	Maintain a traffic signal infrastructure that is appropriate for accommodating current mobility goals
9	Inform and educate all stakeholders of the challenge to maintain a modal balance and superior service.
10	Keep the community fully informed about the development and operation of the traffic signal system so they understand what we do and why we do what we do, so they can judge for themselves how well we are satisfying their needs.

Step 5 – Rationalize Strategies to Support Traffic Signal Management Plan Objectives



At this point you have a set of traffic signal management objectives that are consistent with your agency's transportation goals and objectives. Most of these objectives will be supported by the strategies you described in Step 2. You should now review and revise the strategies so they clearly support your revised TSMP Objectives developed in Step 4. At this point, you may choose to reword the strategies and tactics for consistency, add to them, or consolidate them. This may involve further editing the objectives to ensure that strategies you consider important are not discarded because they were not linked to an appropriately worded objective.

If you can't clearly describe an objective that would justify employing a specific strategy, you should seriously consider dropping that strategy, because it cannot be justified within the context of your TSMP. This review process also provides the opportunity to confirm that all the stated tactics are, in fact, legitimately supporting your objectives. At this point, you may need to consider dropping a tactic (even a long-standing activity) if you cannot show that it is actually supporting your objectives and is consistent with your listed strategies. Now look at the objectives brought forward from Step 4 and identify any that are not yet support by strategies and tactics. If you have any, create additional strategies what will support those objectives. You may choose to identify those strategies in your action plan for future implementation.

One way to verify that the strategies and tactics are meeting the objectives is to develop a traceability matrix. To do this, start by listing your goals and objectives, organized in a way that shows which objectives support which goals. Then for each objective, list all the strategies that support each objective. It is quite likely that some strategies will support more than one objective, so you should list those several times, under each relevant objective. Each strategy is supported by one or more tactic or activity, and each tactic may support one or more strategies. You should now list each tactic that supports each strategy. As before, this may involve listing some tactics multiple times.

Table 8 shows example goals, objectives, strategies and tactics that have been developed in TSMPs by UDOT, City of Walnut Creek and City of South San Francisco.

Table 8. Example traceability between goals, objectives and strategies.

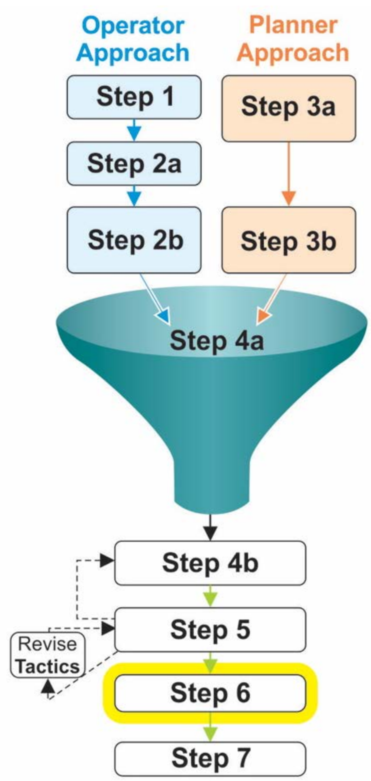
Agency Goal	TSMP Objective	Strategy	Tactic
Maintain the transportation system in the most efficient manner possible	Undertake maintenance in a cost effective manner	Perform regular preventive maintenance on all traffic signals	• Visit each intersection once per month and replace elements that are consumed in normal operation according to life cycle analysis for each element. • Contract maintenance when it is more cost-effective that in-house.
Link communities through an efficient multimodal transportation network	Safely and efficiently accommodate all bicyclists at all traffic signals	Provide bicycle detection and appropriate timing at each signal	• Detect all bicycles arriving at traffic signals. • Adjust signal timing to safely accommodate bicycles when they are detected.
	Safely and efficiently accommodate all pedestrians at all traffic signals	Provide pedestrian detection and crosswalks for all desired pedestrian movements	• Provide push buttons for all signalized crosswalks. • Provide signalized crosswalks for all feasible pedestrian crossings at traffic signals. • Use pedestrian detection to minimize impact of pedestrian crossing times on traffic operation.

Now you need to work upwards from objectives to goals, and also work downwards from goals to objectives. This will help you align the activities with your agency's goals, and provide a basis for enunciating goals that have not been adequately documented so far, but are needed to clearly show justification and support for all the activities.

This then provides a vehicle for detailed reconsideration of what you do, why you do it, and will potentially lead in three different directions:

- Some activities may be determined to be unnecessary or even counter productive.
- Some goals and objectives will be seen as having no activities to support them.
- Some previously unstated goals will be documented and determined to be essential to the agency.

Step 6 – Develop Evaluation Methods



In Step 6 you select evaluation methods, measures and metrics that will allow you to assess both operational success (you are impacting traffic operations as desired) and implementation of strategies (you are effectively doing what you agreed to do). At this point, you have all the necessary elements to compile your TSMP (step 7). Within this document, we define performance measurement as the process of assessing the effectiveness of the traffic signal system in providing the desired traffic operational performance, and how well the objectives have been satisfied. This is measuring the outcomes. We define implementation verification as the process of measuring the activities undertaken by the team and determining to what extent the strategies and tactics have been implemented. This is measuring the outputs. For your operational Objectives, determine the performance measurement that is most appropriate to monitor performance. (See Chapter 4 for more information on selecting performance measures, determining data, and tracking performance of your system.)

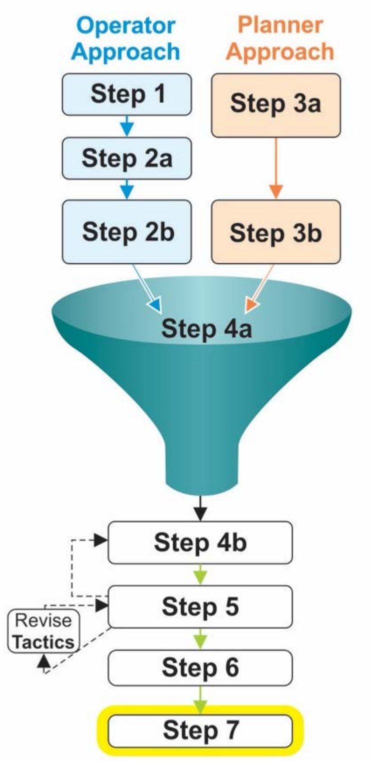
It is best to start with one or two performance measures and build upon them as your system becomes more mature. Examples of performance measures, related directly to the operational objectives implement by City of Mesa, City of Walnut Creek and UDOT, are including in Table 9. In each of these, a single measure of performance was chosen as a determinant of success in meeting an objective. For example, an objective defined by the City of Mesa a decade ago was to provide stable travel times on specified corridors. They defined stability as limiting annual increases in average travel times to be in proportion to the changes in traffic volumes. The travel times were initially measured using floating car surveys on an annual schedule, repeating the surveys during the same week of the year. In recent years, travel times are now measure automatically and continually using Bluetooth readers, providing both a larger sample size and coverage of all periods of the day and days of the week, to allow better evaluation of the performance against the stated objective.

Table 9. Performance measures used in traffic signal management plans.

objective	performance measure	method of measurement	agency
Maintain stable travel times in defined corridors	Average end to end travel time on defined corridor	Floating car (annual peak hour survey) Bluetooth tracking (24/7)	Mesa
Provide predictable travel time on major arterials, consistent with traffic demand	Average end to end travel time. Reliability of travel time	Bluetooth tracking (24/7)	Walnut Creek
Provide smooth flow on defined arterials in unsaturated conditions	Percentage arrivals on green on corridor	High resolution data and Purdue Coordination Diagram	Utah Department of Transportation

Step 7 – Traffic Signal Management Plan Assembly

Now it is time to put the TSMP chapters together. Refer to the proposed Outline of Chapters in the next section to see how to compile the document. Feel free to modify this layout, just as long as you keep the intent of mapping the strategies to your agency's goals.



CHAPTER 4. OUTLINE FOR TRAFFIC SIGNAL MANAGEMENT PLANS

Although the practical plan development process described above tends to work bottom up from the tactics to strategies, the plan should be organized in a logical fashion consistent with traditional strategic or master plans. The following is a suggested outline for a traffic signal management plan (TSMP).

EXECUTIVE SUMMARY

The executive summary provides a brief overview of what is in the document. This is a good place to list the TSMP objectives and discuss how they connect the strategies and tactics to the agency's goals.

CHAPTER 1 – INTRODUCTION AND BACKGROUND

Include an introduction to the document and a summary of your existing traffic signal system. The purpose of this section is to provide context to your system and create a baseline for activities.

The background summary may include the following:

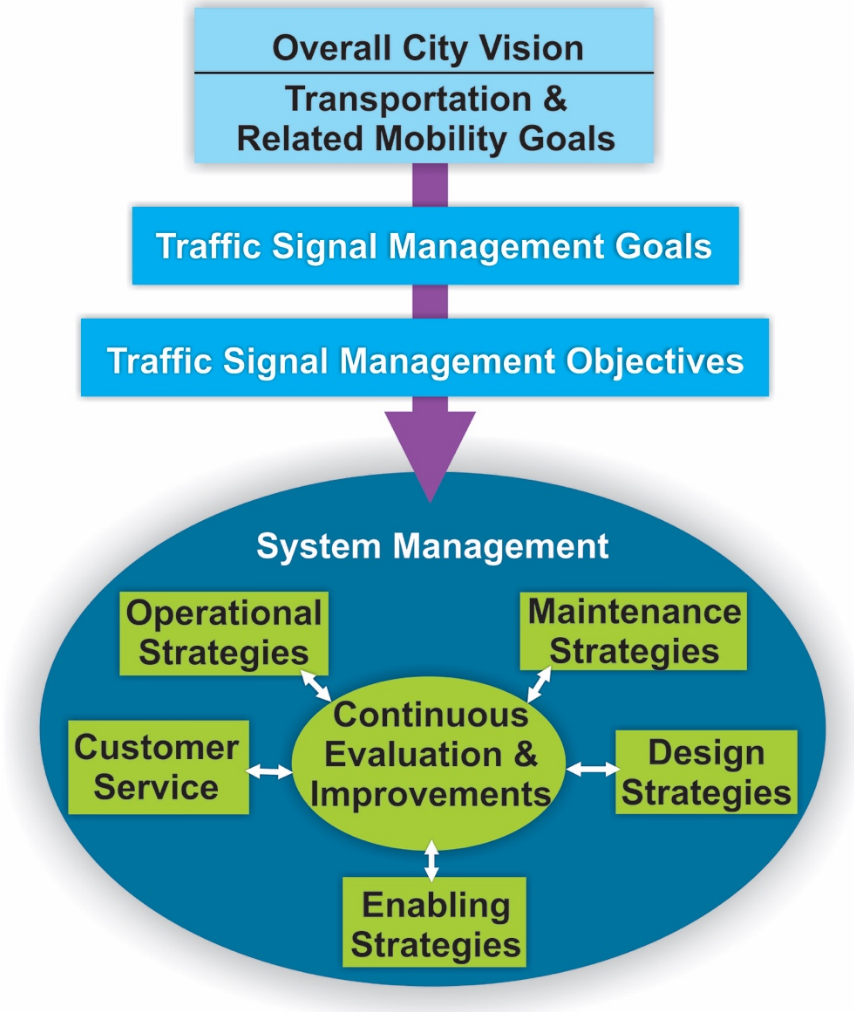
- Purpose of the document and the procedure used to develop it.
- Map/list of existing traffic signals.
- Map/list of existing communications infrastructure.
- Table documenting history of traffic signal updates.
- Description of existing staff organizational structure.
- Description of relationship with adjacent agencies and regional partners.

CHAPTER 2 – GOALS AND OBJECTIVES

This chapter will summarize the agency's transportation goals and the TSMP Objectives that support those goals. This chapter will describe the context within which the TSMP exists. Figure 9 illustrates the context of the City of Walnut Creek TSMP.

Extract from Utah Department of Transportation Draft TSMP

The purpose of this Traffic Signal Management Plan (TSMP) is to provide a framework for delivery of high quality service to the public through an efficient and well-maintained traffic signal system. The plan describes the objectives of traffic signal management within the context of the Utah Department of Transportation (UDOT) vision, mission, strategic goals and accountability. The plan sets out strategies to guide the maintenance, design and operation of the traffic signal system. It also defines appropriate measures of performance to determine the extent to which the objectives are being met, and verification reports to confirm that the defined strategies continue to be appropriately implemented on an ongoing basis.



Source: City of Walnut Creek

Figure 9. Diagram. Traffic signal management plan context diagram.

2.1 Transportation Goals

You may choose to list all the agency goals and then highlight the ones that relate to the signal system or you can list only the ones that relate to the signal system.

2.2 Traffic Signal Management Objectives

List the consolidated Objectives that relate to the agency goals and work for both the planner and operator.

2.3 Performance Measures

Summarize the Performance Measures you use, the method you use to obtain each metric and the objective it supports.

CHAPTER 3 – MAINTENANCE

This chapter documents the maintenance strategies and tactics you will use to meet the traffic signal management objectives.

3.1 Maintenance Strategies & Tactics

It is often convenient to describe three strategies for maintenance:

- Proactive maintenance strategies
- Reactive maintenance strategies
- Administrative maintenance strategies

Proactive maintenance strategies ensure that:

- Components of the traffic signal system that have a limited service life are regularly cleaned, replaced, recalibrated or tuned to prevent equipment failures;
- Information that will prevent damage by others is provided in a timely manner.

Example proactive tactics are included in Table 10.

Table 10. Example proactive maintenance tactics.

Maintain accurate as-built records of all elements of the traffic signal system, in a form readily accessible by maintenance staff when needed.
Visit every intersection once every two months and undertake all preventive maintenance activities, according to relevant procedure.
Provide up to date as-built records in a timely fashion to anyone who needs them in order to prevent damage to the traffic signal system.
Test items susceptible to damage that cannot be identified by observation during preventive maintenance activities, on a regular schedule using defined procedures.
Assign an expected lifespan to each traffic signal element, beyond which failure rate or performance is likely to unacceptable, and plan for timely replacement.

Reactive maintenance strategies ensure efficient and effective response when equipment fails and an emergency response is required to restore operation. Example reactive maintenance tactics are included in Table 11.

Table 11. Example reactive maintenance tactics.

Maintain a sufficient number of generators to be able to restore stop-go operating at up to three intersections at which power has been cut and will not be restored within six hours.
Maintain sufficient spares at the maintenance facility to restore full operation of up to three intersections that experience equipment failures within 24 hours.
Maintain sufficient spares of safety-critical equipment on each maintenance vehicle to allow restoration of safe operation at an intersection that experiences safety-critical equipment failure within two hours.
Provide sufficient technicians on duty, on call or on contract to ensure safety-critical issues can be attended within agreed time parameters. (E.G., blacked out signal within one hour 24/7; signal timing error causing unsafe or illegal driver behavior within XX hours 24/7).
Have contracts in place to accommodate without delay, repairs that cannot be undertaken by maintenance technicians.

Administrative strategies enable the proactive and reactive maintenance to be smoothly implemented and continued in a sustainable manner. Examples of administrative maintenance tactics are shown in Table 12.

Table 12. Example administrative maintenance tactics.

Train all staff to be proficient in all activities to which they are assigned.
Analyze maintenance logs and regularly report effectiveness and efficiency.
Introduce new equipment in a cautious, structured manner with appropriate training and testing equipment.
Provide flexibility to work non-standard hours when required to accommodate emergency and unusual maintenance circumstances.

3.2 Implementation Verification

Define the records and analysis needed to verify, through periodic assessment, the extent to which the maintenance activities have been implemented. Examples of implementation verification measures for maintenance strategies and tactics are included in Table 13. For each metric, you should include the target value to be judged satisfactory, and the frequency of measurement and reporting.

Table 13. Example maintenance implementation verification metrics.

Maintenance Verification Metric	Target	Timing
Comparison of actual vs programmed activities	Variance of zero days	Report monthly
Number of reactive activities, by equipment type	Zero	Report monthly
Time to respond to emergency calls	Varies by type of reported fault	Report monthly
Time to provide requested information (e.g., mark underground facilities)	Three days	Report monthly
Number of staff trained to maintain equipment, by type	Varies by type of equipment	Report annually
Time to clear failures, by type	Varies by type of fault	Report monthly
Detector status report Tabulation of maintenance work orders	Fix detection problems before public notices	Report monthly
Report equipment and spares inventory, actual vs planned.	Zero variance	Report monthly
Report staff status actual vs planned	Zero variance	Report monthly

CHAPTER 4 – OPERATIONS

This chapter documents the operations strategies and tactics you will use to meet the signal system objectives.

4.1 Operations Strategies and Tactics

List the strategies that relate to operations and briefly describe which objectives are being met by the strategies. It is often convenient to group your tactics under the following operations strategies:

- Operate the system efficiently
- Coordinate signals where this will improve traffic operation
- Time signals to provide multimodal safety and efficiency
- Use phasing and timing to operate intersections efficiently
- Operate signals in coordination with regional partners using compatible strategies

Example tactics supporting system efficiency are included in Table 14.

Table 14. Example system efficiency tactics.

Install hardware and software to continually monitor performance under all conditions to which the operational strategies are being applied, and report the quality of that performance.
Automatically monitor traffic conditions and review signal timing whenever conditions change beyond a pre-determined amount.
Operate signals in a mode that suits current traffic conditions (e.g., use adaptive signal control to automatically adjust signal timing to suit the current traffic conditions; or use traffic responsive pattern selection to select the timing pattern most appropriate for the current traffic conditions).

Example tactics supporting effective signal coordination are included in Table 15.

Table 15. Example signal coordination tactics.

When needed to accommodate demand, provide a "pipeline" along arterial roads, to maximize flow on the coordinated route while keeping side street delay to an acceptable level.
While accommodating demand, as far as possible, coordinate signals along arterial roads to minimize stops along the arterial, while keeping side street delay to an acceptable level.
Away from major arterials, distribute phase splits to balance delays on all approaches.
Where protected/permissive left turns are provided, allow the protected phase to be excluded from the signal pattern when the permissive phase will provide sufficient capacity to safely accommodate all left turns without carryover queues.
When providing coordination, include consideration of "complete street" policies.
Review, and revise as appropriate, coordinated signal timing at least once every two years.

Example tactics supporting multimodal safety and efficiency are included in Table 16.

Table 16. Example multimodal safety and efficiency tactics.

Provide adequate phase green and clearance times for bicycles on each traffic signal phase, using relevant Caltrans and national standards.
Use phase clearance times and pedestrian walk and clearance times calculated to comply with CA MUTCD and other applicable standards.
Depending on the area, optimum synchronization of vehicular traffic may be compromised to accommodate pedestrian, bicycle and transit needs.

Example tactics supporting intersection efficiency are included in Table 17.

Table 17. Example intersection efficiency tactics.

Review signal timing at applicable traffic signals whenever a policy related to timing is modified.
Use signal timings and flexible phasing arrangements to prevent queues exceeding critical lengths in left turn bays, in short blocks on arterial roads and on freeway off-ramps.

Example tactics supporting regional coordination and compatibility are included in Table 18.

Table 18. Example regional coordination and compatibility tactics.

Coordinate signals across jurisdictional boundaries by: operating all signals on one system; coordinating patterns across boundaries by synchronizing clocks and timing patterns; or coordinating patterns across boundaries by interconnecting systems.
Participate in regular operations coordination meetings with adjacent agencies.
Coordinate arterial signals with ramp intersection signals.
Coordinate arterial signals with ramp meters.
Coordinate signals to accommodate traffic diverted by freeway incidents.

4.2 Implementation Verification

Define the records and analysis needed to verify, through periodic assessment, the extent to which the operations activities have been implemented. Examples of implementation verification measures for operations strategies and tactics are included in Table 19. For each metric, you should include the target value to be judged satisfactory, and the frequency of measurement and reporting.

Table 19. Example operations implementation verification metrics.

Operations Verification Metric	Target	Timing
Arterial volume (Throughput)		Monthly report
Minor phase max-out		Monthly report
Number of stops, weighted by volume	# stops per mile	Periodic floating car
Frequency queue exceeds limit	Zero blockages	Continuous detection
No. intersections with bicycle timing	All intersections	Annual report

CHAPTER 5 – DESIGN

This chapter documents the design strategies (or standards) you will use to meet the operational objectives. This section links how design standards impact maintenance and operations resources. It will also show how design elements need to be driven by the operations strategies (e.g., detection in the right place, correct type of detection, use of suitable signal phasing, control of variety of equipment).

5.1 Design Strategies and Tactics

List the strategies that relate to design and briefly describe which objectives are being met by the strategies. It is often convenient to group your tactics under the following design strategies:

- Operations support.
- Maintenance support.
- Multimodal accommodation.
- Regional coordination.
- Manage design process efficiently.

Example tactics supporting operations are included in Table 20.

Table 20. Example operations support tactics.

Design signals to allow application of versatile operational strategies to suit varying traffic conditions and changing community expectations (include relevant details).
Specify detection systems that have a proven record of high performance and reliability, and are maintainable at a high level of availability (include relevant details).
Design a communications system to have a high performance level in terms of capacity (bandwidth), communication speed, reliability and availability, suitable to accommodate all operational requirements.
Design system to allow efficient setup, fine tuning and monitoring by operations staff.
Provide high standard communications from the TOC to every City-operated traffic signal.
Use non-invasive detection technology on approaches requiring high street maintenance or underground utility activity that would damage normal loops.
Use robust detection installation that will be less affected by pavement deterioration, road maintenance or construction activities.

Example tactics supporting maintenance are included in Table 21.

Table 21. Example maintenance support tactics.

Design the traffic signal system to allow a high level of efficiency and cost-effectiveness of maintenance and operation activities (reference design standards).
Design system to automatically detect and report faults.
Design system to minimize failure rates of equipment units.
Design signals to minimize risk of damage due to crashes and vandalism.
Design system to allow fast and efficient response by maintenance staff.
Design communications system to self-diagnose and report faults.
Design communications system to be self-healing.
Design communications system to minimize damage by others.
Design communications to have low risk of damage by others.

Example tactics supporting multimodal accommodation are included in Table 22.

Table 22. Example multimodal accommodation tactics.

Provide a high level of accessibility of traffic signals to all road users (e.g., facilities accommodating pedestrians, cyclists, transit passengers).
Provide crosswalks for all reasonable pedestrian movements at traffic signals.
Provide push buttons for all pedestrian phases.
Provide bicycle detection in each bicycle lane at each traffic signal.
Provide bicycle detection in each traffic lane at each traffic signal.
Upgrade intersection elements to current ADA standards when significant modifications or construction work are undertaken in the vicinity of the intersection. (Need to have a policy defining what is significant, and what thresholds will be used to determine what work is appropriate.)

Example tactics supporting regional coordination and compatibility are included in Table 23.

Table 23. Example regional coordination and compatibility tactics.

Interconnect signals across jurisdiction boundaries.
Design arterial signals to coordinate with ramp intersection signals.
Design arterial signals to coordinate with ramp meters.

Example tactics supporting efficient design management are included in Table 24.

Table 24. Example design management tactics.

Follow systems engineering principles for all new system elements and when considering major changes to the system (Describe approach in an appendix; List suitable references and guidebooks, such as FHWA's guidance documents and standards).
Maintain a design review checklist to identify all elements that must be included in a design and the appropriate standard or specification.
Design system to share high bandwidth communications with other departments and agencies where it will be feasible and cost-effective.
Specify materials to minimize deterioration of performance and appearance that would require continued maintenance or early replacement.
Routinely review existing traffic signal installations to ensure their design is still appropriate for the prevailing conditions (e.g., appropriate number of phases, appropriately accommodate pedestrians and bicycles, the need for the signal is still valid).

5.2 Implementation Verification

Define the records and analysis needed to verify, through periodic assessment, the extent to which the operations activities have been implemented. Examples of implementation verification measures for design strategies and tactics are included in Table 25. For each metric, you should include the target value to be judged satisfactory, and the frequency of measurement and reporting.

Table 25. Example operations implementation verification metrics.

Verification Metric	Target	Timing
Document number of signals with full vehicle-actuated capability.	100%	Annual review
Document number of signals with full communications capability.	100%	Annual review
Document reliability of detection, by type.	Annual failure rate, by type	Annual review
Document actual vs planned communications bandwidth, by intersection.	Actual = Planned	Annual review
Document number of detectors not operating as designed, and reason for failure.	95% serviceable at any one time	Monthly report
Document resources required for setup, fine tuning and monitoring activities.		Annual review
Confirm specifications consistent with needs of all operations and maintenance.		Annual review
Document faults found during maintenance are consistent with reports and alarms generated by system.	System reports 100% of faults	Monthly review
Confirm all required details are in design review checklist.		Annual review
Report design exceptions, variations from standards and design review checklist.		Annual review

CHAPTER 6 – MANAGEMENT AND ADMINISTRATION

This chapter documents the strategies and tactics that are associated with enabling activities (management, administration and customer service). These strategies relate to the management of the staff, personnel issues, programming and budgeting, not the day to day activities on the street.

6.1 Management and Administration Strategies

List the strategies that relate to management and administration and briefly describe which objectives are being met by the strategies. It is often convenient to group your tactics under the following management and administration strategies:

- Personnel
- Inter-department coordination
- Budgeting and programming
- Customer service

Example tactics supporting personnel strategies are included in Table 26.

Table 26. Example personnel tactics.

Provide a well-trained group of staff with sufficient resources to handle staff changes and temporary fluctuations without compromising the performance of the traffic signal system.
Coordinate the activities of all relevant staff involved in planning, designing, operating and maintaining the traffic signal system.
Develop and implement a succession plan for each staff position.
Document procedures to the extent necessary for a new or temporarily assigned staff member to be able to efficiently complete the duties of the position.
Define qualifications appropriate for all staff and a policy to ensure staff remain appropriately qualified.

Example tactics supporting inter-departmental coordination are included in Table 27.

Table 27. Example interdepartmental coordination tactics.

Define when and how to coordinate planning reviews with operations and maintenance staff.
Define when and how to coordinate CIP development, grant applications and internal budgeting.
Define how to handle design reviews.

Example tactics supporting budgeting and programming are included in Table 28.

Table 28. Example budgeting and programming tactics.

Maintain a list of intersections that require upgrade or improvement when modifications are proposed by others (e.g., developer of adjacent property). (List should be based on regular assessment of intersection operations, maintenance history, obsolete or defective equipment, within an undergrounding district, listed in the CIP, etc.).
Maintain a plan to avoid obsolescence as current equipment ceases to be supported by vendors.
Regularly review new technology developments beyond traffic signals that will require modifications to existing equipment and practices (e.g., connected vehicles).

Example tactics supporting customer service are included in Table 29

Table 29. Example customer service tactics.

Empower all employees to be ambassadors of the City by providing them with a good understanding of the traffic signal system, and training them to recognize when it is appropriate to discuss with customers and when to refer to a more qualified staff member.
Measure and report our performance in responding to complaints.
Tell customers ahead of time what to expect (e.g., normal operations, planned events such as community events and lane closures, and expected incidents such as weather events).
Provide timely information in response to unplanned and unexpected incidents and emergencies.
Report regularly to officials, show where the traffic signal management plan is leading and how it is responding to the City's goals and objectives.
Engender pride in the traffic signal system.
Provide procedures and standards to all staff for customer service activities, such as: ▪ Accepting and responding to trouble calls. ▪ Accepting and responding to requests to modify the way the traffic signal system is designed or operates. ▪ Dealing with media requests. ▪ Reporting system performance to City Council.

6.2 Implementation Verification

Define the records and analysis needed to verify, through periodic assessment, the extent to which the management and administration activities have been implemented. Examples of implementation verification measures for management and administration strategies and tactics are included in Table 30. For each metric, you should include the target value to be judged satisfactory, and the frequency of measurement and reporting.

Table 30. Example management and administration implementation verification metrics.

Management Verification Metric	Target	Timing
Time to respond to customer	Initial response – X days	Monthly report
Time to close out request	Closeout – two weeks	Monthly report
Types of inquiries		Monthly report
Percentage of inquiries satisfied		Monthly report

CHAPTER 7 – INTERAGENCY COMMUNICATION & COLLABORATION

This chapter documents the existing relationship between your agency and adjacent agencies that may have influence on the transportation system. Discuss how you communicate and collaborate on operational issues and planning for future projects. Document where your operational objectives do not align perfectly with your neighboring agencies, particularly where your operations interface such as at jurisdiction boundaries, at freeway interchanges and where arterial roads pass through shopping and business districts. Examples of non-alignment of operational objectives include:

- A regional agency wanting to maximize throughput on arterials during peak hours, but a local agency wanting to provide smooth flow at that time.
- A highway agency using ramp metering to protect freeway flow, which causes queuing that, interferes with arterial operation.
- A transit agency wishing to have higher performance through use of signal priority, while a local or highway agency regards overall traffic efficiency as paramount.

Strategies will typically fall into the following categories:

- Staff from partner agencies with similar responsibilities regularly meet, maintaining a forum for discussing traffic signal system issues of mutual interest (such as planning, design, operations and maintenance).
- Partner agencies cooperate to present a unified program or complementary projects when seeking funding.
- Maintain cooperative agreements for important issues such as system design and compatibility, and supportive maintenance arrangements.

CHAPTER 8 – ACTION PLAN

This chapter documents a framework to help you identify areas of improvement, better organize your work plan, and secure funding and other support. Document where you are today and where you want to be in the future. You then can create an action plan on how to get from one point to the other.

The key elements of the action plan should be:

- Document procedures and activities that are currently performed on an ad hoc basis. Capture for posterity the good practices currently performed by staff who have developed their practices through experience and in response to the constraints under which they work, but have not written them down. This will be important for sustainability of your operations in the face of staff turnover and resource limitations.
- Define how you will measure both what you do (your outputs) and what you achieve in the eyes of the community (your outcomes). Use this section to plan what resources you need and systems that must be in place to make those measurements.
- Define how you will use the results of your measurements to review and revise your operations in order to optimize your activities, to provide the outputs most efficiently and achieve the best outcomes possible within your resource limitations.

This chapter also documents events or circumstances that can trigger review and revision of the TSMP, and define a process to control how updates are developed and implemented, in a manner that will not be counterproductive.

An example action plan is illustrated in Table 31.

Table 31. Sample traffic signal management plan action plan.

ID	Action	Timing
1	Prepare a list of procedures that are applicable to the signal management tactics; consolidate into an appendix to this document or (if they existing in other manuals of procedures) specify their storage location in the list.	Three months after adoption
2	Prepare procedures for activities that are not adequately described in existing procedures. (List the procedures that are not currently documented, or for which the documentation is dispersed and needs to be consolidated).	Twelve months after adoption
3	Prepare staff training, backup and transition plan for each position	Six months after adoption
4	Introduce the traffic signal management plan the entire design, maintenance and operations team	One month after adoption
5	Develop a quarterly assessment and action plan	Quarterly
6	Prepare an assessment of the impact of Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) developments on traffic signal management.	Six months after adoption
7	Schedule a refresh of the document in one year’s time	Twelve months after adoption

APPENDIX A. PERFORMANCE MEASUREMENT CASE STUDIES

LINKING TRAFFIC SIGNAL PERFORMANCE MEASURES TO AGENCY OBJECTIVES - CASE STUDY OF MESA, ARIZONA (POPULATION: 500,000)

Agency representative: Avery Rhodes
Interviewer: David Hale and Kevin Fehon
Interview date: 05/14/2015

Operational Objective

The City of Mesa has used travel time data, since 2006, as a measure of traffic signal system performance. The travel time metric is used to monitor the operational objective of stable travel times along certain corridors. The objective is to ensure that along each corridor, the growth rate of traffic volume always exceeds the growth rate of travel times. If travel time growth rate along a corridor increases by an amount greater than traffic volume growth rate, this would trigger a review of the need to update signal timings.

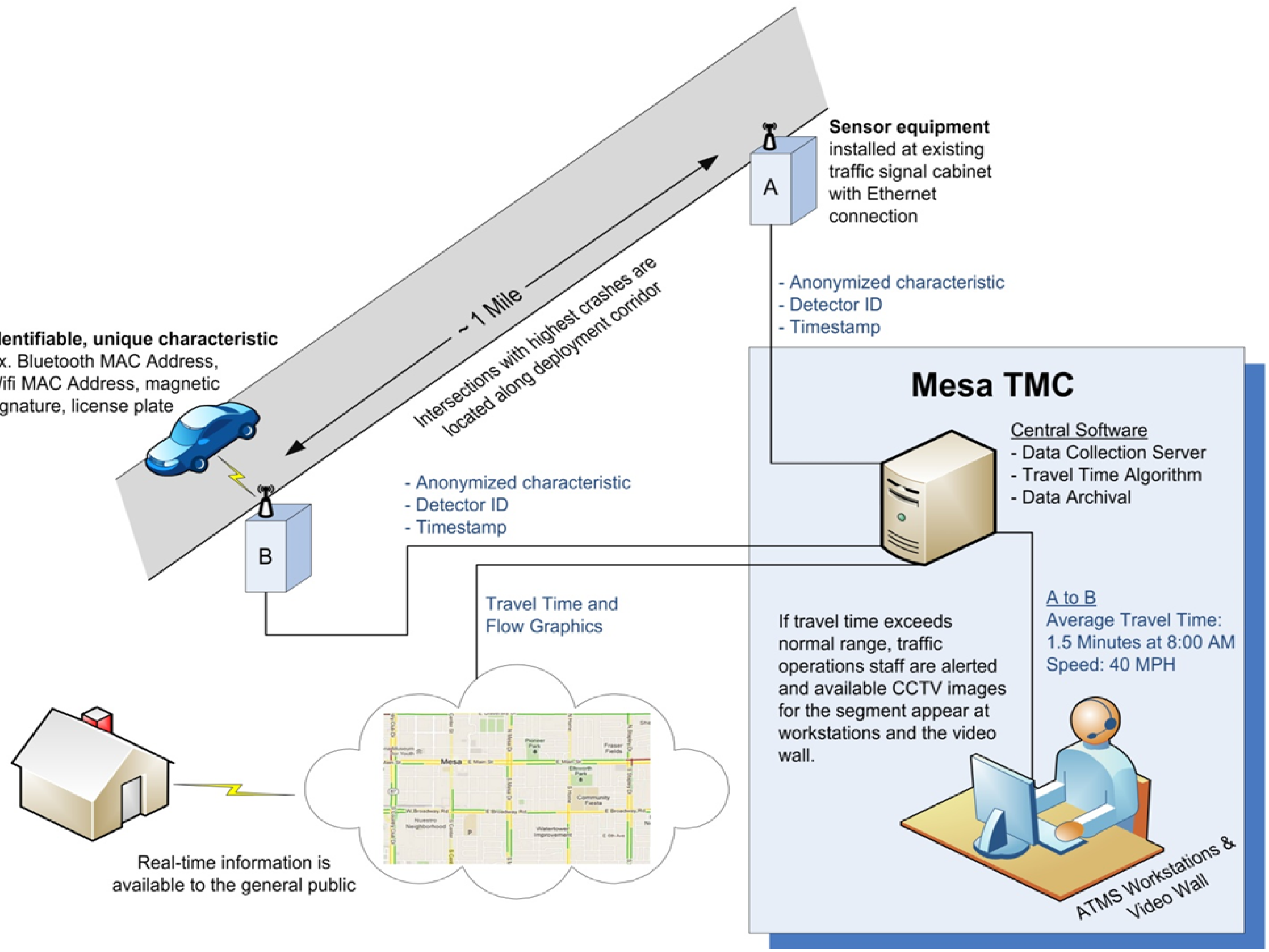
Floating Car Travel Time Measurement

The original method of collecting corridor travel times was by floating car surveys, between defined origin-destination (O-D) pairs. Floating car surveys were typically conducted during the first two weeks of April, or during the first week of October. These time frames were considered to represent "average" traffic conditions for Mesa. The floating car surveys were performed along four major arterials, during the p.m. peak (3:30 p.m. – 5:30 p.m.). Data were collected using hand held electronic data collection boards by staff members traveling at a speed they believed to be representative of typical traffic at the time. Since the travel time data are limited (i.e., only for two weeks of the year, only during the p.m. peak, and only a limited number of runs per peak period), the City could only use the metric to monitor high level trends.

Migration to Bluetooth™ Travel Time Measurement

Starting in 2012, the City tested a new method of collecting travel time data; MAC address matching (Bluetooth). The average travel times measured using this method were found to be very similar to those obtained by floating car surveys for the PM peak period, which provided confidence that it could replace the floating car method. However, significant additional benefits were also realized. The automated method reduces the amount of direct manual labor needed. It increases the sample size and reliability of measurements. It allows assessment of travel times over the whole day, weekends, and throughout the various seasons. It also has the ability to identify traffic issues in real time. Such traffic issues include:

- Incidents – which would result in short term increased travel times.
- New development – which would gradually increase travel times due to increase in traffic.
- Bad detection/timing parameters – which may result in increased travel times.

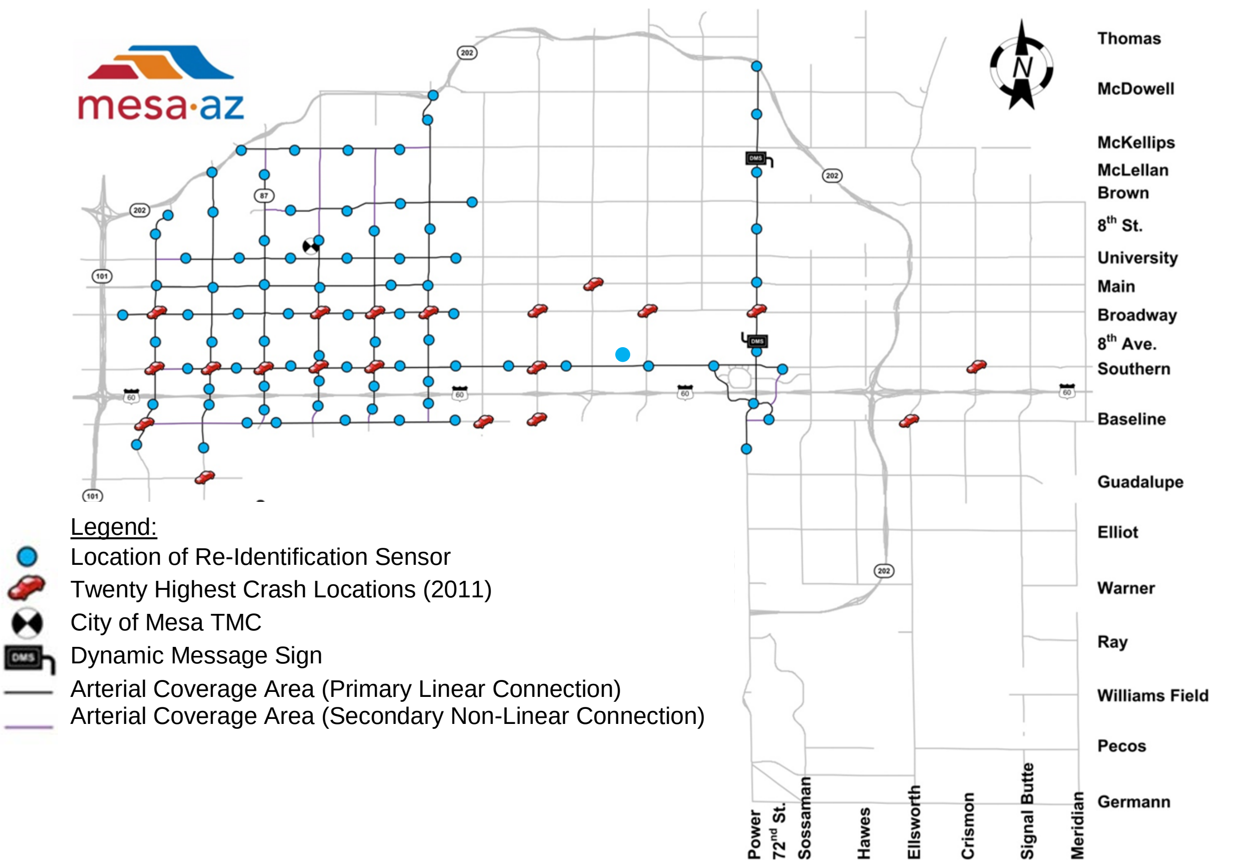


Source: City of Mesa

Figure 10. Diagram. High-level system concept diagram.

The Bluetooth technology has improved the city's data collection and analysis. The automated system (illustrated above) is constantly operating, so the City is able to collect data on more corridors, 24 hours a day, instead of just during the p.m. peak periods. Raw data are uploaded on an as-needed basis for reporting and archiving, but the Bluetooth map refreshes every 30 seconds. Recurrent congestion is expected in certain locations every day, but unexpected congestion is detected when analysts spot abnormal congestion patterns in certain locations. The City currently does not have the resources to constantly monitor these outputs, to discern when crashes or other events are affecting traffic operations. A color-coded problem detection system is expected to pay dividends in the future, in terms of cost-effectiveness and accuracy, but it is not yet fully automated.

Twenty major arterial streets are now covered by the Bluetooth-based travel time study system, while a smaller number of corridors are still monitored via floating car surveys. The city currently maintains 82 sensors at one-mile spacing, with an estimated 40 percent of the city being covered (illustrated below). Bluetooth data are collected by matching MAC addresses detected by one sensor (A) with a second sensor (B), and computing travel times between the points. Travel times for the one-mile increments are added together to calculate total travel times along predetermined routes.



Source: City of Mesa

Figure 11. Map. Distribution of MAC address readers in Mesa, Arizona.

Experimentation with WiFi Travel Time Measurement

The city is concerned about possible deterioration of Bluetooth reliability over time. “Undiscoverable” mode is the new default on many electronic devices, possibly for privacy reasons; whereas in the past, devices used to be shipped with “discoverable” mode enabled by default. The low number of Bluetooth matches (3-6 percent of total volume) is concerning. This low number may continue to decline as undiscoverable devices continue to be purchased, and as older (discoverable) devices are discarded.

Because of this, the city is experimenting with WiFi readers as an alternative to Bluetooth readers. WiFi is another technology that matches unique electronic signatures of electronic devices. It is too early to tell if the WiFi data provides the same reliability and accuracy that the Bluetooth readers have. However, it is noted that while Bluetooth handshaking occurs continually, the WiFi seek typically occurs approximately every 30 seconds. Therefore it is possible that the sample of vehicles detected using WiFi may be biased towards vehicles that stop adjacent to each monitoring site, compared to those detected using Bluetooth.

Lessons Learned

Over time, the city aims to gradually automate their travel time data collection system to the maximum extent possible. However for now, the ARID-Bluetooth system requires a human to observe variations from “normal” traffic conditions. Purdue’s automated signal performance measure (SPM) concepts may provide a pathway to enabling automation, and providing residents with faster problem response times. The city is moving in the direction of identifying problems before they get reported as complaints. They are cooperating with other agencies within the region. The city is providing data feeds from 10 intersections to the regional Utah Department of Transportation (UDOT) automated SPM software that has been installed on pilot basis. This is marking a move by the region to invest in automated SPMs. The UDOT system is illustrated on:

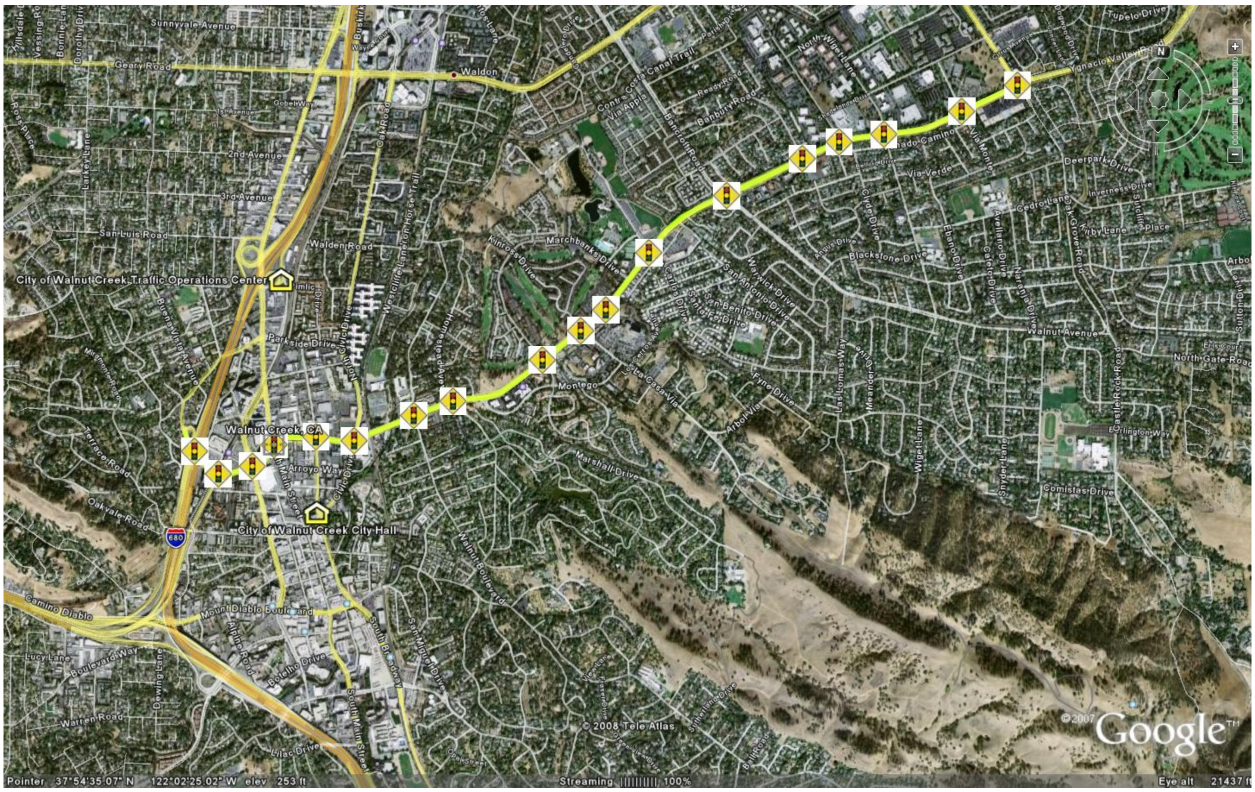
www.udottraffic.utah.gov/signalperformancemetrics

However this automation requires extra detection, compared to the detection provided at most intersections in Mesa. Part of the City’s evaluation of this system will be to weigh the benefits against the costs of this additional detection.

LINKING TRAFFIC SIGNAL PERFORMANCE MEASURES TO AGENCY OBJECTIVES - CASE STUDY OF WALNUT CREEK, CALIFORNIA (POPULATION: 70,000) - CASE STUDY DATE: 08/27/2015

Operational Objectives

Ygnacio Valley Road is defined by the San Francisco Metropolitan Transportation Commission (MTC) as an arterial-level "route of regional significance" traversing Walnut Creek, providing the primary access to downtown and various neighborhoods, and connecting I-680 to several cities to the east of Walnut Creek. It is a major commuter route that carries in excess of 100,000 vehicles per day, and experiences significant variation in traffic demand, as a result of incidents on freeways for which it provides an alternative route, and concerts and other events at an outdoor concert pavilion and at a performing arts center. The primary operational objective for this corridor is to provide predictable and stable travel times that are consistent with the level of demand for the various periods of the day and days of the week.



Source: Google Maps and City of Walnut Creek

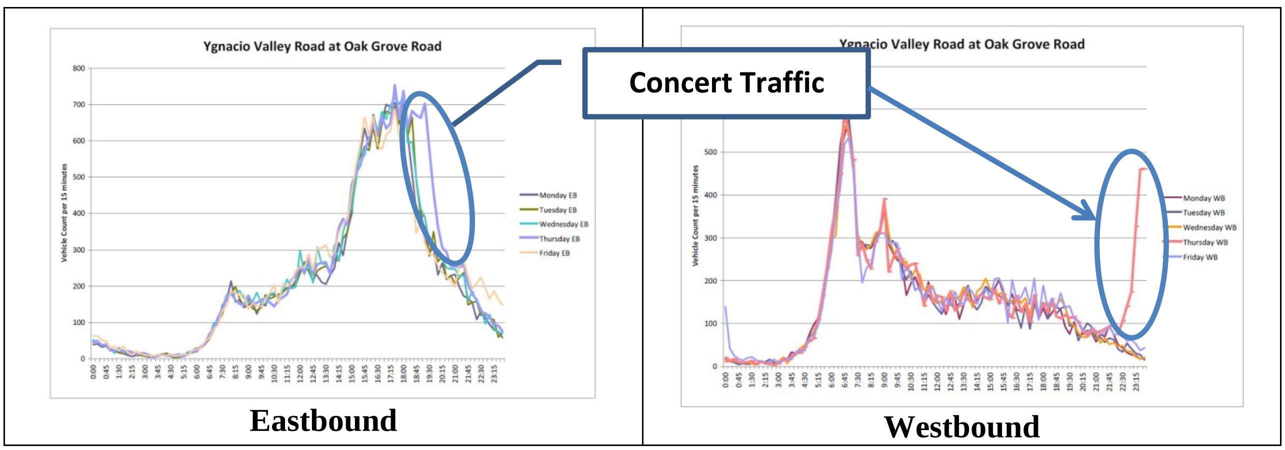
Figure 12. Map. Location of Ygnacio Valley Road, Walnut Creek.

Background

Since the 1980's, the City of Walnut Creek has devoted significant resources to traffic signal system maintenance and coordinated signal timing. During the past 35 years, the majority of signals within the city have been coordinated using a central signal system, which has been upgraded and replaced several times. While the city has devoted considerable local resources to equipment purchases, operation and maintenance, their ability to perform this high level of operations and maintenance has been aided greatly by a series of grant funding opportunities.

Each time the city has received a grant to update its coordinated signal timing, it has been required to submit final reports containing before-and-after studies, to validate the retiming effectiveness. The studies were typically accomplished by using floating cars to measure travel time, stopped delay, and numbers of stops, which were used to calculate a benefit/cost (B/C) ratio. As a result, the corridor has been retimed approximately every three to five years since the mid-1980's, so there is a long-term record of travel time performance along the corridor. In addition, staff have continually maintained and fine-tuned the signal timing during the intervening years, the formal travel time surveys have been periodically supplemented by less formal travel time surveys conducted by staff at various times of the day, to highlight any deterioration in travel times that may need attention between the major retiming projects.

The city is also collecting extensive traffic volume data through its central signal system, and these data are sometimes cross-correlated with the travel times. In some cases where travel time anomalies have been identified, the city has been able to use traffic volume anomalies to partially or fully explain the deviations. These volume and travel time cross-correlations are not fully automated, and the city does not maintain a formal policy for how often these cross-correlations are analyzed. Review of the volume data in 2010 showed the variability in traffic demand along the corridor, as illustrated in Figure 13.



Source: City of Walnut Creek

Figure 13. Chart. Illustration of demand variation on Ygnacio Valley Road.

Installation of ATMS.NOW and Bluetooth™ Travel Time Readers

In 2010, the city upgraded its Naztec Streetwise signal system to the more modern ATMS.now, in order to add adaptive signal control technology (ASCT). The ASCT capability was desired for addressing and mitigating some unstable operation on the corridor. To validate its effectiveness in meeting the operational objective, the city needed to measure travel times along the corridor. However, to assess the ASCT benefits, which can be significant at unpredictable times of the day, they knew floating car surveys conducted using traditional methods, during the traditional periods of AM peak, mid-day and PM peak, would be inadequate. To expand floating car surveys to cover all periods during which adaptive operation may perform differently from traditional time of day (TOD) operation was cost prohibitive, and could not reliably capture times when traffic demand varied because of incidents on the alternative freeway routes. This motivated them to deploy Bluetooth readers, which continuously collect data at all times. These were installed (initially as a temporary deployment) along Ygnacio Valley Road as the adaptive system was being fine-tuned and evaluated, during 2012.

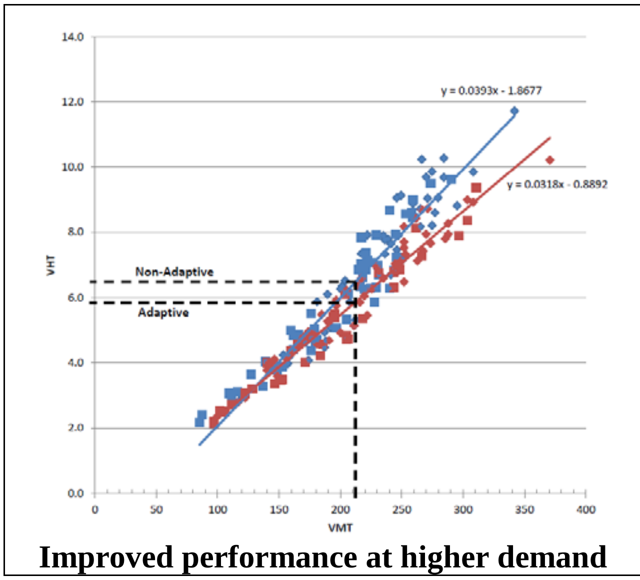
Ygnacio Valley Road is divided into three relatively homogeneous sections by two significant crossing arterials, with a freeway at the western end and another crossing arterial at the eastern end. The complete corridor remains coordinated at all times except during the overnight hours, when coordination is temporarily lifted due to low volumes. To conduct the before-and-after studies, a Latin-Squares survey design ensured that both adaptive and non-adaptive operation were applied to the full corridor at comparable times on comparable days, to remove the uncertainty associated with daily and seasonal variations in traffic patterns and demands. By installing one reader at each of the four major boundary intersections, it became possible to reliably measure travel times for each section on a 24/7/365 basis.

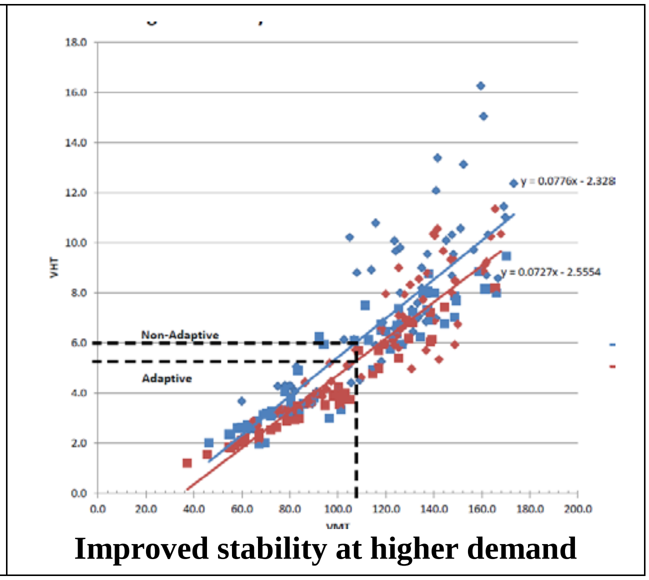
Initial Use of Bluetooth Data

The Bluetooth data was initially used for the Before/After evaluation of the ASCT. Because it was expected that the ASCT would automatically vary its operation based on the measured traffic volumes, the most appropriate method for comparing the two operating modes was to relate the measured travel times to the measured demand present at the same time. The Bluetooth travel time data was combined with the traffic volume data from the traffic signal system to calculate vehicle hours of travel (VHT) and vehicle miles of travel (VMT) for each 15 minute period of the two-week evaluation period, for each of the three sections of the corridor. By plotting these data and running regression analyses, various comparisons could be made to examine:

- The overall difference in travel times under the two operating conditions
- The relative stability of travel times under the two operating conditions

The data, a sample of which is shown in Figure 14, illustrated the variability in travel time with demand, and in some cases the instability of travel times as demand varies. This was useful for the city staff to determine the suitability of ASCT for their situation, and evaluate it against their objective of providing stable travel times consistent with the traffic demand.



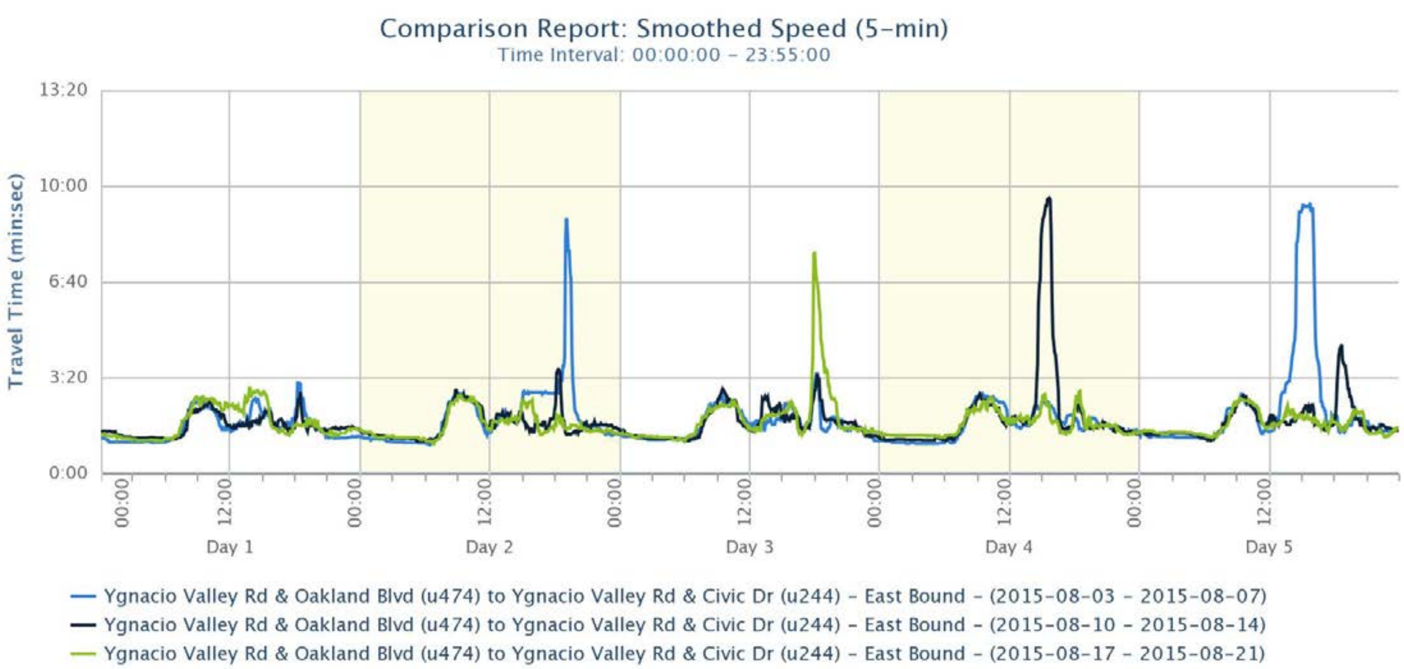


Source: City of Walnut Creek

Figure 14. Chart. Sample analysis using Bluetooth and traffic volume data.

Longer Term Use of BlueToad Data

Over the longer term, in the three years since the readers were installed, staff have used the Bluetooth data to continually monitor the travel times in both directions on the corridor, and to provide guidance on when there was a need to review signal timing to accommodate issues. It has also provided a very useful resource for verifying the validity of citizen complaints about signal operation. The example BlueToad report shown in Figure 15, covering weekdays of three consecutive weeks in August, 2015, shows relative stability of travel time but with occasional significant outliers occurring once during the three week period on each weekday except Monday. This is an example of a report that can provide staff with the opportunity to periodically examine the operation, at very little cost, and have accurate data that would formerly have been unavailable.



Source: City of Walnut Creek

Figure 15. Graph. Sample BlueToad™ travel time report for Ygnacio Valley Road.

Lessons Learned

Overall, the city was quite satisfied with performance of the Bluetooth system, in achieving their initial objective of assessing the ASCT performance. This success inspired them to continue using the system, and a permanent installation replaced the temporary deployment. It now provides a continuous and lasting assessment of signal timing plan effectiveness and stability over time, allowing continuous measurement of the system's performance against the objective of predictable and stable travel times on this important corridor. As a result of this successful experience, the system is in the process of being expanded to include the other important coordinated routes within the city.

LINKING TRAFFIC SIGNAL PERFORMANCE MEASURES TO AGENCY OBJECTIVES - CASE STUDY (SIGNAL PROGRESSION) OF UTAH DEPARTMENT OF TRANSPORTATION - OPERATIONAL OBJECTIVE

The Utah Department of Transportation (UDOT) has identified the operational objective of providing smooth flow along suitable corridors (such as linear arterials that connect regional activity centers and freeways), particularly in under-saturated conditions. Percent Arrivals on Green (AoG) is a measure of how effectively bandwidth promotes progression with coordinated traffic signal parameters designed to promote automobile flow without stops along arterials. This high-resolution signal performance measure can assess progression through both adaptive and non-adaptive signal corridors.

Background

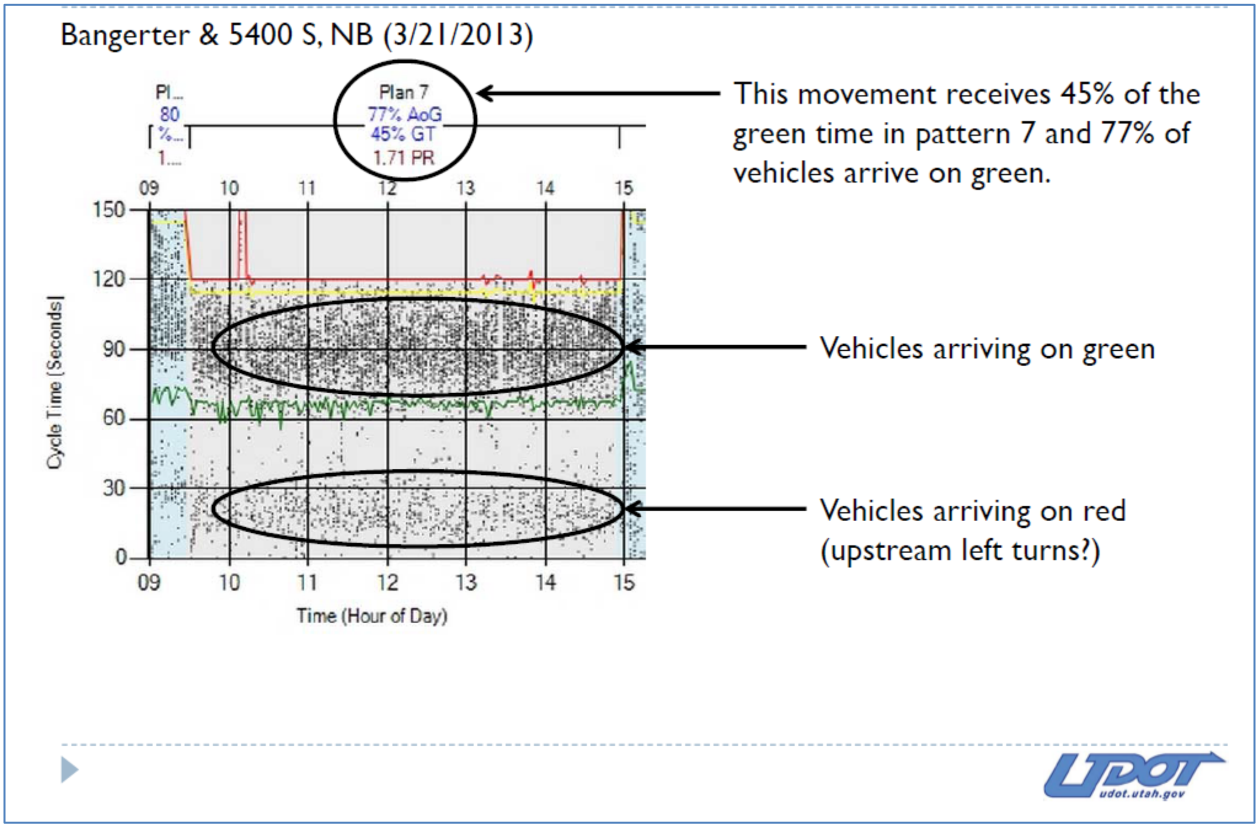
Coordinated signal timing plans are typically prepared on the basis of computer analysis, using tools such as Synchro™. The traditional approach involves extensive data collection of volumes and travel times; development of a calibrated model of the existing coordination (if applicable); optimization of the timings based on the in-built objective function (minimizing a function that is usually some combination of stops and delays); manual adjustment of the suggested timing using time-space diagrams to provide bandwidth and progression that is considered by the analyst to provide more acceptable operation; and fine tuning of those timings in the field based on roadside and windscreen observations.

UDOT's experience has been that while the cycle length and phase splits recommended by the software are often close to the final adopted settings, much fine tuning is required of the offsets to successfully accommodate the variations in average travel speeds often encountered from block to block, which in turn often vary with time of day, depending on traffic density and the prevalence of disturbances to flow caused by turning vehicles using mid-block driveways, percentage of larger vehicles in the traffic stream and differences in driver populations. Because the fine tuning is based simply on observation, there is no single metric that can be used to confirm that the optimum offsets have been selected. Attempts to simulate the effect of the fine tuning within the computer model can only be indicative, and not accurately reflect the actual vehicle operation, because of the many underlying assumptions built into the model coding. Assessment of the quality of coordination has historically been mainly undertaken using limited floating car surveys. These are often in the form of "before and after" studies related to signal retiming projects and, of necessity because of the expense, are generally limited to short periods of the day (AM, PM and Mid-Day peak periods) on days of the week and months when traffic is considered "typical." Even when these are supplemented by informal travel time surveys by operators, they have very limited sample size and do not provide a rigorous assessment of the signal timing performance.

As identified in the *2012 National Traffic Signal Report Card*, many agencies recognize that traffic patterns and volumes change over time, and there is a need to review and recalibrate signal timing regularly to accommodate these changes. Because historically there has been no on-line measure of performance available, FHWA recommends that agencies should review their signal timing once every three to five years. However, this means that a significant investment is already sunk by the time an up to date model of the existing traffic volumes and signal operation is completed, and an assessment can be made of whether new timings are likely to better than the existing timings.

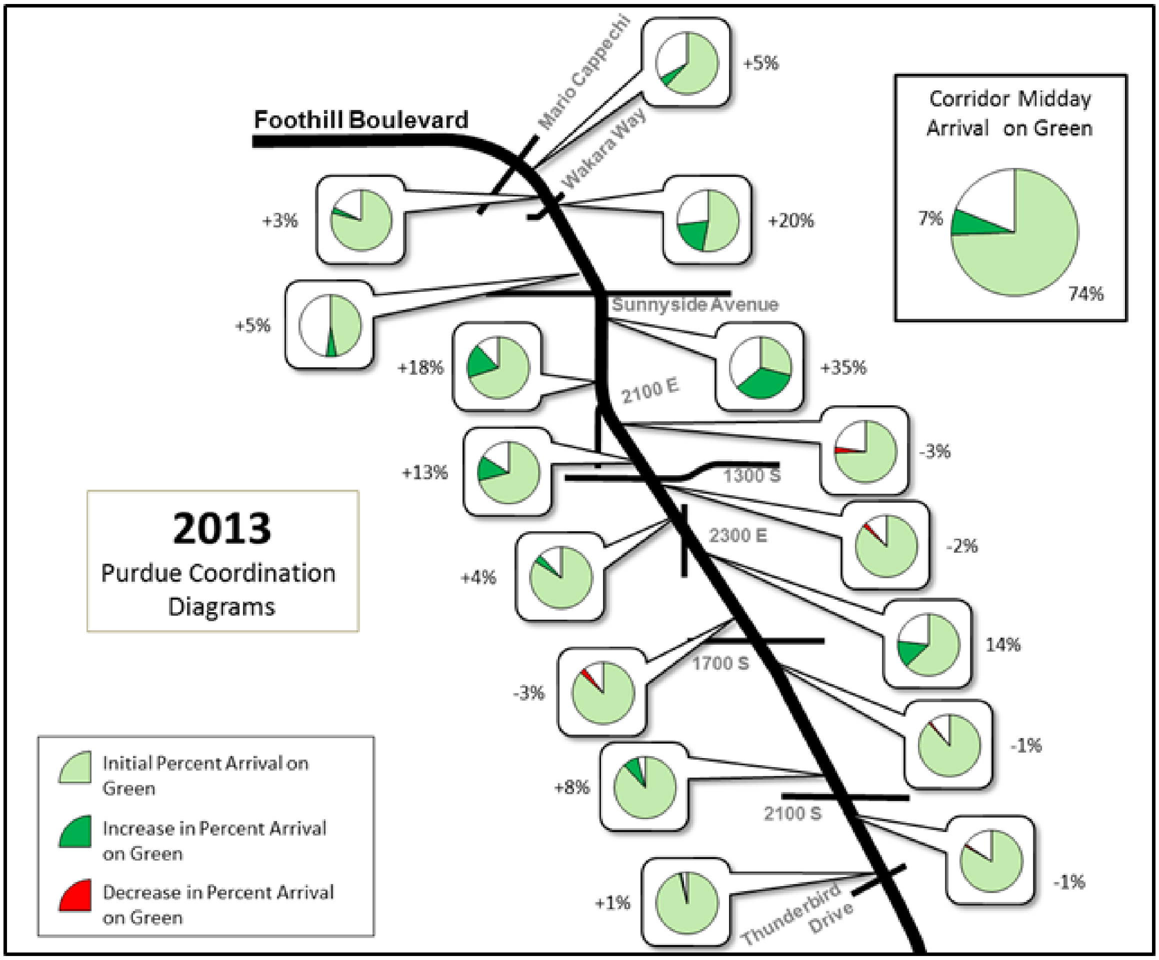
Migration to Systematic Performance Monitoring

The Purdue Coordination Diagram (PCD) provides a graphical method to illustrate the stage of a cycle at which vehicles arrive at an intersection. For a specific approach of an intersection, the arrivals can be plotted in a time scale, as illustrated in Figure 16, in which each dot represents the arrival of a single vehicle. By calculating statistics (such as the AoG) for the coordinated approaches of all intersections within a corridor, during a specific period, it is now possible to derive a single metric (Corridor AoG) that indicates the quality of the coordination, based on the objective of providing smooth flow along a corridor. An example of this is illustrated in Figure17.



Source: Utah Department of Transportation

Figure 16. Diagram. Sample Purdue Coordination Diagram.



Source: Utah Department of Transportation

Figure 17. Diagram. corridor arrival on green report.

UDOT's system of performance monitoring for coordinated corridors now follows a two-phase process. In the first phase, AoG values are observed at each intersection and used during the fine tuning process. When unacceptable locations are identified, signal timings are fine-tuned until all AoGs fall within an acceptable range, and/or the platoons are stopped at acceptable locations. An assessment of the likely effect on one pair of intersections of changing the offset can be provided by the software, as illustrated in Figure 18. Once this process has been completed for all links, this establishes an appropriate baseline against which to monitor ongoing performance, as illustrated in Figure 18.

Source: Utah Department of Transportation

Figure 18. Graph. Using arrivals on green for optimization of offsets.

In the second phase UDOT continuously monitors ongoing performance, comparing the corridor AoG metric to the baseline established during the first phase. A semi-automated system is in place to monitor for significant AoG deviations. This allows for an intelligent assessment of the need for signal retiming, based on the deviation of the metric from the baseline. In this way, retiming can be triggered in a shorter period of time if the deviation exceeds a threshold set by UDOT for the corridor, while unnecessary retiming is avoided if the deviation is still small after the normal retiming interval has elapsed.

Experimenting with Pro-Active Offset Optimization

In addition to the improved decision-making made possible by systematic monitoring of AoG, UDOT has observed significant benefits from semi-automated optimization of AoG. The Purdue Link Pivot (PLP) algorithm uses an iterative approach to identify the impact of potential offset changes for both approaches in a link, to optimize AoG. Data required for applying this algorithm are collected automatically through an intersection's advance detectors, and through phase data obtained directly from the controllers. The PLP is a compelling concept because resource-intensive modeling and calibration are not required. Moreover the PLP easily accommodates elements that are difficult to model, such as link travel times and early returns to main street green. The PLP even automatically considers progression for heavy left turns. However the PLP cannot directly address queues that extend beyond detectors, and large offset changes may require multiple iterations. So rather than following the traditionally labor-intensive process of model optimization, modification and fine tuning, staff can select the cycle length and splits and install them with an initial set of offsets, then use the PLP to approach the optimum.

Lessons Learned

Purdue University's automated signal performance measurement concepts, which include AoG values derived from the PCD, have allowed UDOT to establish an efficient process for continual assessment of the performance of coordination on a corridor against the objective of providing smooth flow. Additional benefits have accrued because resources are shifting from off-line analysis to on-line fine tuning and optimization, and resources for retiming are now better directed towards corridors that need retiming, rather than those next on the schedule.

The monitoring technology set up by UDOT represents a paradigm shift of traffic signal system architecture. In this architecture, controllers are connected to a central traffic signal management system in the traditional fashion, for all management and control functions provided by the vendor. However, a separate communication channel is provided between the controllers and the performance monitoring server. FTP sessions are opened with local controllers to automatically create reports, without interfering with the traffic control functions.

In response to these achievements, it is expected that more agencies will incorporate system requirements related to High Resolution Data performance reporting into traffic signal system specifications. In response to these requirements it is likely that vendors will modify their systems to accommodate and/or incorporate high-resolution data logging. The UDOT system is illustrated on:

www.udottraffic.utah.gov/signalperformancemetrics

LINKING TRAFFIC SIGNAL PERFORMANCE MEASURES TO AGENCY OBJECTIVES - CASE STUDY (DETECTION HEALTH) OF UTAH DEPARTMENT OF TRANSPORTATION - OPERATIONAL OBJECTIVE

The Utah Department of Transportation (UDOT) has established a maintenance objective of keeping traffic signals in a good state of repair and operating in a manner for which they were designed. A maintenance strategy of proactively maintaining the reliability of field infrastructure calls for an activity that regularly monitors the health of intersection detection. While regular preventative maintenance activities might involve annual testing of all intersection detection systems, UDOT has taken this tactic to the next level by adopting a system of analyzing high-resolution signal controller data, to quickly identify detector faults. This allows them to monitor performance against the objective to "keep traffic signals in a good state of repair and operating in the manner for which they were designed"; and also implements the strategy to "identify detector faults in a timely manner." The primary metric for this is the proportion of cycles in a user specified period that are extended to their maximum green time or "max-outs."

When signal phases are observed as maxing-out frequently during time periods when traffic demand is expected to be light, this implies a detector malfunction. Detector failures of inductive loops trigger a constant on condition, causing traffic signal phases they are associated with to "max-out." A high proportion of max-outs would typically only occur in a fully functional signal when there is a high number of queued vehicles in each cycle, resulting in consistent phase failures and carryover queues. While maxing out can also be caused by platoons of vehicles arriving towards the end of green, this would not consistently happen from cycle to cycle unless the upstream signal is coordinated with the phase that experiences this arrival pattern. This high-resolution signal performance measure can be used to assess detector health at both coordinated and non-coordinated signal locations.

Background

Prior to use of the high resolution data, maintenance staff relied on alarms and fault reports generated by the central traffic signal system to identify potential detector faults, or faults were identified when responding to citizen complaints about inappropriate signal timing. Most traffic signal systems flag a detector that has registered continuous presence longer than some pre-set duration (locked on), registers continuous short detections that are too short to be vehicles (oscillating), or does not register presence for a pre-set period of time (not detecting).

When a complaint is received about poor or faulty signal timing, the typical sequence of events involved:

- Receiving a report of a signal timing problem
- Dispatching a technician to the intersection to investigate
- Determining whether the timing problem was related to an equipment malfunction or timing that may require review
- Testing detectors to determine whether or not they are faulty.

However, there were situations in which the technician was unable to identify a fault. In some cases involving video detection, the fault condition only occurred during darkness and the technician typically visited the site during daylight. In the case of loop detectors it may be possible that after a fault occurs the detector unit retunes itself and the fault is cleared.

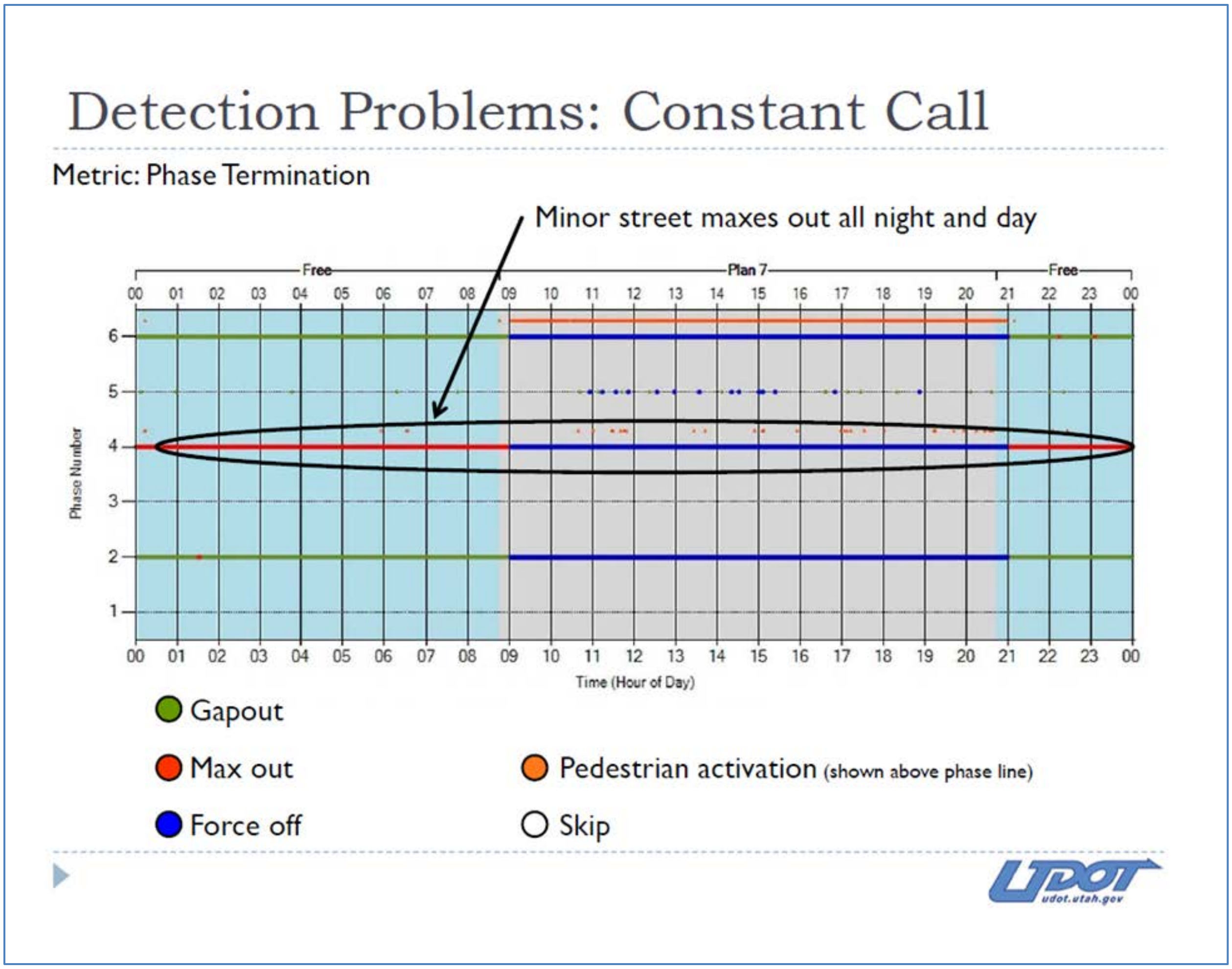
There was clearly benefit to be gained in terms of improved traffic operations and public relations if the detector faults could be identified shortly after they occurred, and before they have sufficient impact on traffic operations that members of the public complain. There was also direct financial benefit to be gained by UDOT if the labor involved in identifying and troubleshooting detector faults could be reduced.

Systematic Performance Monitoring

The UDOT system of detection monitoring produces reports that highlight detection anomalies. This system allows staff to proactively identify and fix detection problems, and reduces the labor involved in identifying faulty detection as the source of a timing problem.

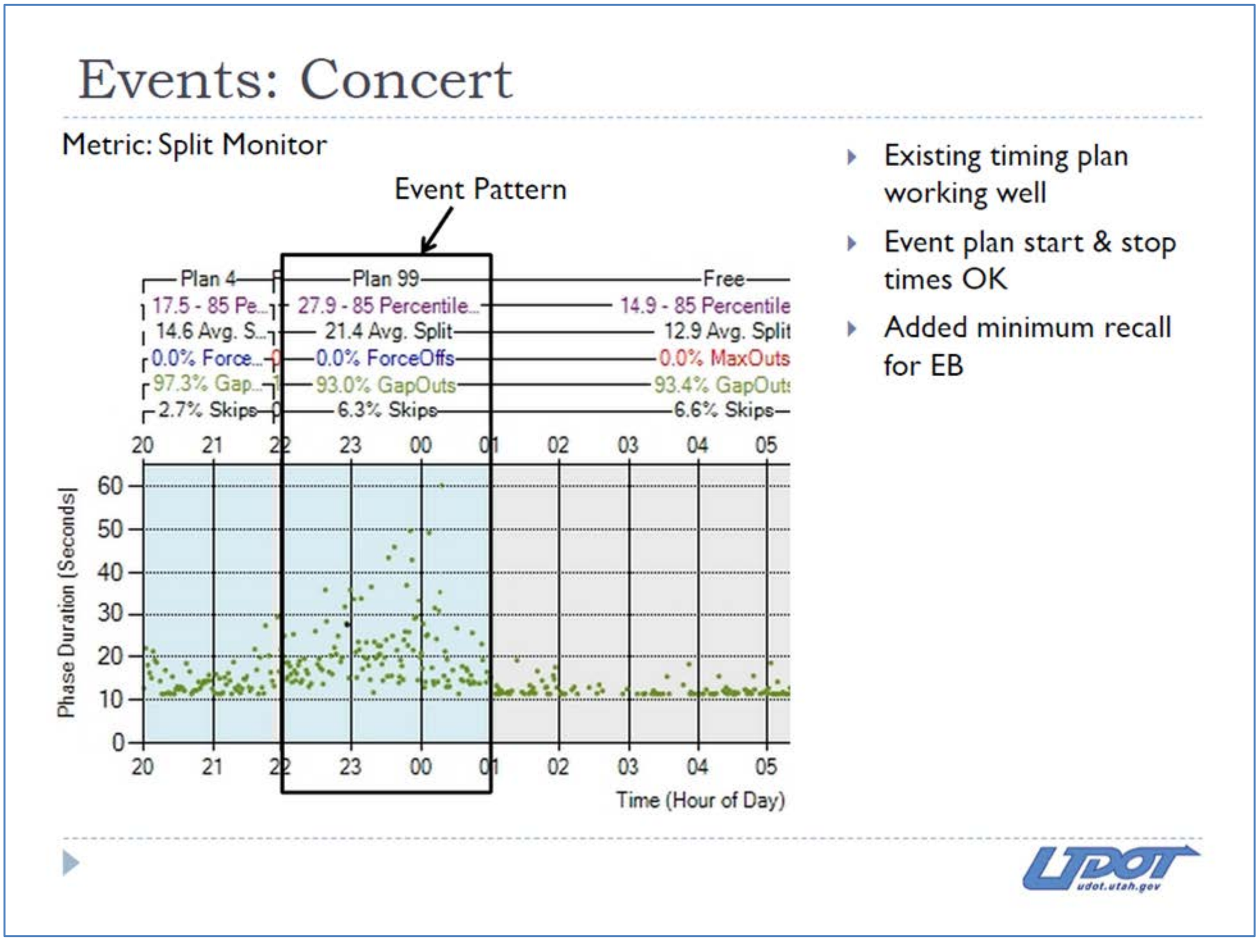
There are two types of reports generated by the UDOT system that are useful in this context: Phase Termination Monitor and Split Monitor. The Phase Termination Monitor identifies, for a specific intersection, the reason for termination of each phase in each cycle. An example is illustrated in Figure 19. This particular report illustrates that for an entire 24 hour period, phase 4 has run to maximum during free operation, and has been forced off by the coordinated timing pattern during coordination. This indicates a high probability that a detector is locked on.

The second relevant report is the Split Monitor report, illustrated in Figure 20. This report shows the actual phase length and reason for phase termination for a specific phase at an intersection, and is useful in confirming whether or not the detection is causing phases to be called and extended as expected for the prevailing traffic conditions.



Source: Utah Department of Transportation

Figure 19. Graph. Termination monitor report.



Source: *Utah Department of Transportation*

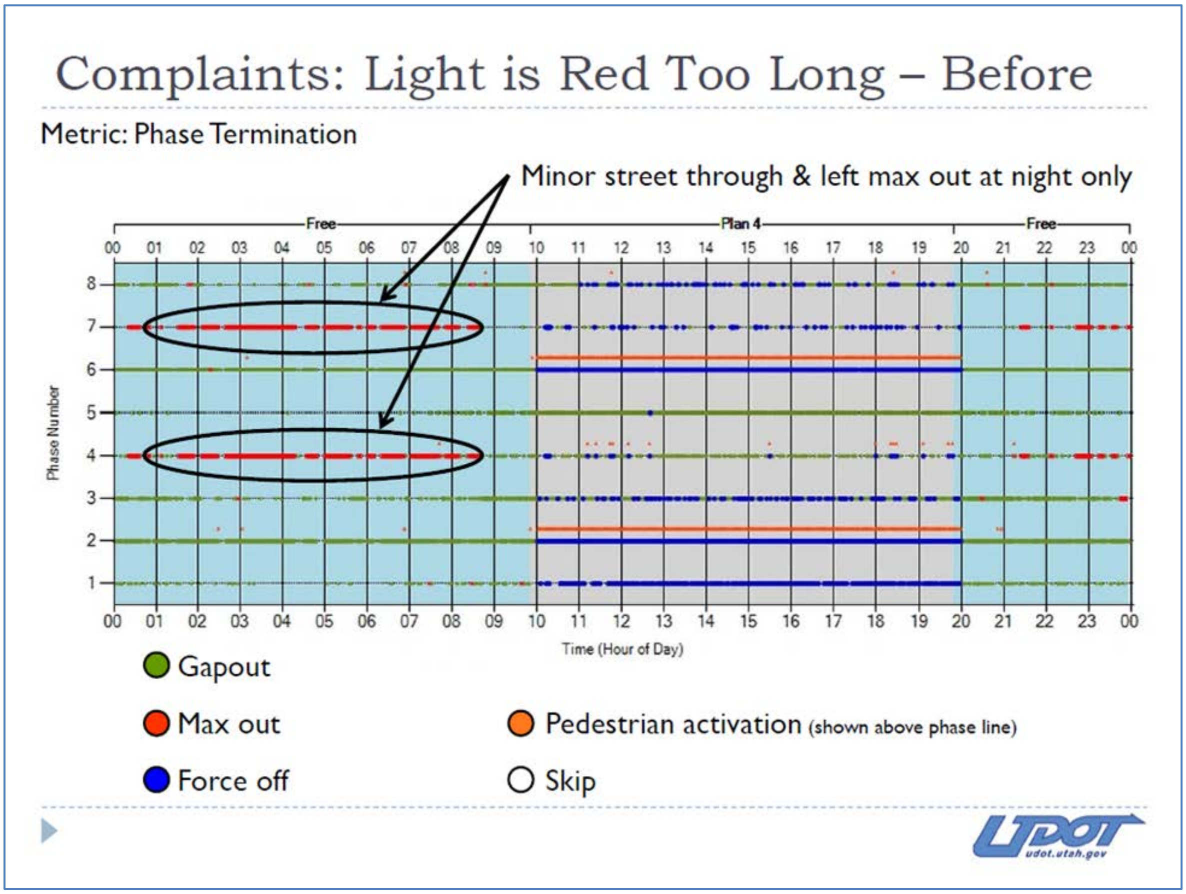
Figure 20. Graph. Split monitor report.

Practical Application

There are two primary ways in which the reports are used to identify potential detection faults. Each day, the reports are reviewed by staff and any locations showing an unexpectedly high incidence of "max-out" are flagged for further review and analysis. Secondly, if a timing complaint is received, a report is generated from historical data to examine the patterns of phase time and phase termination.

The following figures illustrate the automated signal detection reports used by UDOT. In Figure 21, a high percentage of max-outs can be seen on two minor-street phases, during late night hours when max-outs should rarely occur. This wastes valuable time by reducing right-of-way time for the opposing movements, in particular increasing stops on the major street. It is also noticeable that those same phases often gap out during the daylight and early evening hours. This approach used a video detector, and this indicated that the detector was not coping with the lighting conditions during the late night. Subsequent investigation at night showed that the presence of a nearby streetlight and the absence of vehicles moving through the picture led to the video detector incorrectly lock on for extended periods of time, and the problem was then able to be addressed.

The split monitor was then used to quantify the condition with the detection fault (see Figure 22), and then confirm that operation as expected after the condition was rectified (see Figure 23). By contrast, the second report shows that minor-phase max-outs no longer occur after the detection error has been resolved. This allows the opposing major-street through movement to regain access to the green time that it needs, based on its heavier traffic demand, while the minor street phase is rarely required.

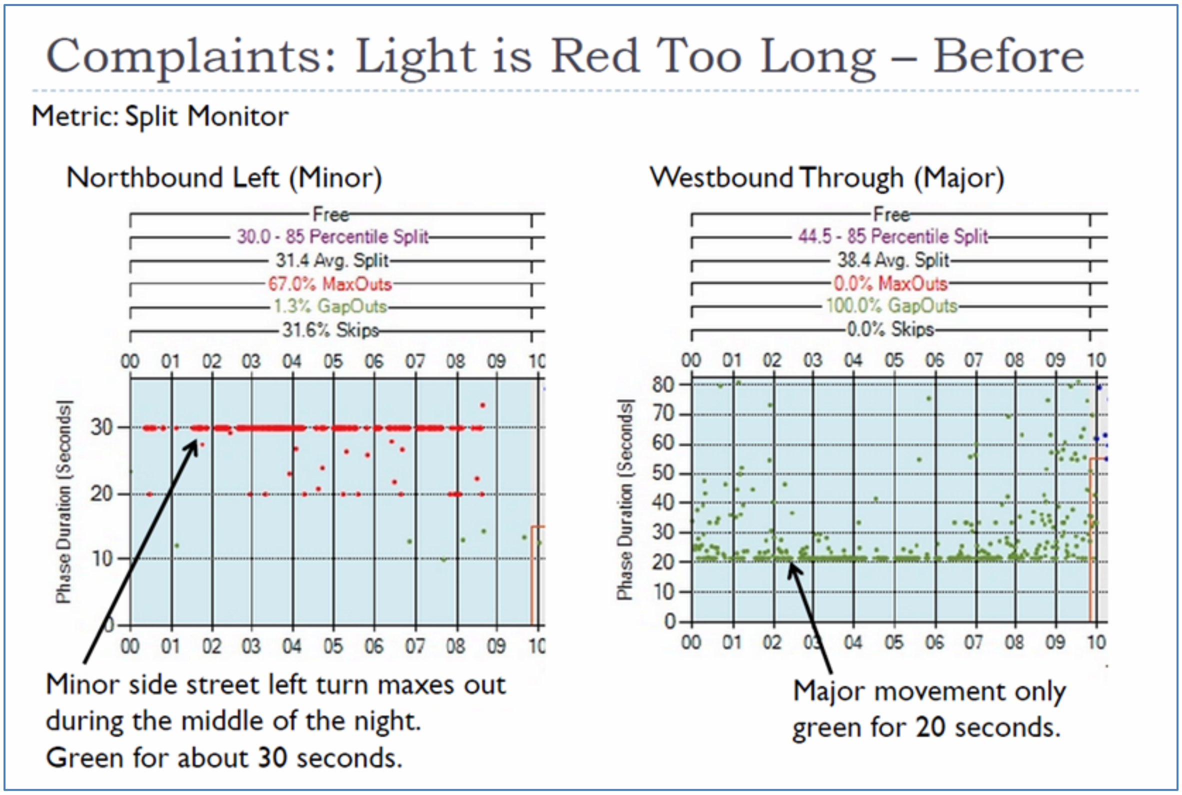


Source: *Utah Department of Transportation*

Figure 21. Graph. Phase termination by max-out at night.

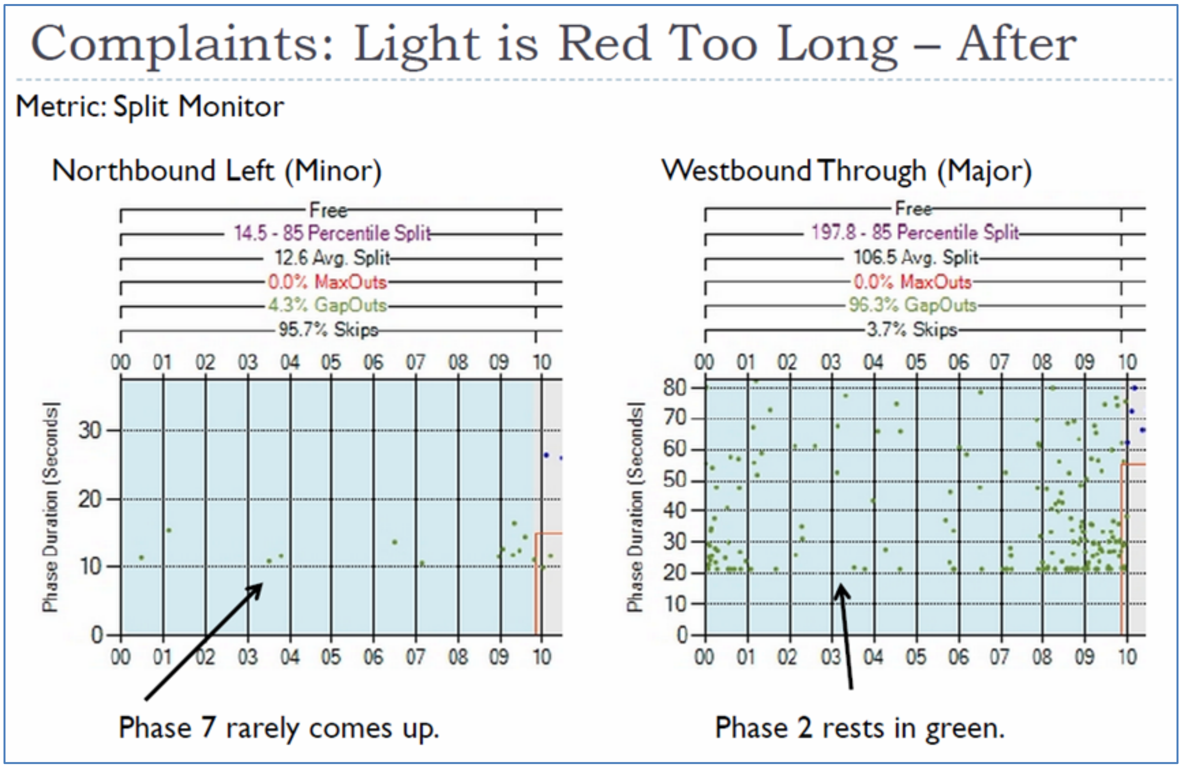
Purdue University's automated signal performance measure concepts have allowed UDOT to establish an efficient procedure for monitoring and maintaining detector health, which has been beneficial from both a reactive and a proactive standpoint. Reactively, it allows UDOT to more quickly and accurately identify reported problems without having to first visit the actual locations. Proactively, it also allows them to continuously and inexpensively monitor detector operations, to reduce complaints from the public. In the future UDOT hopes to further automate the detection monitoring system, to automatically identify and send alerts for detection problems and operational problems. The UDOT system is illustrated on:

www.udottraffic.utah.gov/signalperformancemetrics



Source: Utah Department of Transportation

Figure 22. Graph. Split monitor helped identify problem.



Source: Utah Department of Transportation

Figure 23. Graph. Split Monitor Shows Problem Cleared.

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