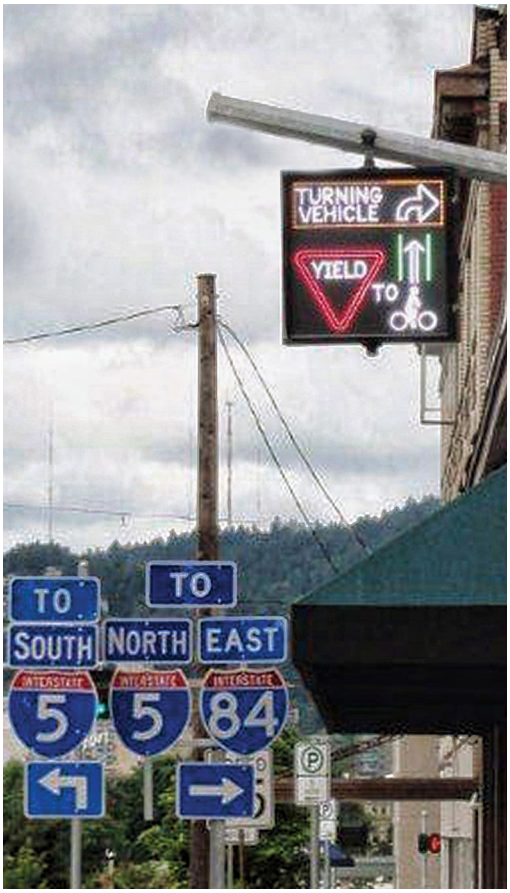

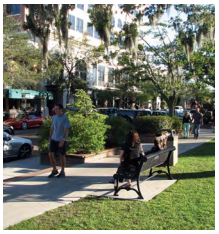

PERFORMANCE-BASED
PRACTICAL DESIGN FOR OPERATIONS

APPLYING PERFORMANCE-BASED PRACTICAL DESIGN METHODS TO COMPLETE STREETS:

A Primer on Employing Performance-Based Practical Design and Transportation Systems Management and Operations to Enhance the Design of Complete Streets

U.S. Department of Transportation
Federal Highway Administration

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16. Abstract

This Primer explains how the application of performance-based practical design (PBPD) principles combined with transportation system management and operations strategies (Operations strategies) can promote the consideration and application of Complete Street design principles to a wider range of contexts.

Complete Streets often involve a reduction or re-purposing of the number of motor vehicle travel lanes on the street. This frees up space for safety and operational improvements benefiting more users of the street: auto drivers, truck drivers, transit passengers, bicyclists, and pedestrians. PBPD, combined with operations strategies, enables the designer to consider applying Complete Street design concepts to a wider range of contexts. The result is a street system that cost-effectively meets the needs of the diverse users of the streets and the objectives of the agency.

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Foreword

The Federal Highway Administration (FHWA) Office of Operations is pleased to present this publication titled "Applying Performance-Based Practical Design Methods to Complete Streets: A Primer".

Urban streets must serve many types of users and trips, and the right-of-way for streets is often fixed due to surrounding development. In recent years there has been an increased desire by agencies to better serve all users of urban streets, regardless of mode of travel. The Complete Streets design principles seek to better share the limited street right-of-way among multiple users while enhancing the livability of the street for adjacent residents.

Performance-Based Practical Design (PBPD) can assist in advancing Complete Streets by emphasizing achievement of corridor or system objectives. In addition, PBPD involves the use of appropriate analysis tools and methods, which can be used to evaluate the performance impacts of Complete Streets planning and design decisions.

Transportation Systems Management and Operations (TSMO) strategies also present opportunities to better serve all modes and support Complete Streets, especially when Complete Streets solutions result in lane reductions. TSMO strategies such as adaptive signal control, changeable lanes at intersections, or reversible lanes along a facility can provide vehicular capacity when and where it is needed most. Examples of TSMO strategies that support non-auto modes in Complete Streets contexts include transit signal priority, which can reduce bus travel time and delay, and bicycle signals to improve mobility and safety for bicyclists at unusual or complex intersections. These strategies may make a Complete Street feasible in instances where simply reducing lanes would create excessive congestion.

This primer includes case studies of Complete Streets and provides insights on the operational and safety effects of implementing Complete Streets and how performance may be enhanced through PBPD and TSMO. This is one of two primers developed to highlight the linkage between PBPD and TSMO. The other primer focuses on narrow lanes and narrow shoulders on freeways. The FHWA Office of Operations is supporting these Primers through related technical assistance. If you have any comments or would like assistance on PBPD and Operations, please contact Jim Hunt jim.hunt@dot.gov or Greg Jones GregM.Jones@dot.gov from the FHWA Office of Operations.

Robert Arnold
Director Office of Transportation Management
Office of Operations, FHWA

Conversion Factors

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)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		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)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		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. (Revised March 2003)

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List of Acronyms and Symbols

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
CSS	Context Sensitive Solutions
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
HSM	Highway Safety Manual
MPO	Metropolitan Planning Organization
NACTO	National Association of City Transportation Officials
NCHRP	National Cooperative Highway Research Program
PBPD	Performance-Based Practical Design
PBPP	Performance-Based Planning and Programming
TSMO	Transportation System Management and Operations
TWLTL	Two-way left-turn lane

OVERVIEW AND PURPOSE OF THE PRIMER

Urban streets must serve many types of users and trips, and the right-of-way for the street is often fixed due to surrounding development. In recent years there has been an increased desire by agencies to better serve all users of urban streets, regardless of mode of travel. The Complete Streets design principles seek to better share the limited street right-of-way among multiple users while enhancing the livability of the street for adjacent residents. (Reference 1)

This Primer describes the principles of **Performance-Based Practical Design** (PBPD) and shows how PBPD and **Transportation System Management and Operations** (TSMO) strategies can be employed to produce Complete Street designs that better meet the needs of travelers and achieve agency policies, goals, and objectives under a wider range of traffic contexts.

PBPD modifies the traditional "top-down, standards-first" approach to a "design up" approach in which designers and decision-makers exercise engineering judgment to build up the roadway and operational improvements from existing conditions to meet both project and system objectives. PBPD uses appropriate analysis tools to evaluate the performance impacts of planning and design decisions in relation to the cost of providing various geometric elements and operational features.

PBPD is the guiding principle for cost-effective design. TSMO is a set of low capital cost solutions that the designer can employ to increase the success of his or her design or can consider as a complete design alternative.

Figure 1. Diagram. Performance-Based Practical Design + Transportation Systems Management and Operations -> Better Complete Streets.

TSMO—also often referred to simply as "operations"—is a set of "integrated strategies to optimize the performance of existing infrastructure through the implementation of multimodal and intermodal, cross-jurisdictional systems, services, and projects designed to preserve capacity and improve security, safety, and reliability of the transportation system." (Reference 2)

Complete Streets "are streets for everyone." "They are designed and operated to enable safe access for all users, including pedestrians, bicyclists, motorists and transit riders of all ages and abilities." (Reference 3) Typical elements that make up a complete street include "sidewalks, bicycle lanes (or wide, paved shoulders), shared-use paths, designated bus lanes, safe and accessible transit stops, and frequent and safe crossings for pedestrians, including median islands, accessible pedestrian signals, and curb extensions." (Reference 1)

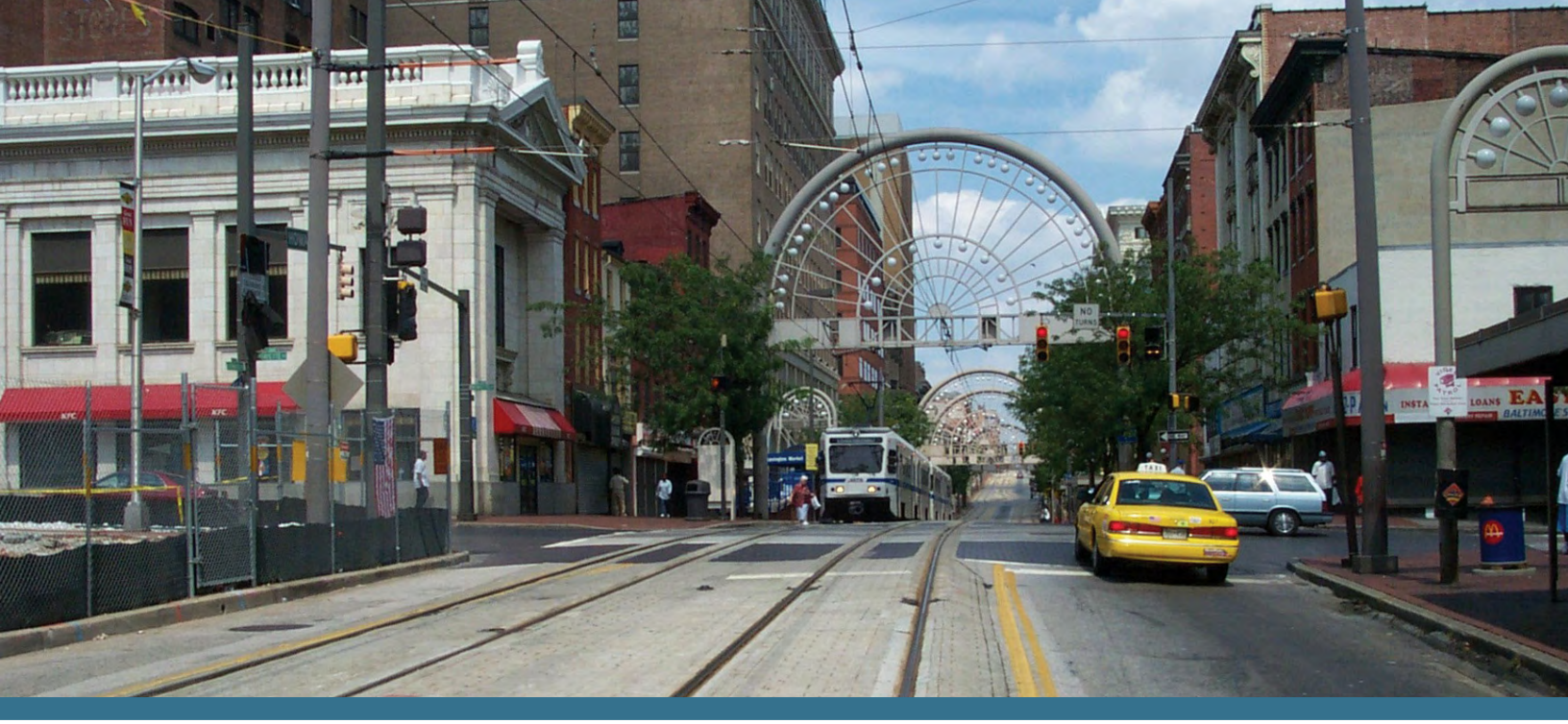
Unless one is designing a new street in an undeveloped area, the designer is usually confronted with all of the right-of-way and design constraints of retrofitting a Complete Street design onto an existing street cross-section. For low volume and low speed streets (under 20,000 average annual daily traffic (AADT) and under 35 mph), many of the design tradeoffs (narrow lanes, reduced lanes, adding bike lanes, etc.) are easy to make, requiring little formal trade-off analysis. The challenge comes in retrofitting Complete Street concepts on a higher volume or higher speed street. That is where the more-formal trade-off analysis implicit in the PBPD process comes into play. TSMO can assist the designer through the PBPD process by increasing the number of design solutions available to the designer and by supporting the success of those design solutions.

Charlotte Department of Transportation

Figure 2. Photo. Complete Street Example.
(Source: Reference 1)

Kenneth Hash, Washington State DOT

Figure 3. Photo. Example Complete Street Result.
(Source: Reference 1)



Source: Kittelson & Associates, Inc.

Chapter 1 Complete Streets: Description and Design Considerations

Complete Streets are literally streets designed for use by everyone. "They are designed and operated to enable safe access for all users, including pedestrians, bicyclists, motorists and transit riders of all ages and abilities." (Reference 3)

"Typical elements that make up a complete street include: sidewalks, bicycle lanes (or wide, paved shoulders), shared-use paths, designated bus lanes, safe and accessible transit stops, and frequent and safe crossings for pedestrians, including median islands, accessible pedestrian signals, and curb extensions." "The common denominator is balancing safety and convenience for everyone using the road." (Reference 1)

A Complete Street design is shown in **Figure 4**.[1] The Elizabeth Street (in Charlotte, North Carolina) right-of-way was originally able to accommodate four travel lanes without on-street parking plus sidewalks with a landscaped buffer. The figure shows the results of a Complete Streets design concept application with a Road Diet reducing Elizabeth Street to two motor vehicle travel lanes, with bus and rail transit service sharing the motor vehicle traveled way, on-street parking for motor vehicles, pedestrians in sidewalks that are separated from the traveled way by landscaped buffers (new street trees in bulb-outs, grass, and densely spaced street light poles on both sides of the street), and bicycles in the bike lanes adjacent to the traveled way.

Figure 4. Photo. Prototype Complete Street.
(Source: Reference 1)

1 Note that every Complete Street design must balance several competing objectives. In the example in this photo the street car tracks improve transit mobility, but by being placed adjacent to the bike lanes they may limit the ability of bicyclists to maneuver around debris in the bike lane. Increased monitoring and maintenance (TSMO) may reduce this issue.

DESIGN AND OPERATIONAL COMPONENTS OF COMPLETE STREETS

The design components of a Complete Street design include traffic and speed control, pedestrian, bicycle, and transit treatments.[2] Operational components may be included in the design treatments to ensure their success.

- Traffic and Speed Control Design Treatments may include: speed humps, bulb-outs/chokers, chicanes, diverters, closures, roadway narrowing, mini roundabouts, roundabouts.
- Pedestrian Design Treatments may include: refuge islands, sidewalk widening, crosswalks, midblock crosswalks.
- Bicycle Design Treatments may include: bike boulevards/neighborhood greenways, shared lane markings, bike lanes, separated bike lanes, on-street parking removal.
- Transit Design Treatments may include: bulb outs at transit stops, bus turnouts (bus pullouts or bus bays), exclusive transit lanes, queue jump lanes.
- Operational components of the design may include: signal-timing improvements (such as pedestrian crossing times, cycle lengths, green times, coordination), speed limit reductions, traffic enforcement, transit priority at the signals, signal coordination timed for transit, bicycle detection at signals, real-time transit arrival information, and "smart" parking management systems.

A crucial consideration in the design of a Complete Street is determining the target design speed and traffic volumes for the street. Unlike conventional road design practices, which design the road to accommodate the predicted traffic volumes and speeds, a Complete Street design approach treats traffic volumes and speeds as additional design parameters to be evaluated within the design process as design alternatives.[3]

Design considerations to be taken into account in setting design objectives and making design decisions should include:

Roadway Classification System and Street Types[4]

- Higher class roadways (such as major arterials) may have a different appropriate balance between mobility and accessibility objectives.
- A suburban arterial will have different mobility and accessibility objectives than an urban street.

Fronting Land Uses

- The adjacent land uses to the street will determine the relative needs for auto, transit, bicycle, and pedestrian accessibility.
- Driveway density may impact the design options and objectives.

Design and Posted Speed

- The agency objectives for the street should vary according to the roadway class, the street type, and fronting land uses. These objectives will in turn drive the selection of the design speed and the posted speed limit for the street. The design speed affects many of the design and operation decisions for a Complete Street design.

Traffic Volumes

- The street volumes and turning patterns should be considered in the Complete Street design process. In general, four-lane, undivided roadways begin to operate in a manner similar to a three-lane roadway as the number of access points and left-turn volumes increase. In this situation, the four-lane, undivided roadway begins to operate as a de facto three-lane roadway and the operational impacts of a Complete Street design that reduces through lanes may be smaller.

Design Vehicles

- Selecting the design vehicles to be used for a Complete Street design is an agency policy decision and may not necessarily be the same choices as would be made for other types of highway projects.

2 Note that not all of these design components are compatible with each other, nor may they be appropriate under differing traffic volumes and speeds. Some may be appropriate for a low volume street but not for a higher volume street.

3 Consult the NACTO Urban Street Design Guide (Reference 4) for more details on design components and operational strategies.

4 Land use is a consideration in addition to roadway classification, as noted in the next major bullet point.

Intersections

- Intersection design treatments and intersection controls are key design decisions. Signalized intersections are often the capacity "pinch points" along a street. Making intersection improvements in conjunction with a Complete Street may minimize adverse operational impacts.

Parking

- Whether or not and to what extent on-street parking must be accommodated in the Complete Street design is a key agency policy decision.

Pedestrian, Bicycle, and Public Transportation Use

- The consideration and targeting of the design to encourage more-extensive transit bicycle and pedestrian use is a key design decision.

THE DESIGN OBJECTIVE: MAKING IT FIT, BALANCING NEEDS

The basic design objective when following Complete Streets design principles is to balance the safety and performance of the street for all modes of travel within a constrained street right of way. Many safety, mobility, and accessibility tradeoffs must be considered and weighed to achieve the solution that best meets the objectives of the agency. Some of the key design decisions to be made are:

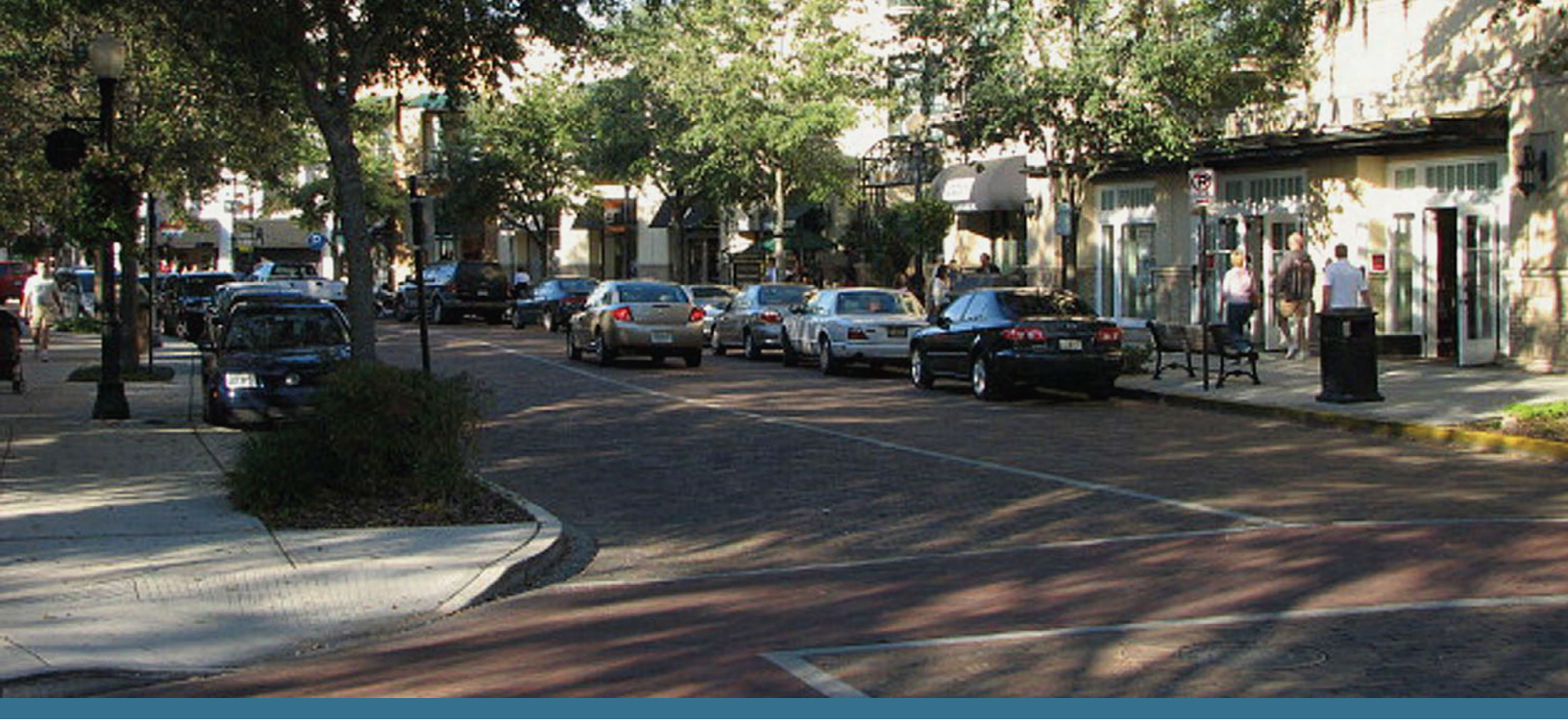
1. Can the multimodal safety and accessibility goals of the agency for the Complete Street project be better achieved with lower speeds, fewer lanes, and narrower motor vehicle travel lanes?
2. Can some of the potential adverse impacts of fewer lanes and narrow lanes be partially or completely mitigated through the application of transportation system management and operations (TSMO) strategies? If so, which TSMO strategies are the most cost-effective at achieving the project goals?
3. Which enhancements to the transit accessibility, bikability, and walkability of a street can best achieve the agency's short- and long-term safety, accessibility, and livability goals for the project and for the street system?

Performance-Based Practical Design supplemented with operations strategies can assist the designer in arriving at the best solution through a series of logical and defensible design decisions.

FURTHER READING ON COMPLETE STREETS DESIGN

The following references can be consulted for more information on the design components and considerations of Complete Streets:

- American Planning Association, "Complete Streets: Best Policy and Implementation Practices", 2010.
- FHWA, "Road Diet Informational Guide", FHWA-SA-14-028, 2014.
- "Complete Streets Design Manual," Smart Growth America.
- "Urban Street Design Guide," National Association of City Transportation Officials.
- "Statewide Lane Elimination Guide," Florida Department of Transportation, 2014.
- FHWA, "Incorporating On-Road Bicycle Networks into Resurfacing Projects," 2016.FHWA, "Workbook for Building On-Road Bike Networks through Routine Resurfacing Programs", 2016 http://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/resurfacing/resurfacing_workbook.pdf
- New York City Department of Transportation, "Street Design Manual", 2015 http://www.nyc.gov/html/dot/downloads/pdf/nycdot-streetdesignmanual-interior-lores.pdf
- Los Angeles County, "Model Design Manual for Living Streets", 2011 http://modelstreetdesignmanual.com/model_street_design_manual.pdf
- Charlotte Department of Transportation, "Urban Street Design Guidelines", 2007 http://charmeck.org/city/charlotte/Transportation/PlansProjects/pages/urban%20street%20design%20guidelines.aspx



Source: Kittelson & Associates, Inc.

Chapter 2 Performance-Based Practical Design

Performance-Based Practical Design (PBPD) in combination with Transportation System Management and Operation (TSMO) strategies can assist planners and engineers in arriving at the best design and operations solution through a series of logical and defensible design decisions.

PERFORMANCE-BASED PRACTICAL DESIGN

PBPD modifies the traditional "top-down, standards-first" approach to a "design up" approach in which designers and decision-makers exercise engineering judgment to build-up the roadway and operational improvements from existing conditions to meet both project and system objectives. PBPD uses appropriate analysis tools to evaluate the performance impacts of planning and design decisions in relation to the cost of providing various geometric elements and operational features.

PBPD should not be viewed as a stand-alone set of activities. Rather, it is an integral part of a broader process known as "Performance-Based Planning and Programming." The FHWA publication "Performance-Based Planning and Programming Guidebook" (Reference 5) describes the application of performance management principles within the planning and programming processes of transportation agencies and regional entities (e.g., MPOs) to achieve desired performance outcomes for the multimodal transportation system. **Figure 5** shows the Performance-Based Planning and Programming (PBPP) process, indicating where PBPD concepts and activities may be applied. As shown in **Figure 5**, PBPD-related activities can be applied to the preliminary engineering and design activities, with any cost savings going to support additional projects as part of the regional programming process. PBPD concepts can also be used during planning activities to help identify strategies and analyze alternatives.

Figure 6 identifies and summarizes the various PBPD concepts and potential activities, starting with "baseline conditions" including design policies and guidelines, current and projected issues and needs, and stakeholder concerns; then moving into analysis such as developing alternatives, analyzing these alternatives in terms of improved performance and costs, coupled with trade-offs and engineering judgment. The results of these PBPD-related activities and concepts (i.e., "Moving Forward") is the selection of the optimal concepts and strategies for design, the identification of any design exceptions, and the documentation of the decisions.

As collectively shown in **Figure 5** and **Figure 6**, PBPD designers apply a "design up" approach by using existing conditions as the baseline and engineer solutions that meet the project purpose based on explicitly defined transportation performance needs as derived from system and regional goals and objectives. This approach differs from a more-conventional approach of setting project design criteria based solely on values listed in design specifications or standards for a set of given conditions. Designers then evaluate the solutions against the tradeoffs based on an objective analysis of performance data. Some of the tradeoffs considered include the estimated costs for each potential solution, coupled with due consideration of agency polices, legal requirements, stakeholder sensitivities, and any other potential constraints.

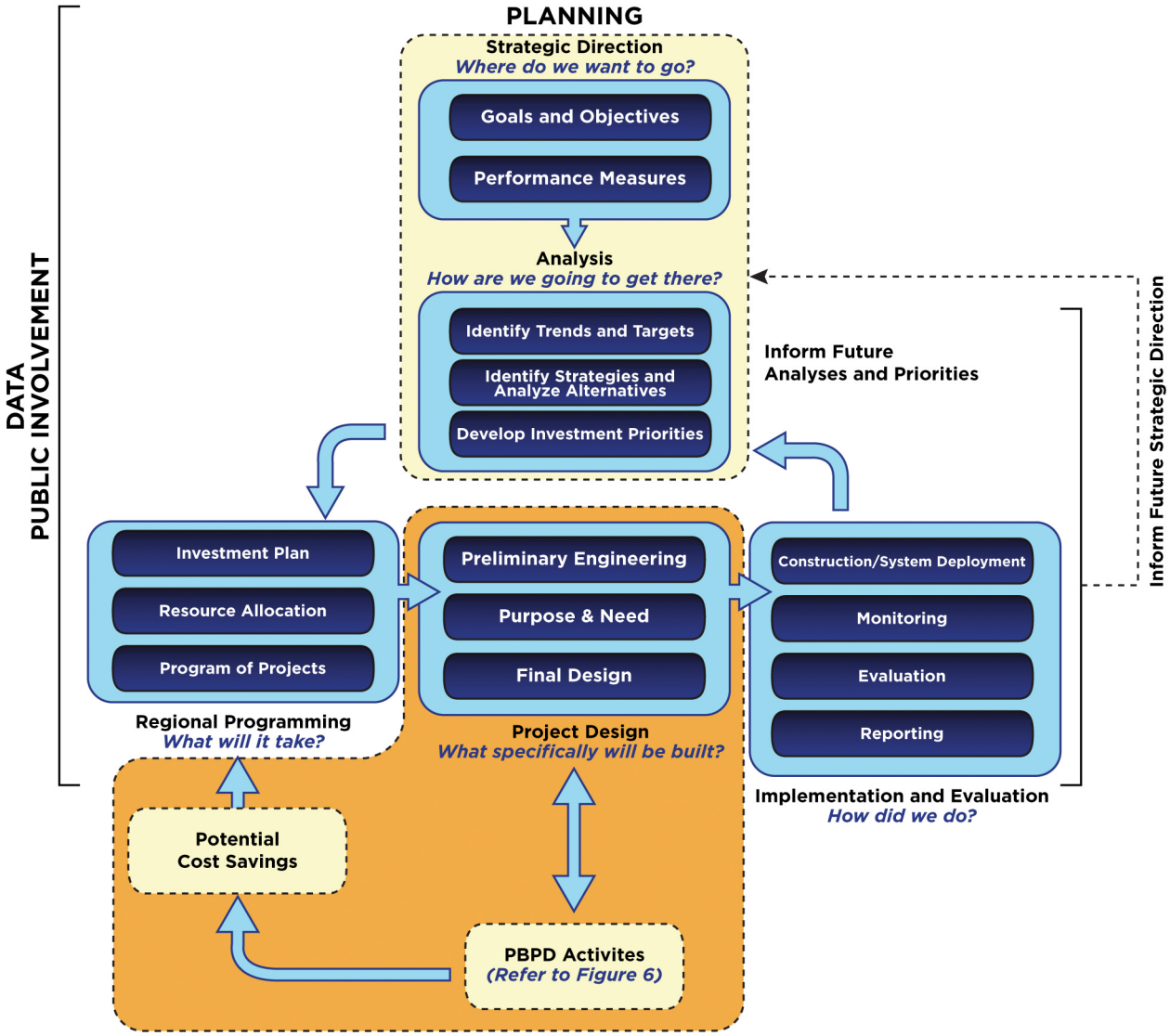


Figure 5. Diagram. Framework for Performance-Based Planning and Programming.
(Source: Adapted from Reference 5)

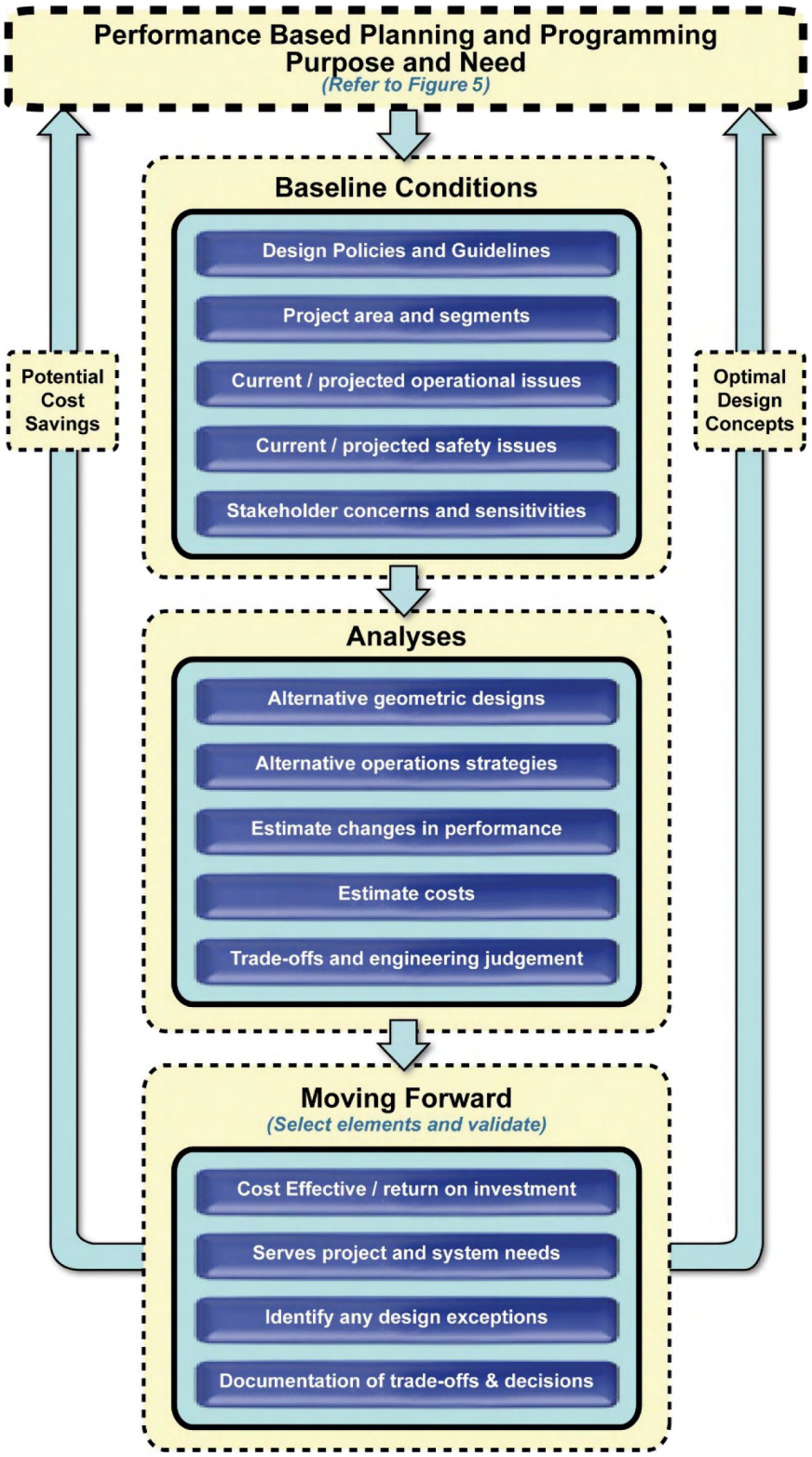


Figure 6. Diagram. Concepts and Activities Associated with Performance-Based Practical Design.
(Figure is based on several Federal Highway Administration documents and presentations on the subject of Performance-Based Practical Design)

A basic tenet of PBPD involves making project decisions that directly serve performance needs while considering whether the same investment of money would yield a greater return on investment if applied to other system needs and/or priorities. It is important to document the design decisions and present them to decision makers showing the benefits relative to the no-build option. These PBPD design and decision-making analyses can easily be transferred to design exception forms for review, approval and record-keeping.

By implementing a PBPD approach, agencies may reduce or eliminate project elements that are determined to be non-essential, resulting in lower cost and improved value by taking advantage of existing design flexibility. Agencies may also use the associated cost saving to deliver a greater number of projects that yield a greater performance return on investment than otherwise possible under existing project development and design approaches.

Relationship between Performance-Based Practical Design and Context-Sensitive Solutions

Context-Sensitive Solutions (CSS) seek a transportation solution that addresses the needs of all road users and the functions of the facility within the context of its setting, considering land use, users, the environment, and other factors. CSS is a collaborative, interdisciplinary approach that includes the viewpoints of all stakeholders in the development of a shared vision of project goals, and uses a defined decision-making process. CSS and PBPD rely on flexibility to achieve results that meet the project purpose and need. PBPD compliments CSS by providing performance information that supports decision-making.

Design Criteria and Design Exceptions

As previously noted, PBPD moves away from the more-conventional "top-down, standards-first" approach to a more performance- and value-based "design up" approach. Designers that focus on the relationships between design dimensions and performance may become less obligated to meet one or more of the design guidelines, such as those found in the AASHTO Green Book ("A Policy on Geometric Design of Highways and Streets"). Design criteria and standards offer many benefits, including promoting consistency, establishing a design "norm," and promoting efficiency in design development.

However, "standard" does not necessarily mean "best," nor are standards intended to be a substitute for engineering judgment and context-specific considerations.

Federal regulations (Reference 6) state that *"Approval ...may be given on a project basis to designs which do not conform to the minimum criteria as set forth in the standards, policies, and standard specifications."* A **design exception** is a documented decision to design a highway element or a segment of highway to design criteria that do not meet minimum values or ranges established for that highway or project. A design exception is NOT an indication of failure or a "flawed" design; rather, it is a necessary and legitimate process to allow professional and engineering judgment in the design process, providing a useful "tool" for employing practicality and flexibility in design decisions in a design-up approach such as PBPD.

As noted in the FHWA document "Mitigation Strategies for Design Exceptions" (Reference 7) there are a broad range of reasons why design exceptions may be considered and found to be necessary. Some of these include the following:

- Impacts to the natural environment
- Social or right-of-way impacts
- Preservation of historic or cultural resources
- Sensitivity to context
- Sensitivity to community values
- Construction or right-of-way costs

A final notice published in the Federal Register on May 5, 2016 (Reference 8) completed FHWA's effort to update the policy regarding controlling criteria for design, applicable to projects on the National Highway System. FHWA reduced the number of controlling criteria from 13 to 10 for Interstate highways, other freeways, and roadways with design speed ≥ 50 mph, and now applies only two of those criteria to low speed roadways (non-freeways with design speed <50 mph). FHWA also clarified when design exceptions are needed and the documentation that is expected to support such requests.

FHWA has adopted new policies to modify highway design standards that encourage greater flexibility in order to achieve a design that best suits the desires of the community, while satisfying the purpose for the project and needs of its users. As an example, FHWA published revisions to current federal policy that will help reduce cost and speed up the design of local

Controlling Criteria for Design Exceptions, 2016

1. Design Speed*
2. Lane Width
3. Shoulder Width
4. Horizontal Curve Radius
5. Superelevation
6. Maximum Grade
7. Stopping Sight Distance
8. Cross Slope
9. Vertical Clearance
10. Design Loading Structural Capacity*

* Design Speed and Design Loading Structural Capacity apply to all roads on the National Highway System

roads and streets. In 1985, thirteen design criteria were prioritized because of their perceived impact on operations and safety. Under the new policy, ten criteria will be prioritized for high speed roadways, and only two criteria will be emphasized for lower-speed roads such as rural roads that become main streets through smaller towns and cities. This will provide state and local engineers to develop flexible design solutions that meet local travel needs and goals.

TRANSPORTATION SYSTEMS MANAGEMENT AND OPERATIONS

Transportation Systems Management and Operations (TSMO)—also often referred to simply as "operations"—is defined as:

"Integrated strategies to optimize the performance of existing infrastructure through the implementation of multimodal and intermodal, cross-jurisdictional systems, services, and projects designed to preserve capacity and improve security, safety, and reliability of the transportation system."

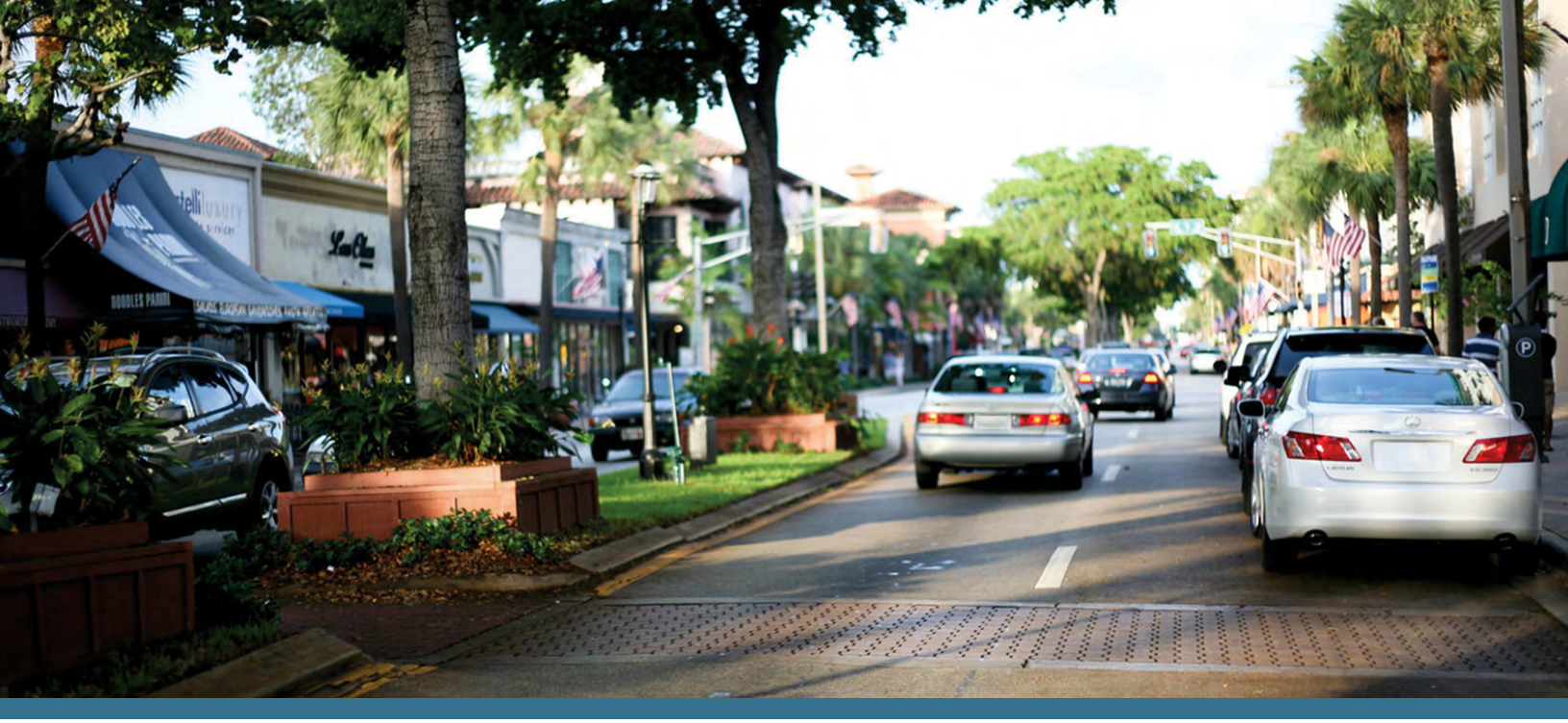
Intelligent Transportation System (ITS) technologies are crucial to the success of these operations strategies. ITS technologies include: devices for monitoring traffic flow on the roadways, hardware and software at transportation management centers (TMCs), and/or "Connected Vehicle" applications. ITS represents the "**enabling technology for operations**."

TSMO strategies—coupled with the supporting ITS technology—are a most-important aspect of delivering transportation services to customers. Experience has shown that aggressive applications of these operations strategies can, in effect, "take back" much of the capacity lost due to congestion and disruptions. Operations strategies also enhance safety, promote reduced emissions, and increase system reliability. Perhaps most importantly, actively managing the transportation network can improve travelers' experiences, providing them with real-time information and choices throughout the trip chain—from origin to destination—leading to network performance optimization and increased efficiency. TSMO strategies are relatively low cost (compared with adding capacity), much quicker to implement (two to three years), and offer substantial benefits (with very positive benefit-cost ratios).

FHWA recommends an "objectives-driven, performance-based approach" for including "operational and management strategies to improve the performance of existing transportation facilities" in the planning process. This objectives-driven, performance-based approach to planning for operations within a metropolitan area—conducted in collaboration among planners, transportation providers, operators, and other stakeholders—is shown in **Figure 7**.

The activities shown in **Figure 7** parallel the PBPD process—including the development of potential strategies based on goals, objectives, and needs; then, evaluating and subsequently selecting strategies in terms of performance and cost. Moreover, low-cost, rapidly deployable, and flexible treatments—as provided by many TSMO strategies—all fall under the umbrella of PBPD.

Figure 7. Flowchart. An Objectives-Driven, Performance-Based Approach.
(Adapted from References 9 and 10)



Source: Kittelson & Associates, Inc.

Chapter 3 Employing Performance-Practical Design and Transportation Systems Management Operations in Designing Complete Streets

Developing Complete Street designs for low-volume, low-speed streets (e.g. under 20,000 AADT and speed limits under 35 mph) requires little in the way of formal performance trade-off analyses. However, as one approaches or exceeds these limits the feasibility of Complete Street design principles comes into question. The designer is faced with a yes/no decision as to whether or not a Complete Street design is feasible. The Performance-Based Practical Design process with TSMO elements included gives planners and designers the tools to develop more-nuanced answers to the feasibility question and to identify low-cost TSMO strategies that can extend the range of feasible application for Complete Street concepts.

SETTING THE DESIGN OBJECTIVES AND PERFORMANCE MEASURES

The first step to employing the PBPD process is to identify the agency's goals for the Complete Street project. The agency's mobility, accessibility, livability and safety goals must then be translated into project objectives. Each project objective should be assigned with a specific performance measure for quantifying the achievement of the project objectives for each design concept.

One of many possible examples of a "Goals/Objectives/Measures" PBPD analysis matrix is shown in **Table 1**. Note that more than one performance measure may be necessary to accurately measure achievement of a given objective, and multiple objectives may be relevant to a single goal. An agency should construct a matrix that meets its needs for assessing alternative design concepts, and yet does not require performance analyses that exceed the resources and tools available to the designer.

IDENTIFYING CANDIDATE DESIGN CONCEPTS

Once the project goals, objectives, and performance measures have been selected then various design concepts are considered to find the practical design that best meets the agency's objectives. The designer consults the various design manuals and guides on Complete Streets to identify and develop alternative design concepts for PBPD analysis.

Table 1. Example: Performance-Based Practical Design Performance Analysis Matrix.

Agency Goals	Maximize System Cost Effectiveness	Maximize System Safety	Promote Sustainability	Promote Livability
Project Objectives	Reduce travel times and costs by X% below existing within 1 year of project opening	Reduce crashes by X% from existing within 1 year of project opening	Reduce greenhouse gas vehicle emissions by X% from existing within 1 year of project opening	Increase active mode use by X% from existing within 1 year of project opening
Project Performance Measures	Person-hours of delay Estimated Cost of Improvements	Crashes	Grams CO_2 equivalent emitted per day	HCM Bike LOS HCM Ped LOS
Example of Meeting the Objective through Design	Select design features that do not unduly increase auto, bus, or truck delay at best project cost-effectiveness. Keep v/c ratio below 1.00.	Increase buffers between opposing traffic and between traffic and non-motor vehicle modes.	Select design features that reduce attractiveness of street for high speed auto use.	Select design features that encourage walking and bicycling.

HCM = Highway Capacity Manual. LOS = Level of Service

A few key references are listed here:

- "Complete Streets: Best Policy and Implementation Practices", American Planning Association, 2010.
- "Complete Streets Design Manual," Smart Growth America
- "Urban Street Design Guide," National Association of City Transportation Officials.

Additional useful design references for Complete Streets are listed at the end of Chapter 1.

Figure 7 and Figure 8 illustrate some example bicycle and pedestrian design treatments. FHWA's Separated Bike Lane Planning and Design Guide (Reference 11) should be consulted for additional examples. Additional pedestrian design treatments not shown here include: Pedestrian Hybrid Beacons (PHB), pedestrian refuge islands, raised crosswalks, crosswalk visibility enhancements, and rectangular rapid flash beacons (RRFBs).

Figure 9 illustrates how the project objectives and performance measures, once translated into design objectives are then used to generate design options. In this figure, only one of several potential design concepts is shown.

For this particular design concept, the number of travel lanes and the widths of the travel lanes are reduced in order to provide cross-sectional width for new bike lanes dedicated exclusively to bicycles, a median buffer (a two-way left turn lane) between opposing traffic, a striped buffer between traffic and the bike lanes and, a landscaped buffer between traffic and pedestrians.

The TSMO strategies listed in the box in the figure would enable consideration of this design concept for moderately higher volume and speed streets than would be feasible in the absence of TSMO strategies.

Least Separation

Signed Routes (No Pavement Markings)
A roadway designated as a preferred route for bicycles.

Shared Lane Markings
A shared roadway with pavement markings providing wayfinding guidance to bicyclists and alerting drivers that bicyclists are likely to be operating in mixed traffic.

On-Street Bike Lanes
An on-road bicycle facility designated by striping, signing, and pavement markings.

On-Street Buffered Bike Lanes
Bike lanes with a painted buffer increase lateral separation between bicyclists and motor vehicles.

Separated Bike Lanes

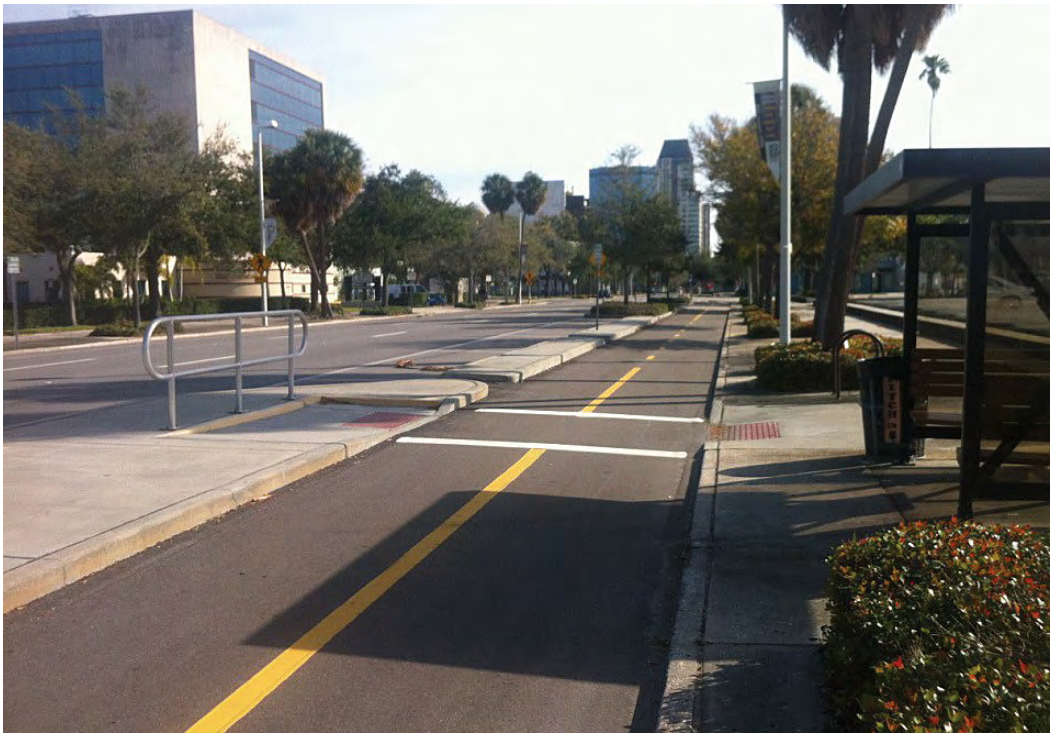
A separated bike lane is an exclusive facility for bicyclists that is located within or directly adjacent to the roadway and that is physically separated from motor vehicle traffic with a vertical element.

Off Street Trails / Sidepaths
Bicycle facilities physically separated from traffic, but intended for shared uses by a variety of groups, including pedestrians, bicyclists, and joggers.

Most Separation

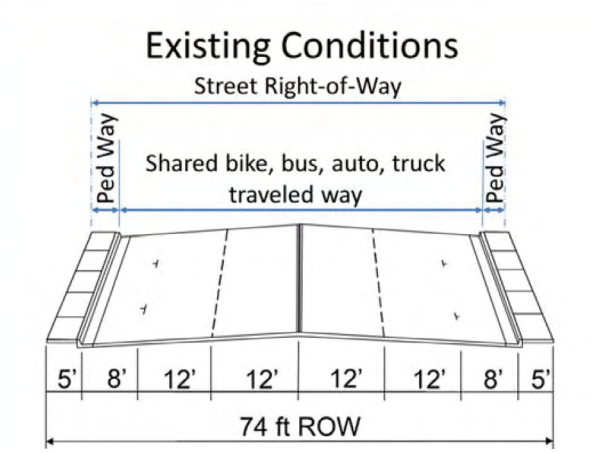
Figure 8. Chart. Levels of Separation of Bicycle Treatment Options.
(Source: Reference 11)

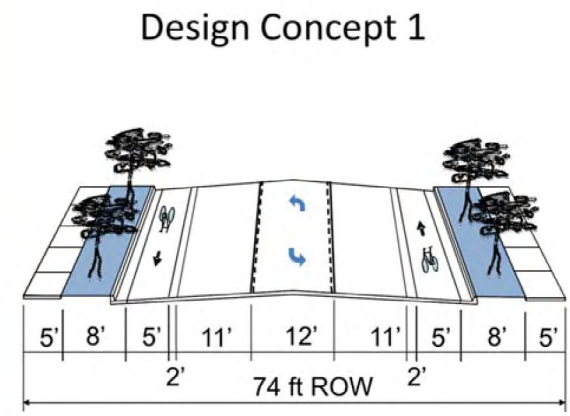
First Avenue, New York City

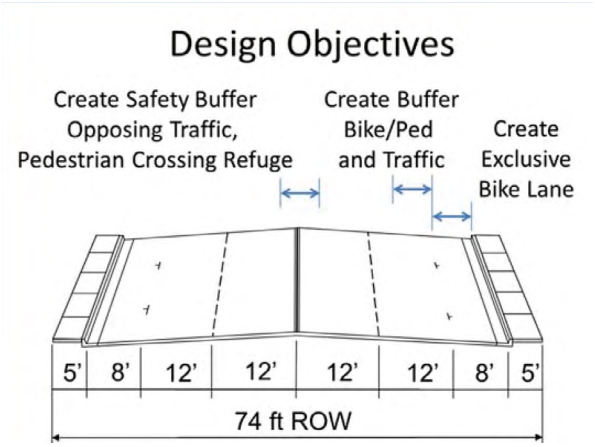


First Avenue South, St. Petersburg, Florida

Figure 9. Photos. Additional Bicycle and Pedestrian Design Treatment Examples.
(Source: Reference 11)







TSMO Strategies to Enhance Achievement of Project Objectives

- Lowered speed limit to improve safety.
- Added left turn pockets at major signalized intersections for capacity.
- Revised signal timing at intersections to compensate for lost through capacity.
- Added bicycle detectors at signals.
- Added bicycle box left turns for safety.

Figure 10. Diagrams. Application of Performance-Based Practical Design to Generate One of Many Potential Complete Street Design.

ROLE OF TRANSPORTATION SYSTEM MANAGEMENT OPERATIONS IN COMPLETE STREETS

Complete Streets sometimes involve reducing motor-vehicle travel lanes, which may increase delays due to motor-vehicle congestion and reduce auto, truck, and bus speeds on the street.[5] Complete Streets may also narrow the travel lanes to make room for additional safety buffers on the street. TSMO strategies can augment achievement of the design objectives of Complete Streets. Table 2 provides some illustrative examples of TSMO strategies targeted to specific design objectives. The text below describes some of these strategies in more detail. The reader should consult the FHWA TSMO primer (Reference 12) and the AASHTO Guidance (Reference 13) for a more-complete list of TSMO strategies and additional information on their effects on operations and safety. TSMO strategies for reducing motor vehicle speeds, and especially TSMO strategies that reduce the differential between high and low speed vehicles include:

- Signal coordination plans that favor a lower target speed for motor vehicles that is more compatible with the multimodal safety objectives of Complete Streets.
- Lower posted speed limits
- Radar speed advisory signs.
- Automated speed enforcement (where enabling legislation is in place)
- Automated red light enforcement (where enabling legislation is in place)

Table 2. Example: Applications of Transportation Systems Management Operations Strategies to Support Performance-Based Practical Design in Complete Streets.

Operational Objective	Geometric TSMO Strategies	Control TSMO Strategies	Other TSMO Strategies
Lower Traffic Speeds to Improve Safety	• Pavement surface treatments • Speed Humps	• Lower Speed Limit • Lower Signal Progression Speed	• Radar Speed Advisory Signs • Automated Speed Enforcement
Reduce Crashes	• Access Management. • Consolidated driveways	• Review traffic and ped clearance intervals. • Improve signal head visibility. • Review mid-block ped crossings.	• Automated red light enforcement. • Ped HAWK beacon. • Higher intensity street lighting • Bicycle boxes
Preserve Traffic Capacity to maintain bus, truck, and auto speeds	• Turn pockets at signals	• Change signal timing • Adaptive signal timing • Bus Signal Priority • Bus/bike queue jumps	• Weather management and response (snow removal).

This table is intended to be illustrative of some of the TSMO strategies that may be employed. See the FHWA Primer on TSMO and AASHTO Guidance for more information.

5 A common misconception is that reducing the number of through lanes (a Road Diet) will cause traffic to become more congested. However, when applied correctly in the right locations, a Road Diet can still maintain a roadway's effective capacity. For example, when a corridor contains a large number of access points (driveways) the majority of through traffic will tend to utilize the outside lanes to avoid being delayed by left-turning vehicles slowing and stopping in the inside lanes. These four-lane corridors essentially behave like a three-lane road (one through lane in each direction and one two-way left turn lane). Thus, when a Road Diet is installed and reconstructed to a three-lane section, the roadway is unlikely to experience a change in capacity. A PBPD analysis of the traffic performance of the design concept can reveal conditions when capacity is maintained or lost.

TSMO strategies can be a means to reinforce achievement of the Complete Street objectives to enhance multimodal safety and convenience. Examples include:

- Bike and Transit queue jump lanes
- Pedestrian scramble, diagonal crossing phase
- Passive pedestrian sensors that activate pedestrian warning signs/lights (for example HAWK beacons) for unsignalized pedestrian crossings
- Weather management and response strategies (snow clearance)

TSMO strategies can enhance the motor-vehicle capacity of a specific Complete Street design concept. Examples of capacity-enhancing TSMO strategies include:

- Re-timing the traffic signals to give higher green times per cycle (g/c) to the street approach with the reduced motor-vehicle travel lanes.
- Increasing the cycle length to provide more overall capacity at the intersection (lost time per hour during amber and all-red change intervals is reduced when there are fewer cycles per hour). [6]
- Adding left- and right-turn pockets at an intersection so that lower capacity turns can be made outside of the through lanes. [7] (These pockets should be considered carefully, because they might increase pedestrian crossing times, distances and conflicts, thus reducing some of the other pedestrian safety benefits of the design).
- Dropping on-street auto parking on the approaches and exits to a signal so that an additional through lane can be maintained for several hundred feet before and after the signal.
- Transit queue jump lanes with dynamic transit signal priority on the approach to the signal may enable buses to avoid the motor-vehicle congestion effects of fewer travel lanes on the street.

There are also institutional and policy considerations to take into account when developing Complete Street designs. The FHWA Guide: "The Role of Transportation Systems Management & Operations in Supporting Livability and Sustainability: A Primer," provides information on how TSMO strategies can support livability and sustainability policies.

FURTHER READING ON TRANSPORTATION SYSTEM MANAGEMENT AND OPERATIONS STRATEGIES

The following references can be consulted for more information on TSMO strategies for supporting a Complete Street design.

- FHWA, "Designing for Transportation Management and Operations: A Primer," FHWA HOP-13-013, available at National Operations Center of Excellence: http://www.transportationops.org/publications/designing-transportation-management-and-operations-primer-0

- FHWA, "Regional Concept for Transportation Operations," FHWA-HOP-07-122, available at: http://ops.fhwa.dot.gov/publications/rctoprimer/prim0701.htm

- FHWA, "Creating an Effective Program to Advance Transportation System management and Operations, a Primer", FHWA-HOP-12-003, available at: http://ops.fhwa.dot.gov/Publications/fhwahop12003/background.htm

- AASHTO, Transportation Systems Management and Operations (TSMO), available at http://www.aashtoTSMOguidance.org/

- FHWA, The Role of Transportation Systems Management & Operations in Supporting Livability and Sustainability: A Primer, FHWA-HOP-12-004, January 2012. Available at: http://www.ops.fhwa.dot.gov/publications/fhwahop12004/fhwahop12004.pdf

6 Note however, that increasing cycle lengths will usually increase average delay for all users of the street

7 Note that left turn pockets are a natural outcome of a road diet employing a Two-Way Left Turn Lane.

Source: Kittelson & Associates, Inc.

Chapter 4 Analyzing the Tradeoffs

Once the candidate design concepts have been identified, the next step in the Performance-Based Practical Design (PBPD) analysis process is to quantify how the design concepts affect performance, and ultimately achievement of the project objectives. If one option includes reconfiguring the roadway to include a two-way, left-turn lane to the street, how much does that increase safety? What affect will fewer and/or narrower lanes have on traffic operations, pedestrian and bicycle safety, and motor vehicle crash rates?

This chapter provides a brief summary of what is known about the relationships between Complete Streets and the typical project objectives of reducing crashes, avoiding excessive delays to transit service, and increasing the use of the street by pedestrians and bicyclists. The analyst is then referred to various national references to obtain more specifics on the available analysis methods and tools.

Complete Street design concepts may reconfigure through traffic lanes. They may also narrow motor-vehicle travel lanes to secure additional safety buffers between motorized and non-motorized modes using the street. [8]

These design decisions may:

- Adversely affect bus transit, rail transit, and trucks using the street (unless transit is given exclusive lanes on the street).
- Encourage through traffic (including trucks) to divert to other streets.
- Reduce the potential conflicts between motorized and non-motorized users of the streets.
- Reduce number and severity of crashes, and especially bicycle and pedestrian involved crashes on the street.

LANE WIDTHS – OPERATIONAL EFFECTS ON MOTOR VEHICLES

The impacts of lane widths (in the range of 10 to 12 feet) vary according to the free-flow speed of the street. High speed streets (with free-flow speeds greater than 35 mph) generally are more sensitive to narrow lane widths than low-speed streets.

Moderate- to Low-Speed Streets. Signalized intersections generally dictate the capacity of an urban street (a street with traffic signals spaced no more than two miles apart). As shown in **Table 3**, lane widths in the range of 10 feet to 12 feet generally have little effect on the capacity of a traffic signal (Exhibit 18-13 of Reference 14).

8 Narrow lanes generally have little to no capacity or speed effect on low speed streets (speed limits under 35 mph).

Table 3. Lane Width Adjustment Factors for Urban Signalized Intersections.

Average Lane Width (feet)	Effect on Capacity
<10.0	4% reduction
≥10.0-12.9	0% (no change)
≥12.9	4% increase

(Adapted from Exhibit 18-13 of Reference 14)

Table 4. Effects of Narrow Lanes on High Speed Roadway Free-Flow Speed and Capacity.

Lane Width (ft)	Reduction in free-flow speed (mi/h)	Change in Capacity
>= 12 ft	0.0	0% (no change)
>=11 – 12 ft	1.9	2% reduction
>=10-11 ft	6.6	7% reduction

(Adapted from Exhibit 14-18 of Reference 14)

As indicated by the HCM 2010 adjustment factors in **Table 3**, the reduction of lane widths below 10 feet is associated with a reduction in capacity of four percent at signalized intersections on urban streets. Wide lanes, over 12.9 feet, are associated with the opposite effect, an increase in capacity of four percent. There may also be speed effects with exceptionally wide lanes (greater than 12.9 feet), but these effects are not documented for low- to moderate-speed streets.

Lane widths in the 10 to 12 foot range have not been identified in the 2010 HCM as a significant factor influencing traffic speeds in between intersections (for signal controlled streets with free-flow speeds in the 25 mph to 45 mph range).

Moderate to High Speed Streets. Narrow lanes can reduce both the free-flow speed and the capacity of higher speed roads (those with free-flow speeds of 45 mph or higher, and with signals more than two miles apart) (see **Table 4**).

Narrow lanes can reduce the free-flow speed of high speed roads by two to seven mph. A reduction of five mph in the free-flow speed can reduce the capacity of a high-speed highway by about five percent (source: page 14-4, 2010 HCM. Reducing the free-flow speed from 50 to 45 mph reduces the capacity from 2,000 passenger cars per hour per lane to 1900.).

LANE WIDTHS – SAFETY

The Highway Safety Manual (HSM) safety performance functions for urban and suburban arterials are not sensitive to lane width. The available research at this time on the effects of narrow lanes on crashes on urban streets is mixed. In some cases, narrow lanes appear to exhibit reduced crash rates. In other cases, narrow lanes appear to increase crashes. In other cases, a particular width has lower crash rates than wider or narrower widths.

There is a National Cooperative Highway Research project currently investigating the effects of narrow lanes on safety and operations of urban and suburban streets (NCHRP 03-112, Operational and Safety Considerations in Making Lane Width Decisions on Urban and Suburban Arterials), which may bring more clarity to the mixed results of previous studies. Its estimated completion date is August 2017. The following paragraphs highlight the results of available research.

The Florida Department of Transportation (FDOT) conducted statistical analysis to evaluate the impacts of restriping multilane roadways to increase the outside lane width by "borrowing" width from inner lanes (Reference 16). The crash severity and frequency of the imbalanced lanes (i.e., asymmetrical) was assessed on four-lane roadways with either a flush, two-way left-turn lane (TWLTL) or a raised median.

The study did not differentiate between the width of the center TWLTL or raised median. The study identified two trends that were statistically significant, as follows:

> "Given a 24-foot lane width for inside and outside through lanes, restriping the outside through lane to provide 13-foot lane width and leaving the inside lane with 11-foot lane width would result in a slight reduction of crashes for four-lane sections with raised median."
>
> "...if an extra 0.5 foot is added to the outside asymmetric lane to make it 13.5 feet wide while keeping the inside lane at 11 feet, a decrease in crashes is found for four-lane sections with raised or two-way-left-turn-lane (TWLTL) medians." (Reference 16)

Potts et al. conducted research on the relationship between lane width and safety for roadway segments and intersection approaches on urban and suburban arterials as part of NCHRP Project 3-72: *Lane Widths, Channelized Right Turns, and Right-turn Deceleration Lanes in Urban and Suburban Areas*. (Reference 17) The research included data from various roadway and intersection types in Minnesota and Michigan ranging from two-lane, undivided to four-lane, divided roadways. They also considered how Average Annual Daily Traffic (AADT) and lane width together influence safety.

Several trends were observed in the data from Minnesota and Michigan, but inconsistencies exist between states. The researchers noted that "crash frequency in [Minnesota] was higher for 10-foot lanes than for 11- and 12-foot lanes on four-lane, undivided arterials," but the same was not true in Michigan. They also found that crash frequency in Michigan "was higher for 9-foot lanes than for 10-foot lanes on four-lane, divided arterials." The same was not true is Minnesota.

The researchers concluded that "...there was no indication of an increase in crash frequencies as lane width decreased for arterial roadway segments or arterial intersection approaches." They noted the inconsistencies between states related to four-lane undivided and divided arterials and that, in these cases, the inconsistencies should not infer "the use of narrower lanes must be avoided." But, rather the inconsistencies indicate that "narrower lanes [must] be used cautiously in these situations unless local experience indicates otherwise."

EFFECTS OF LANE RECONFIGURATIONS ON CAPACITY

It is possible to reduce the number of travel lanes on a street and have no effect on capacity. The effect depends on the balance between demand and capacity for the different turn and through lanes on the streets. A Highway Capacity Manual signalized intersection analysis should be conducted to determine the capacity effects of a design concept and the potential of various TSMO measures (like retiming the signal) to boost capacity.

EFFECTS OF COMPLETE STREETS ON RELIABILITY

There is no available data on the general effects of Complete Streets on motor vehicle travel-time reliability. The Sixth Edition of the Highway Capacity Manual (Reference 18) does provide a method and tool for estimating the change in reliability on a signalized street on a case-by-case basis. This tool is a recent development and adequate application experience using this tool has not yet been obtained to enable drawing any general conclusions on the reliability effects of Complete Street designs.

COMBINED EFFECTS OF COMPLETE STREETS ON SAFETY AND MOBILITY

Complete Streets employ a combination of design strategies to achieve their goals: reduced lanes, narrowed lanes, lower speeds, median buffers between opposing traffic flows, buffers between motorized and non-motorized users, among many other strategies. These individual strategies, when employed in combination, have synergistic effects greater than (or less than) the effects of each strategy alone.

This section consequently presents the results of research, before-after studies, and case studies of the combined safety and mobility effects of various Complete Streets and Road Diets[9] that have been implemented in practice.

9 A Road Diet is a design treatment that replaces one or more through traffic lanes with other street features designed to improve safety for all users of the street (such as two-way-left turn lanes and bike lanes).

Capacity Effects of Complete Streets Employing Road Diets

The FHWA summary report, "Evaluation of Lane Reduction 'Road Diet' Measures on Crashes" (Reference 19) noted that: "Under most annual average daily traffic (AADT) conditions tested, Road Diets appeared to have minimal effects on vehicle capacity because left-turning vehicles were moved into a common two-way left-turn lane (TWLTL). However, for Road Diets with AADTs above approximately 20,000 vehicles, there is an increased likelihood that traffic congestion will increase to the point of diverting traffic to alternative routes."

Safety Effects of Complete Streets Employing Road Diets

The same FHWA summary report, "Evaluation of Lane Reduction 'Road Diet' Measures on Crashes" (Reference 19), re-evaluated two prior studies of the safety effects of Road Diets that involved changing four-lane, undivided highways into two-lane highways with a median two-way, left-turn lane (TWLTL). One study evaluated 30 treatment sites and 51 reference sites in eight cities in California and Washington. The other study looked at 15 treatment sites and 15 reference sites in small towns in Iowa.

The report found significant differences in the safety effects observed in the two studies but noted that: "These differences may be a function of traffic volumes and characteristics of the urban environments where the Road Diets were implemented. The sites in Iowa ranged in AADT from 3,718 to 13,908 and were predominately on U.S. or State routes passing through small urban towns with an average population of 17,000. The sites in Washington and California ranged in AADT from 6,194 to 26,376 and were predominately on corridors in suburban environments that surrounded larger cities with an average population of 269,000. In addition, based on a separate study of one site in Iowa, there appeared to be a traffic calming effect that resulted in a 4–5 mi/h reduction in 85th percentile free-flow speed and a 30-percent reduction in the percentage of vehicles traveling more than 5 mi/h over the speed limit (i.e., vehicles traveling 35 mi/h or higher)."

The report concludes that a 47 percent reduction in crashes might be expected for Road Diets implemented in conditions similar to those of the Iowa sites. A lower 19 percent reduction in crashes might be expected for Road Diets implemented in conditions more similar to those of the Washington and California sites. If the proposed Road Diet treatment site does not match any of the Iowa, Washington or California site conditions, then an average 29% crash reduction might be expected.

FURTHER READING ON SAFETY AND MOBILITY EFFECTS

- 2010 Highway Capacity Manual, Transportation Research Board, 2010
- Highway Capacity Manual, 6th Edition, Transportation Research Board, 2016
- Highway Safety Manual, AASHTO, 2014
- FHWA, Road Diet Informational Guide, (FHWA-SA-14-028), 2014, http://safety.fhwa.dot.gov/road_diets/info_guide/ , Accessed January 13, 2016.
- Evaluation of Lane Reduction "Road Diet" Measures on Crashes" (FHWA-HRT-10-053, HRDS-06/06-10(1M)E)

Source: Kittelson & Associates, Inc.

Chapter 5 Case Studies

This chapter presents four case studies illustrating the application of Performance-Based Practical Design (PBPD) concepts to the development of Road Diets and Complete Street designs. The first three case studies illustrate the application of PBPD concepts for situations where the traffic volumes were low enough that few Transportation Systems Management Operations (TSMO) strategies were required for a successful result. The fourth case study reworks one of the first three cases, but at moderately higher traffic volumes. This fourth case study illustrates how TSMO strategies can make a Complete Street design feasible and cost-effective under slightly higher volume conditions that might have otherwise precluded its further consideration by the agency.

Additional Complete Street and Road Diet case studies (without the emphasis on PBPD and TSMO) can be found in the following documents:

- Road Diet Case Studies (FHWA-SA-15-052) describes two dozen case studies of Road Diets in the United States. Additional information about Road Diets can be found at the FHWA Office of Safety Road Diets website at http://safety.fhwa.dot.gov/road_diets.
- The Minnesota DOT research report, "Complete Streets from Policy to Project, The Planning and Implementation of Complete Streets at Multiple Scales," has an appendix with several Complete Street case studies. It can be found at: http://www.dot.state.mn.us/research/TS/2013/201330.pdf
- Additional case studies can be found at the following FHWA websites:
    - Livability Initiative http://www.fhwa.dot.gov/livability/case_studies
    - What is CSS? http://contextsensitivesolutions.org/content/topics/what_is_css/changing-society-communities/complete-streets/

CASE STUDY #1 – EDGEWATER DRIVE, ORLANDO, FLORIDA

A 1.5 mile long section of Edgewater Drive between Lakeview Street and W Par Street was examined for a Road Diet with the objective of bringing its design and operation into better conformity with the City's College Park Neighborhood Horizon Plan, which had been recently approved by the local neighborhood association and accepted by the Orlando City Council (References 20 and 21). In this case, the existing road already had narrow 10-foot wide lanes, so the use of 10-foot lanes in the Road Diet was not an issue.

Project Setting

The study section of Edgewater Drive extended 1.5 miles from Lakeview Street to W Par Street. There are 9 traffic signals on this stretch of Edgewater Drive. It carried approximately 20,000 ADT at the time of the study. The roadway serves as the College Park neighborhood's main street, while accommodating some through traffic.

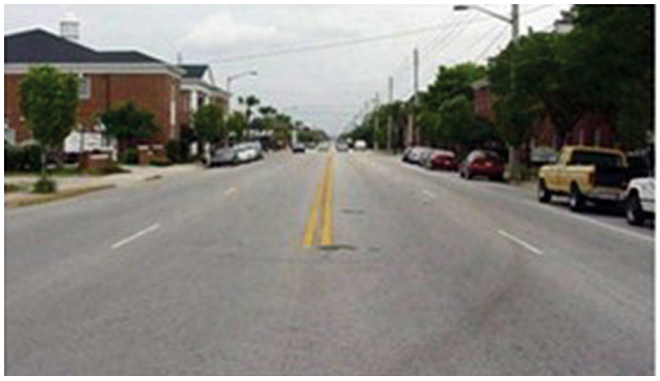
Performance-Based Practical Design

The four-lane configuration of Edgewater Drive with narrow lanes did not provide sufficient room for the wider sidewalks, bicycle lanes, streetscape and other neighborhood improvements called for in the recently adopted Neighborhood Horizon Plan. Preservation of existing curbside parking was a high priority for this stretch of Edgewater Drive due to the requirements of the existing land uses. A cost-effectiveness assessment of shifting the curbs one foot inwards to obtain wider sidewalks concluded that the costs exceeded the benefits to pedestrians of shifting the curbs. The design analysis determined that the most cost-effective Road Diet project would be to drop two travel lanes and use the cross-section gained for two bike lanes, a two-way, left-turn lane (TWLTL), and slightly wide parking lanes (see **Figure 11**).

Before and After Analysis

A before and after analysis of the Road Diet project concluded that:

- Traffic volumes dropped 12% on Edgewater Drive with the Road Diet.
- Traffic volumes on parallel and other neighborhood streets both increased and decreased (between -35% and + 31%). The average effect was a 4% decrease on all the parallel and other neighborhood streets studied.
- On-street parking utilization increased from 29% utilization to 41% utilization with the Road Diet.
- Pedestrian and bicycle volumes increased by 6% to 25% on Edgewater Drive. Bicycle and pedestrian volumes crossing Edgewater Drive (East-West) increased by 50% to 60%.
- The proportion of traffic traveling at over 35 mph on Edgewater Drive, which had been 10% on the middle section of the project, decreased to 9% with the Road Diet. The decreases in high speed traffic were greater at the northern and southern ends of the project.
- Crash rates (per million vehicle miles) were reduced 34%, injury rates were reduced 68% with the Road Diet.



Road Before

Road After

Figure 11. Photos. Edgewater Drive, Orlando – Before and After Road Diet Complete Street Design.
(Source: Reference 22)

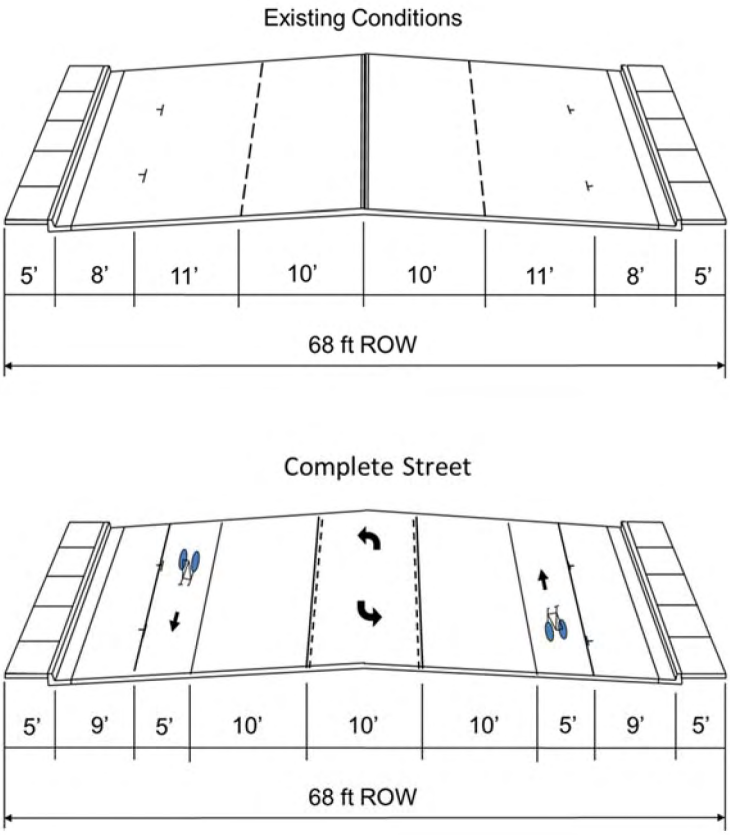


Figure 12. Diagrams. Edgewater Drive Road Diet Configuration

CASE STUDY #2 – CORDOVA STREET, PASADENA, CALIFORNIA

A half-mile long section of Cordova Street between Lake and Hill Avenues was examined for a Road Diet. The project objectives were to: lower speeds, improve pedestrian safety, install bicycle lanes and improve pavement conditions. A four-lane, undivided street with no parking was converted to a two-lane street with a two-way, left-turn lane, bike lanes, and on-street parking (see **Figure 13**).

Project Setting

Cordova Street is located in a multi-family and commercial area of the City of Pasadena. It carries approximately 11,000 vehicles a day. The project section is one-half mile long.

Performance-Based Practical Design

The City's objectives for the Road Diet project were to: install bicycle lanes (implementing the City's bicycle system objectives), lower traffic speeds, and improve pedestrian safety.

The preservation of on-street parking was a high priority for the city given the needs of the adjacent land uses. Thus, on-street parking was retained in the Road Diet.

An early assessment determined that shifting the curb lines inward to increase the buffer space between motor vehicle traffic and pedestrians would greatly increase the costs and have marginal benefits to pedestrian safety. Consequently the curb lines were left in place.

The conversion of four through lanes to two lanes, a two-way, left-turn lane, and bike lanes was identified as a design solution that achieved the City's objective of installing bicycle lanes, while potentially improving pedestrian safety by potentially reducing auto speeds on the street.

The selected design reduces the number of through lanes from four to two, adds bicycle lanes and a two-way, left-turn lane (see **Figure 14**). The existing travel lane widths of 11 feet per lane were retained in the Road Diet. The two-way, left-turn became left-turn pockets at the intersections. The parking lanes are replaced with crosshatching within 40 feet of the intersection.

Before and After Analysis

The City of Pasadena found that the Cordova Street Road Diet (Reference 23):

- Improved bicycle level of the street without adversely affecting pedestrian and motor vehicle levels of service.
- Caused a slight reduction in total collisions and injuries.
- Reduced traffic speeds on the street.

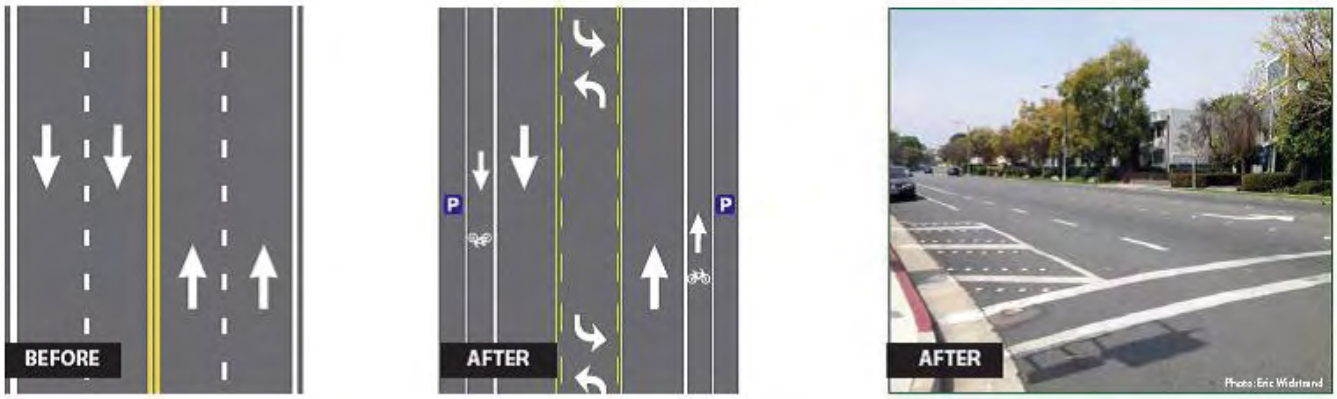


Figure 13. Diagrams. Cordova Street, Pasadena – Before and After Road Diet.
(Source: Reference 23)

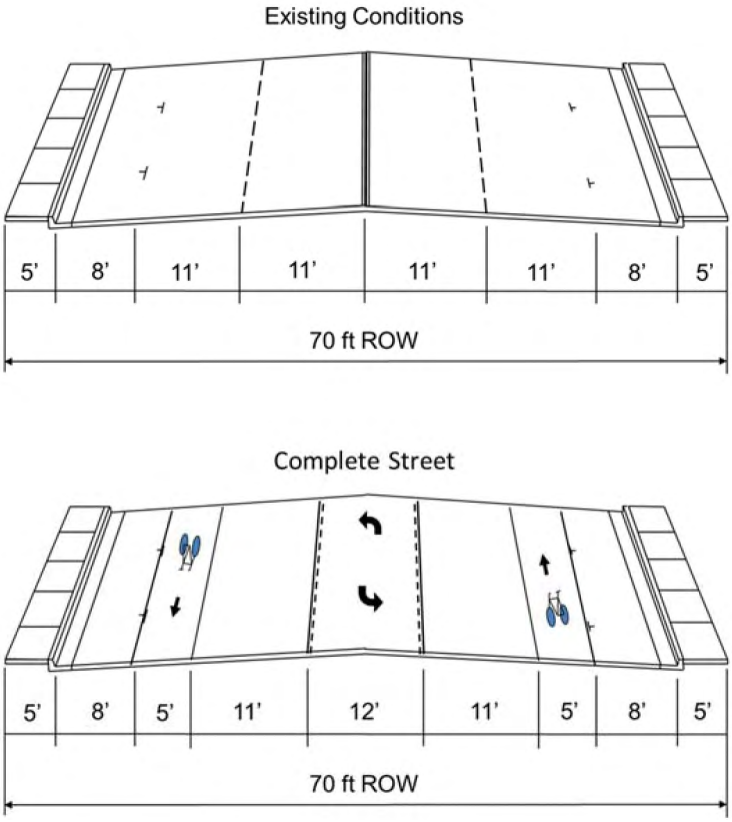


Figure 14. Diagrams. Cordova Street Road Diet Configuration
(Source: Reference 24)

CASE STUDY #3 – INGERSOLL AVENUE, DES MOINES, IOWA

A two-mile long section of Ingersoll Avenue between Polk Boulevard and Martin Luther King Parkway was examined for a Road Diet (see **Figure 15**). The City's objective was to reduce traffic speeds, improve pedestrian and bicycle access, and add landscaping.

Project Setting

The study section of Ingersoll Avenue extended two miles from Polk Blvd. to MLK Parkway. It carried between 11,000 and 17,000 vehicles a day at the time of the study.

Performance-Based Practical Design

The objectives of the Road Diet project were to reduce traffic speeds and increase safety for motorized and non-motorized modes on the street. The preservation of on-street parking was a high priority for the city given the needs of the adjacent land uses. Thus on-street parking was retained in the Road Diet. An early assessment determined that shifting the curb lines inward to increase the buffer space between motor vehicle traffic and pedestrians would greatly increase project costs and have marginal benefits to pedestrian safety. Consequently the curb lines were left in place.

The conversion of four through lanes to two lanes, a two-way, left-turn lane, and bike lanes was identified as a design solution that achieved the City's objective of installing bicycle lanes, while improving overall safety for the street. The selected design reduces the number of through lanes from four to two, adds bicycle lanes and a two-way, left-turn lane (see **Figure 15**). The two-way, left-turn lane became a left-turn pocket at the intersections. The parking lanes were replaced with right-turn lanes at the intersections.

Before and After Analysis

A simple before and after assessment of the Road Diet project found (Reference 23):

- A 30-percent reduction in crashes. (Reference 10)
- A five-percent increase in lunch period traffic.

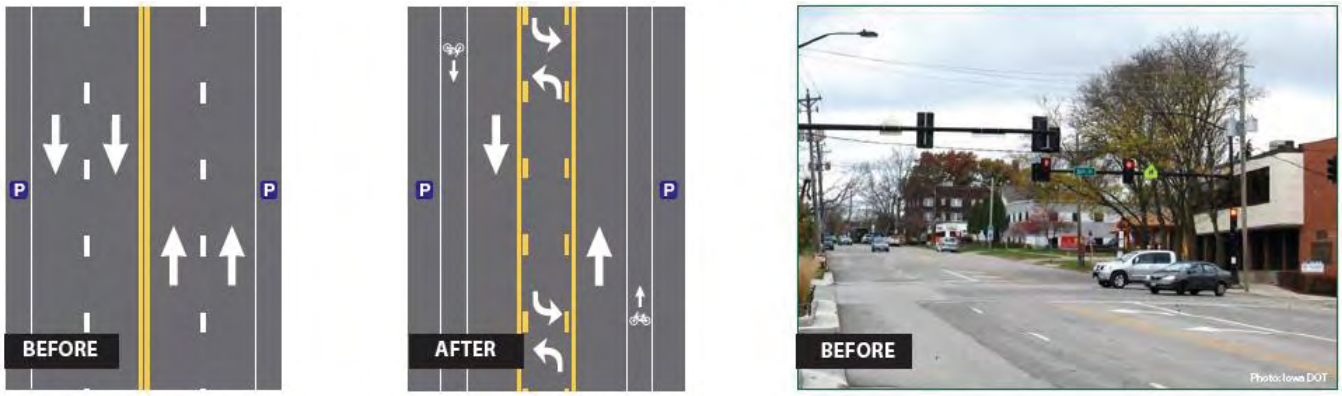


Figure 15. Diagrams. Ingersoll Avenue, Des Moines – Before and After Road Diet.
(Source: Reference 23)

CASE STUDY #4 – EMPLOYING TSMO TO EXPAND APPLICATION OF COMPLETE STREETS

The three case studies already described did not require the application of significant TSMO strategies to enhance the feasibility of their Complete Street designs. The traffic volumes and speeds were low enough that the design objectives could be achieved without employing significant TSMO measures.
To demonstrate how TSMO might support a Complete Street design, Case Study #3, Ingersoll Avenue, in Des Moines, Iowa, will be re-worked to assume a starting condition with moderately higher traffic volumes and speeds.

Traffic Operations Analysis

In this hypothetical extension of the Ingersoll Avenue example, the volumes are high enough that the agency needed to perform a traffic operations analysis to identify which TSMO measures might need to be employed to ensure that the Complete Street design would not sacrifice the agency's mobility goals for the street. A number of tools could be used to evaluate traffic operations of the modified street, but the Highway Capacity Manual (HCM) is most common. The methodology of this peer-reviewed publication is the underlying methodology of many deterministic software tools. An HCM analysis could be performed at each signalized intersection and other critical unsignalized intersections and major driveways under the modified street condition, following the procedures as described in the relevant chapters of that reference. HCM analysis uses peak-hour turning movements at each intersection and driveway to be evaluated. Existing signal-timing parameters would be another useful input; however, HCM supplied default values could be employed for the preliminary engineering analysis. The agency can later use the HCM analysis to determine the desired field settings for the signals when the Complete Street design is in place.

Identification of Operations Problems, Development of TSMO Solutions

If the HCM analysis determines that one or more intersection (or major driveway) movements might have operational problems (defined as LOS "F" delay, or excessive queues interfering with traffic, transit, bike, and pedestrian operations and safety on the street), then various TSMO solutions might be considered to support the Complete Street design.

- For through traffic operational problems, the signal timing might be examined and optimized to reduce delays and queuing. Signals might be coordinated to reduce through traffic queuing.

- For turn movement traffic operational problems, various TSMO mitigations might be considered.

    - Optimize the signal timing to reduce turn pocket queue overflows.
    - Consider removing curb parking on the approach to the intersection to provide an extra turn lane.
    - Consider implementing Active Transportation and Demand Management (ATDM) features, like dynamic turn lanes, where left or right turns are allowed from the through lane as well as from the dedicated turn lane. This requires special signing, and signal control software to implement. There must be sufficient receiving lanes in the cross street for this option.

- If traffic operations problems threaten expeditious transit service on the street, the signal timing might be examined and optimized. A transit signal priority (TSP) system might be implemented. More-sophisticated versions of TSP may include transit vehicle identification and detection systems.

- If high traffic speeds are a concern for the Complete Street design, then the signal coordination might be re-examined to develop timing plans that favor lower through speeds.

Source: Kittelson & Associates, Inc.

Chapter 6 Summary and Conclusions

This primer has highlighted how Performance-Based Practical Design (PBPD) supported by Transportation System Management and Operations (TSMO) strategies can advance Complete Street projects. It points out several references on design concepts for Complete Streets and methods for assessing the mobility and safety tradeoffs of different Complete Street design options.

PBPD considerations resulted in significant efficiencies for the Complete Street projects by ruling out early on design options that involved expensive shifting of curbs and gutters to achieve minor improvements in the achievements of the pedestrian safety objectives of the Complete Streets. Complete Streets preserved the existing curb lines and were able to achieve the majority of their safety and mobility objectives. Although not explicitly addressed in the primer, success with Complete Streets and Road Diets is also affected by institutional considerations and policy considerations.

The following guides should be consulted for more information on these considerations and how TSMO strategies can support those policies:

- FHWA, "Road Diet Informational Guide"
- FHWA, "Incorporating On-Road Bicycle Networks into Resurfacing Projects"
- FHWA, "Separated Bike Lane Planning and Design Guide"
- The NACTO "Urban Street Design Guide"
- FHWA Guide: "The Role of Transportation Systems Management & Operations in Supporting Livability and Sustainability: A Primer on Livability and Sustainability Considerations"

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