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NATIONAL
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SYNTHESIS 293

Reducing and Mitigating Impacts of Lane Occupancy During Construction and Maintenance

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

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Reducing and Mitigating Impacts of Lane Occupancy During Construction and Maintenance

A Synthesis of Highway Practice

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SUBJECT AREAS
Planning and Administration, Materials and Construction, and Maintenance

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communication and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association *of* State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis report will be of interest to programming and planning, design, contract, construction, and maintenance engineers, and others interested in reducing and mitigating the impacts of lane occupancy during construction and maintenance activities. It describes the current state of the practice for reducing and mitigating the impacts of lane occupancy during construction and maintenance. Information for the synthesis was collected by surveying U.S. and Canadian transportation agencies and by conducting a literature search to gather additional information.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board provides information on programming and planning, design, contract, construction, and maintenance techniques, methods, and processes used to reduce lane occupancy during construction and maintenance activities. Information on their relative impact and the type of facilities they are used for is included. In addition, information on the measures transportation agencies use to evaluate the effectiveness of the various techniques, methods, and processes is also included.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the available information was assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the author's research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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REDUCING AND MITIGATING IMPACTS OF LANE OCCUPANCY DURING CONSTRUCTION AND MAINTENANCE

SUMMARY

The safe and efficient flow of traffic approaching and traveling through construction and maintenance work zones is a major concern. The traveling public is demanding nearly unlimited mobility; with less tolerance for delays, especially those caused by construction and maintenance operations. These delays often have a negative impact on public attitudes toward transportation agencies. In addition, delays caused by work zone operations may affect commerce, both in terms of transportation time and access to and from businesses.

A major problem facing most transportation agencies is how to reduce lane occupancy and mitigate its impact on road users during construction and maintenance operations. A literature review was conducted and a survey questionnaire was distributed to transportation agencies in the United States and Canada in order to identify current techniques, methods, and processes used to address this problem. Forty-four agencies responded. The phases of a project in which these techniques are implemented include programming, planning, design, contracting, and construction, as well as maintenance.

Achieving the objective of reducing lane occupancy begins in the programming and planning phase of project development. A key focus involves developing a project-specific traffic management plan and identifying those policy decisions that effect this plan. Concerns vital to developing this plan include evaluating regional and system issues and performing an economic analysis that incorporates construction costs related to traffic management/control strategies, as well as road user costs. Each of these costs increases rapidly for facilities that have high traffic volumes.

The safety of the traveling public and that of workers within work zones is guided by policy directives aimed at proactive efforts to prevent accidents. Developing traffic management plans that involve the public is critical, and policies that focus on public perceptions are often formulated to ensure this involvement. Moreover, the breadth of this plan is a function of the project type. Reconstruction of high-volume facilities often requires a corridor approach, which may require consideration of different management strategies, techniques, and initiatives that exist beyond the subject improvement project. Projects involving lower traffic volumes focus directly on how to reduce the impacts of lane closures without much concern for traffic diversions to other roadways or consideration of other traffic mitigation strategies.

The overall project plan may include actions to proceed with the traffic management plan as a basis for design, contracting, and construction. Maintenance requirements for a facility can also be considered during early project phases. When planning a project, consideration can be given to pavement or bridge design and material options that could accelerate construction, reduce periodic maintenance, and provide means for accelerating future

maintenance and/or replacement activities. In plans and specification development, there are many design features that could incorporate maintenance considerations.

In design, two techniques associated with developing project phasing and traffic control plans (TCPs) are the use of off-peak hours and detouring. Both techniques have a significant impact on reducing lane occupancy and, in particular, mitigating the impact of lane occupancy on road users. Innovative contracting methods could complement the TCP. Contract methods such as lane rental, cost-plus-time bidding, and the use of incentives and disincentives, may reduce contractor time in work zones.

During the preparation of TCPs constructibility reviews are considered an important practice to achieve the objective of reducing lane occupancy. Particularly noteworthy is the scheduling of major construction activities while analyzing maintenance of traffic and project phasing approaches from a construction perspective. Such integration of traffic and phasing approaches could result in TCPs that help mitigate the impact of lane occupancy. Design features are often changed through constructibility reviews to promote TCPs that are more efficient and timely. These changes may require the use of different materials, such as high early strength concrete. This material, often referred to as fast-track concrete, can help minimize lane occupancy for concrete pavement projects by reducing the time needed, after construction, for opening the work zone to traffic.

Movable barriers are an effective means of setting up a temporary work zone and moving the work zone as construction is completed or as traffic demands require. The movable barrier can help maximize the space available within the work zone and provide a safe working environment. Motorist safety is improved as well by the clear boundary established between the work zone and traffic.

Specifying prefabricated facility components is another approach that can be used to reduce lane occupancy. Prefabricated bridge components, such as beams and deck panels, are used to accelerate reconstruction of bridges and interchanges. In addition, temporary bridges are frequently used to allow for the complete closure of traffic in one direction over an existing bridge while it is being repaired or replaced.

Many transportation agencies are employing a variety of alternate contracting methods to accelerate construction and reduce the time contractors occupy work zones. One method, lane rental, focuses specifically on lane closures. Although this method is used less frequently than other methods, in the right situation, lane rental can have a significant impact on reducing lane occupancy. Cost-plus-time (A+B) contract bidding generally reduces the total time of construction, but may not substantially reduce lane occupancy during the construction period. To implement this method, many contractors work off-peak hours, nights, and weekends to complete construction within the time bid. This reduces the impact on the traveling public, a basic goal of reducing lane occupancy.

Several newer contracting practices have the potential to reduce time in work zones. Cost-plus-time bidding can be used in conjunction with requesting the contractor to prepare final TCPs. Costs for traffic control are bid lump sum based on the contractor's TCP and staging of construction. Best-value contracting, where both technical/management capability and price are evaluated, offers a potential for ensuring timely completion of very complex projects. Concepts to accelerate construction time can be included in the technical and management evaluation. Design-build contracting is an alternate contracting method of increasing interest to state agencies. If agencies incorporate objectives related to reducing lane occupancy in design-build projects, the design-build contractor can propose designs that reduce lane occupancy and reduce road user costs.

Before commencing construction, and continuing during construction, both partnering and value engineering can offer an agency the opportunity to evaluate issues that impact lane occupancy with input from the contractor. Phasing, staging, and scheduling are areas where changes can be recommended by the contractor to accelerate construction time in work zones. Planning is critical for ensuring that techniques incorporated into contract documents or proposed by the contractor are effective in reducing lane occupancy.

Minimizing time in work zones during maintenance operations also is critical to both the agency and road users. Most techniques focus on time restrictions, such as working off-peak hours during the week, at night, or on weekends. Other techniques consider traffic management and control of lanes. Detours and individual lane closures are more suitable for some maintenance operations, such as replacing pavement markings or restriping. Rapid setting materials for patching and mobile equipment such as an automatic cone placing and retrieval machine help to accelerate maintenance operations and, in the latter case, protect both the worker and the motorist.

The techniques, methods, and processes identified in current practice can be applied to almost any facility and project type. A greater opportunity to reduce lane occupancy however may occur on reconstruction projects for facilities in urban settings, such as freeways, interchanges, and intersections. Reconstruction projects in rural settings, such as roadway widening and realignment, may also benefit substantially from the application of these techniques. Certain techniques may be best suited for some very specific facility and project types. It is important to match the application of techniques to reduce lane occupancy to fit specific facility and project characteristics.

Agencies may want to consider the broad spectrum of techniques that could be implemented during the various phases of the development of transportation projects. If a project objective is to reduce lane occupancy and the project is complex, then many of the techniques can be applied on a single project. Alternatively, if a project is less complex, and perhaps not in an urban setting, fewer techniques may be implemented. These decisions are typically made during the programming and planning phases or early in the design phase of a project, and are designed to promote practices that effectively reduce lane occupancy and its impact on the traveling public.

CHAPTER ONE

INTRODUCTION

BACKGROUND

The safe and efficient flow of traffic approaching and traveling through work zones is a major concern to highway users and those involved in maintaining and improving roadways. More frequently, the traveling public is demanding increased mobility, while displaying less tolerance for delays, increased travel time, and inconvenience because of congestion, especially congestion caused by highway facility construction and maintenance operations.

Construction and maintenance operations inevitably require work forces to occupy the roadway. There is a need to provide for sufficient space to perform construction and maintenance operations, while reducing the impact of these operations on the traveling public. This is an important issue, because both motorist safety and the safety of the work force are affected. Moreover, motorists are delayed when they are not able to travel at normal speeds through work zones. While these delays often have a negative impact on safety and public attitudes toward transportation agencies, delays caused by work zone operations also may impact commerce, both in terms of transportation time and access to and from businesses.

State transportation agencies are now performing less new construction and more rehabilitation and/or reconstruction of highway facilities. Because more dollars have been allocated for this work through the Transportation Equity Act for the 21st Century, an increase in construction and maintenance work will occur and, correspondingly, the number of work zones will sharply increase. Given this general scenario, one problem all transportation agencies face is how to reduce lane occupancy and mitigate the often undesirable impacts of lane occupancy during construction and maintenance operations. This is a problem that should be considered at all levels of program and project development of highway transportation facilities and when planning and executing maintenance operations for these facilities. Many and varied techniques, methods, and processes are currently being used in practice to address this problem.

OBJECTIVES

The objectives of this synthesis study were fourfold:

- To identify programming/planning, design, contractual, construction, and maintenance techniques, methods, and processes employed to reduce lane occupancy;
- To assess the relative impact of these techniques, methods, and processes on reducing lane occupancy and mitigating its impact;
- To assess the types of facilities and projects that are best suited for the application of techniques, methods, and processes to reduce lane occupancy; and
- To identify methods currently employed to measure and evaluate the effectiveness of these techniques, methods, and processes in reducing lane occupancy and mitigating the impact of lane occupancy.

APPROACH AND METHODOLOGY

The scope of the synthesis is broad and, as indicated in the first objective, covers work performed in all phases of the life cycle of a facility. Moreover, an estimation of the relative impact of the techniques, methods, and processes on reducing lane occupancy is presented. Knowledge of facility and project types where the techniques are used is also considered. The broad scope and factors addressed in this synthesis influenced the methodology for locating, gathering, and assembling information and data.

A framework was established for categorizing information and data collection. This framework covers the following areas:

- Programming and planning,
- Design,
- Contracting,
- Construction, and
- Maintenance.

Within each area, specific issues and techniques that would influence lane occupancy were identified. At the programming and planning level, information was gathered, for example, on policy formulation and travel management planning provisions to support traffic management and traffic control. For design, information was sought regarding project phasing, traffic control, construction sequencing, constructibility, materials, construction equipment, and prefabrication. Similarly, for contracting the focus was on cost-plus-time bidding, lane rental, and incentives and disincentives. Other contracting techniques were also reviewed. The construction level covered partnering, value engineering clauses, construction methods, and testing methods; however, the literature search and survey were not confined to only these specific issues. Techniques used to reduce lane occupancy during maintenance were discussed initially from the context of planning/programming and design. This discussion was developed in terms of how decisions made in these areas influence the level of maintenance of a facility after it is opened to traffic.

Based on this framework, two main sources of information were used to develop the synthesis materials:

1. A review of the literature pertaining to all five areas of the framework was undertaken with a specific focus on the concept of reducing lane occupancy during construction and maintenance.

2. A survey questionnaire that focused on techniques to reduce lane occupancy was sent to all U.S. Departments of Transportation (DOTs) and selected transportation agencies in Canada.

Literature Review

A review of the literature and ongoing research relative to the techniques, methods, and processes necessary to reduce lane occupancy was conducted. One primary source was the Transportation Research Information Services (TRIS). Other databases were also explored, including Internet web sites. When possible, related research currently being conducted through other transportation agencies was reviewed. A limited number of contacts were made with consultants and other groups, such as the AASHTO Highway Subcommittee on Construction, to obtain input on lane occupancy reduction methods.

Because of the broad categories covered by this synthesis, it was necessary to carefully screen literature references to extract only information that pertained to reducing lane occupancy and mitigating the impacts of lane occupancy. Several of the more frequently cited references could be of additional value to the reader (e.g., Graham and Migletz 1994; *Meeting the Customer's Needs...* 1998; FHWA Quality Journey web site 1999; Saag 1999). Some interpretation was required in making the assessment of what literature to include because, in part, many techniques, methods, and processes *indirectly* lead to reduction of lane occupancy.

Survey

A survey was designed to identify the techniques, methods, and processes used by transportation agencies to reduce lane occupancy during both construction and maintenance. The format and questions were based on the data collection framework. The survey included five stand-alone sections, each corresponding to an area of the framework. Each section was designed to enable individuals from different divisions or groups within a transportation agency to complete the sections corresponding to their area of expertise. This format was designed to facilitate completion of the survey because it covers many disciplines and reduces the time that any one individual would need to complete it. A copy of the survey questionnaire is presented in Appendix A.

The questionnaire explained the purpose of the synthesis, and background information presented the objectives of the questionnaire, instructions on its distribution, and several key definitions. For the purposes of this synthesis the following definitions are provided:

Maintenance—Periodic activities whose primary function is to preserve existing pavements or bridges so that they may achieve their applied loading and design life (sometimes called normal, routine, minor rehabilitation, and/or preventive maintenance).

Construction—Includes activities whose primary purpose is to significantly extend the service life of an existing pavement or bridge, such as resurfacing, restoration, rehabilitation, replacement, and/or reconstruction. New construction may add capacity.

Because techniques that reduce and mitigate the impacts of lane occupancy could potentially be applied during both construction and maintenance, respondents were asked to identify whether or not a technique used for construction could also be used for maintenance.

Lane occupancy reduction techniques used by transportation agencies may have different levels of impact. To obtain information on the relative impact of these techniques, respondents were asked to assess the *Level of Impact* using the following three-category scale:

- *High (H)*—Technique leads to a substantial reduction in lane occupancy.
- *Medium (M)*—Technique leads to a moderate reduction in lane occupancy.
- *Low (L)*—Technique leads to a minimal or no reduction in lane occupancy.

In each section of the questionnaire, agencies were also asked to identify techniques, methods, and processes for reducing lane occupancy not necessarily addressed under those issues associated with each area of the synthesis framework. This was an important feature of the questionnaire, because it provided a means of capturing techniques that might otherwise be overlooked.

Facility and Project Applicability

One factor of interest in the study was to identify which facility and project types would align with which techniques to reduce lane occupancy during construction. This information was captured in a general way through one specific question in each section of the questionnaire, in which agency personnel were asked to identify the facility and project types that were best suited for the techniques identified. Trends emerged based on the frequency that different facility and project types were cited in the context of a category of techniques identified by participants in the survey.

For the purpose of this synthesis, facility types for pavements and elevated structures could include but are not limited to urban freeways and interchanges, depressed freeways, rural freeways and highways on new alignment, rural bridges, urban bridges, intersections, and city streets. Project types for pavements could include resurfacing, restoration, reconstruction, and new construction. Types of projects for elevated structures might include minor rehabilitation (overlay), major rehabilitation (deck improvement or widening), and/or complete replacement.

Agency personnel were also asked to list the maintenance activities that were best suited for applying a technique to reduce lane occupancy during maintenance operations. Trends emerged based on the frequency that maintenance activities were cited in the context of a specific technique.

Effectiveness

The questionnaire attempted to gather information on agency practices relevant to evaluating the effectiveness of techniques, methods, and processes used to reduce lane occupancy during construction and maintenance. This was accomplished by asking participants if their agency had a process to assess the effectiveness of the techniques cited and how the agency measures effectiveness of these techniques. Survey participants were also queried as to how their agency determines if a measure of effectiveness that was identified for a technique was achieved in practice. The intent of this series of questions was to assess how well the techniques either reduce and/or mitigate the impact of lane occupancy. A definition of effectiveness was not provided in the questionnaire background information.

Survey Response

The survey questionnaire was distributed to all state DOTs, Puerto Rico, the District of Columbia, and to 13 transportation agencies in Canada. A total of 44 responses, 38 from U.S. and 6 from Canadian transportation agencies, were received. Of the 44 questionnaires returned, 30 agencies completed all 5 sections. The remaining 14 agencies completed 1 or more, but not all 5 sections. The results of this questionnaire are summarized and discussed under each area of the study framework.

ORGANIZATION

The remainder of the synthesis is organized in the following sequence. Chapter 2 provides a brief discussion of global or agency-wide issues with respect to lane occupancy that would be addressed during the programming and planning phase of a transportation project. Chapters 3 through 6 provide an overview of current techniques to reduce lane occupancy used during design, contracting, construction, and maintenance, respectively. This overview is based on the literature, current research, and agency practice as derived from the questionnaire. Application of these techniques to different types of facilities and projects is also presented. Chapter 7 briefly discusses the integration of techniques across all phases of transportation project development. A summary of major conclusions is provided in chapter 8. The same technique is often cited in more than one chapter. In this case, the technique is discussed from different perspectives and applications consistent with the subject of the chapter.

PROGRAMMING AND PLANNING ISSUES

The five-area framework identified in chapter 1 served as a basis for accumulating relevant information on reducing lane occupancy. This framework is closely aligned with the development process for a highway facility. Techniques used to reduce and mitigate the impacts of lane occupancy could be applied during different phases of project development and execution.

The transportation development process is shown in Figure 1 (Saag 1999). This process is comprised of three main areas:

- Regional and system programming,
- Project development and execution (planning, development and mitigation, right-of-way, design, and construction), and
- Operation (maintenance, etc.).

The first area has a regional and system focus that encompasses both general programming requirements and multimodal and travel management issues for an agency over a broad geographical location. The work performed in this area sets a basis for the development of individual projects for transportation facilities.

The development process for a project commences with planning activities, as shown in Figure 1. Performing these activities effectively is critical to achieving project success. Decisions made at this stage will influence the selection of design and construction features and the impact design and construction results will have on facility maintenance. If program and individual project strategies are derived in part by the objective of reducing lane occupancy, then policy decisions and project strategies established during programming and planning would influence the selection of techniques employed on the project.

At this stage in the transportation development process the most critical area of focus, in the context of reducing lane occupancy, is traffic management planning and the policy-related decisions needed to enforce it. This would encompass a variety of issues including economic impacts, safety considerations, public perceptions, and traffic-handling strategies, as related to traffic moving through work zones. Proper evaluation of these issues can provide a strategy for reducing motorist delays and accidents in work zones *(Meeting the Customers Needs...* 1998). Finally, in the planning phase, project decision makers should evaluate the types of practices that could be used on the project to reduce lane occupancy and/or mitigate the adverse effects of lane occupancy on road users. These practices and their associated techniques would be implemented during the different phases of project development and execution.

REGIONAL AND SYSTEM ISSUES

Multimodal Considerations

Ideally, efforts to mitigate the impacts of construction and maintenance operations should begin even before the decision to construct or reconstruct a facility has been made. Proper consideration of how a facility fits into the system-wide transportation "big picture" for the region can greatly increase the useful life of the facility and minimize the need for future expansion or reconstruction.

It is important to recognize that an area's transportation system consists of a network of highways and streets, transit services, nonmotorized modes of transportation, and access linkages to intermodal terminals *(Toolbox for Alleviating Traffic Congestion* 1997). Consideration of the various modes and supporting components of those modes is a key step in the initial planning considerations for facility work. These modes and components can include the expansion, upgrading, or initiation of the following *(Toolbox for Alleviating Traffic Congestion* 1997):

- General use lanes,
- Exclusive lanes (high-occupancy lanes, bus lanes),
- Public transit (light or heavy rail),
- Park-and-ride access points,
- Transit-oriented development in the area, and
- Bike and pedestrian facilities.

In addition, this phase of planning should include travel demand management considerations, which will support the associated multimodal infrastructure that is being considered for implementation.

Interagency Coordination

Another key approach to mitigating the impacts of maintenance and construction operations on lane occupancy is through improved interagency coordination and cooperation between various projects and maintenance efforts in a

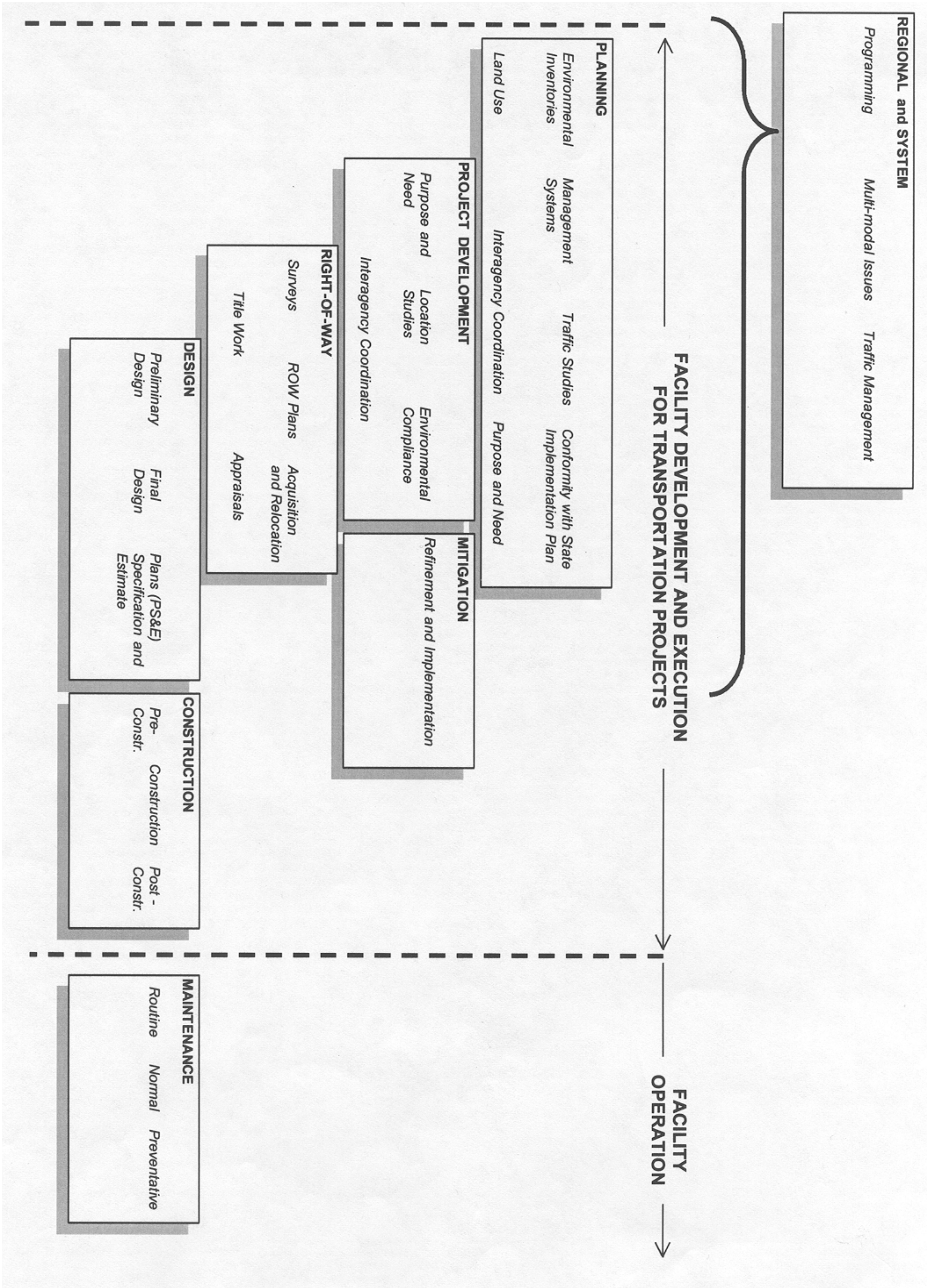

Figure 1 Development process for a transportation facility (adapted from Saag 1999).

corridor *(Meeting the Customers Needs...* 1998). It is known that many motorists will change travel routes to avoid construction delays. However, if the roadway chosen as the alternative is also undergoing construction, the impact of diverted traffic can be significantly worsened. Careful scheduling of various projects between agencies can help reduce the occurrence of multiple work zones within the corridor and, thus, minimize motorist delay.

Interagency coordination can also be beneficial where multiple tasks need to be accomplished (e.g., roadside maintenance, utility work, and restriping). Several states have begun using a "maintenance gang" approach, where multiple activities are performed when a travel lane is closed. This approach eliminates the need to close a lane for each maintenance activity. Proper coordination can also help reduce wasted effort often caused when one activity is performed by a work crew, only to have another crew tear up the results of the earlier effort (this can happen easily with utility work). This approach, involving multiple activity coordination, can work for construction projects as well.

Traffic Management Considerations

Traffic management considerations have become increasingly important in recent years. A national emphasis has been placed on establishing and using intelligent transportation system technologies and strategies to better anticipate and respond to the dynamic nature of travel demands.

Many intelligent transportation system technologies that can be implemented in a roadway corridor have infrastructure needs that are best addressed early in the planning process. These technologies include *(Freeway Management Handbook* 1997):

- Traffic surveillance capabilities (including closed-circuit television, inductive loop, radar, microwave, or other vehicle detectors);
- Ramp metering on controlled-access facilities;
- Improved traffic signal operations on nonaccessed control facilities or on connectors with controlled-access facilities;
- Incident management programs and techniques (including service patrols, coordinated enforcement activities, improved response and clearance capabilities, etc.); and
- Traveler information systems (including variable message signs and highway advisory radio systems deployed on the roadways, kiosks and computer terminals accessed away from the roadway, and in-vehicle information systems).

The requirements placed by these technologies on the facility infrastructure (i.e., communication needs, supports, etc.) can have a major benefit when making planning level decisions for the facility. In addition, the proper planning of these components early in the process may assist in identifying opportunities for implementation of the technologies within the facility and then using them to better manage traffic throughout the remainder of the construction process.

The Route 22 reconstruction project in Pennsylvania offers an excellent illustration of the use of many of these components *(Work Zones Getting Smarter* 1999). On this 4-lane freeway that serves Allentown and Bethlehem, a real-time traffic control and motorist advisory system was used to create a smart work zone that included:

- Traffic queue detectors to monitor traffic along the corridor,
- A computer program that anticipates traffic flow conditions when delays are detected,
- A highway advisory radio frequency for messages on traffic conditions,
- A radio communication system to a traffic control center computer to relay messages,
- Changeable message signs to alert motorists to delays, and
- A temporary ramp metering system on ramp entrances.

ECONOMIC IMPACTS

Construction Related Costs

Traditionally, only work zone traffic control costs have been considered in life-cycle cost or other analysis procedures (Abrams and Wang 1981; Walls and Smith 1998). However, when a project strategy requires long-term lane closures, and especially under high-traffic-volume conditions, accommodating traffic that is diverted from the roadway because of these closures becomes a major operational and jurisdictional concern (Krammes et al. 1989).

Traffic control costs at the work zone are dictated by the fundamental principles and requirements cited in Part VI of the *Manual on Uniform Traffic Control Devices* (1988). Several state highway agencies have expanded these requirements and adopted their own versions of this manual.

Work zone traffic control requirements and costs can vary *(Manual on Uniform Traffic Control Devices* 1988). Costs for a given traffic control set-up at a work zone include those for individual traffic control devices (TCDs) used, whether owned or rented, as well as labor costs required to install, operate (such as by flagging), and eventually remove the TCDs. Situations that involve setting up

TABLE 1

OFF-SITE TRAFFIC MANAGEMENT ACTIONS IMPLEMENTED DURING PAST FREEWAY RECONSTRUCTION PROJECTS

Types of Actions	Actions Implemented
Actions to Improve Alternative Route Use	Traffic signal timing adjustments Traffic signal equipment improvements Left-turn restrictions at critical intersections Parking restrictions Police control of critical locations Reversible lanes Alternating, one-way street pairs Intersection widening and channelization Resurfacing and other pavement repairs Signing and lighting improvements Public notification and information
Actions to Improve HOV Use	New or expanded commuter rail service Expanded rapid transit service New or expanded bus service New HOV-only ramps and lanes New or expanded park-and-ride lots New or expanded ridesharing programs

Source: Ullman et al. 1989; Dudek and Ullman 1992.
Note: HOV = high-occupancy vehicle.

and taking down the work zone each day or night will have greater traffic control costs than for a set-up that remains in place for the duration of a project. However, these higher traffic control costs may be more than offset by reducing or eliminating long delays and queues, resulting in increased road user costs, during the peak traffic periods if lanes are closed.

In certain project situations, such as a high-volume freeway in an urban area, traffic management and control costs typically extend beyond the project limits onto other roadways and travel modes in the corridor. Beginning in 1986, the FHWA began allowing these types of actions to be included in, and paid for by, federal construction dollars ("The Flexibility Document" 1986). These costs are incurred to help mitigate the impacts on travelers displaced by reconstruction activities. Table 1 summarizes several types of impact mitigation actions that have been implemented.

Previous experience suggests that on high-volume urban freeways, where traffic demands already exceeded roadway capacity and are causing recurrent congestion even before the start of construction, the number of travelers diverted to other routes and modes in the corridor will be approximately equal to the peak-period reduction in freeway capacity required by the reconstruction project (Krammes et al. 1990). This diversion to other routes will not occur immediately, however. Also, drivers appear to experiment with the different routes and departure times early in the project, resulting in widely varying conditions on a day-to-day basis. Eventually, however, travelers settle into their new patterns, some remaining on the freeway and others choosing to use other routes, departure times, and travel modes. As a result, delays and congestion are often only slightly greater, if experienced at all, on the freeway during construction, than they were prior to construction.

Implementation of these impact mitigation strategies on roadways and travel modes away from the construction project have been particularly critical to the successful completion of reconstruction projects. Such implementation efforts have offered the additional benefit of improved cooperation between state and local transportation agencies. These improvements continue to serve motorists and provide value to the local agencies even after the freeway reconstruction project is completed.

Road User Cost

Critical to an economic evaluation is the cost to the road user. The primary road user costs associated with work zone activity include vehicle operating, delay, and crash costs.

Vehicle Operating Costs

Generally speaking, most vehicle operating cost analyses can be traced back to data obtained and published in the late 1960s (Winfrey 1968). Although these costs can be updated to account for the effects of inflation, they do not reflect the dramatic improvements in vehicle fuel efficiency that auto manufacturers have achieved over this time. Similarly, these data do not reflect changes in truck weight, size, and tire type. Nevertheless, vehicle-operating costs tend to be quite small in comparison with motorist delay costs and, as a result, are generally not a major concern in user cost analysis.

Motorist Delay Costs

Motorist delay costs, specifically the selection of the unit value of time, are much more significant in the user cost analysis and so tend to be much more controversial. Based on several analysis approaches, recent FHWA research recommended the following unit values of time for motorist delay cost analyses (costs are per vehicle-hour) (Walls and Smith 1998):

Passenger cars	$10–13
Trucks	
Single unit	$17–20
Combinations	$21–24

These data are developed based on a number of factors and include more than the operator's hourly wage rate for a typical working day.

Crash Costs

It is generally accepted that the crash rate at a work zone location is somewhat higher than the crash rate at that same location when a work zone is not present *(Summary Report on Work Zone Accidents* 1987). However, the magnitude of this increase can vary widely (Ullman and Krammes 1991; Pal and Sinha 1996). It also appears that crashes in work zones tend to be more severe than they are when a work zone is not present. Unfortunately, it is difficult to identify and compare crash costs for alternative work zone traffic control configurations. Road projects that require a longer period of time to complete will most likely have higher work zone crash costs than those that require less time. In addition, daytime and nighttime work zone activities appear to have a different effect on crash costs. Specifically, the data suggest that, on a given roadway section, nighttime crash frequencies increase by a greater percentage than do daytime crash frequencies once a construction zone is installed *(Summary Report on Work Zone Accidents* 1987; Ullman and Krammes 1991).

SAFETY CONSIDERATIONS

Safety is a major concern for the traveling public, transportation agencies, and the highway maintenance and construction industry. Establishing work zones for construction and maintenance activities through lane closures poses inherent hazards for road users approaching and traveling through the work zone. This disruption of normal traveling practice can result in accidents both to motorists and to construction and maintenance workers. Although traffic volumes have risen considerably since 1980, the annual number of work zone fatalities has remained fairly constant *(Meeting the Customer's Needs* 1998). With more highway work shifting to maintaining, rehabilitating, or reconstructing existing facilities, and with the increasing level of funding, the number of work zones will likely increase. As a consequence, the potential for a greater number of accidents and subsequent fatalities related to work zones is likely to increase *(Meeting the Customer's Needs* 1998). Thus, safety during construction and maintenance operations can be centered on traffic management principles using appropriate safety strategies devised during project planning and implemented as the project develops.

The Utah DOT has adopted a public campaign and outreach initiative, "Work Zone Accident Reduction/Prevention Project," to help prevent work zone accidents. The Utah DOT hold monthly meetings to identify and discuss where work zones are located, distribute educational materials during compliance reviews and public meetings, and conduct mass mailings to motor carriers to identify work zone hazards. This initiative is intended to reach a level of zero work zone fatalities and to prevent increases in crash rates ("Work Zone Accident Reduction/Prevention Project" 1999).

PUBLIC PERCEPTION

Public information campaigns have been a significant component of the overall traffic management plan for several past reconstruction projects on high-volume urban freeways (Saag 1999). These campaigns have been critical not only from the standpoint of encouraging motorists to alter travel patterns (taking alternative routes, changing departure times, etc.) during reconstruction, but also to increase public acceptance of the project and any inconveniences that it may cause ("Get In, Get Out, Stay Out!" 2000). These efforts appear to have been very successful. Surveys conducted at many of the projects showed that the public was very supportive of the reconstruction activity and highly tolerant of the delays and congestion that were created (Saag 1999).

In contrast to the motoring public's reaction, businesses located near reconstruction activities appear to be much less tolerant. However, the concerns expressed by businesses regarding lost revenues and depressed property values are often exaggerated. Recent research into the business impacts of facility construction found that the actual effects of reconstruction on revenues and property values were less than what nearby businesses had estimated (Buffington and Wildenthal 1997). Although there are instances where reconstruction does, on a temporary basis, adversely affect business sales and property values, it appears that the long-term transportation mobility and accessibility benefits to the businesses compensate for these temporary losses (Buffington and Wildenthal 1998).

It is apparent that both public and business concerns are indeed a consideration for construction projects, especially on high-volume roadways, although it is not immediately apparent exactly how these concerns are balanced against other issues in decision making for project planning. It is evident that DOTs desire to reduce the potential for travel delays during construction and have adopted policies that require roadwork to occur during off-peak hours. However, it is also evident that an agency cannot always adhere to these policies and must on occasion undertake a major reconstruction project that requires significant reductions in roadway capacity. In these instances, adequate attention to public information campaigns and to making efforts to complete the work as quickly as possible help appease the public and actually garner support for the project.

In 1995, the Florida DOT (FLDOT) instituted a best practice "Lane Closure Policy" for interstate construction. This policy requires that the work zone maintain the existing number of lanes for the various work phases and permit lane closures on interstate construction only where two travel lanes normally exist. In this situation, the use of temporary roads is often necessary. Public criticism of unnecessary lane closures on existing facilities was a major driving force behind the adoption of this policy. The benefits realized by FLDOT include reduced driver delay and frustration and better public relations ("Lane Closure Policy" 1998).

TRAFFIC MANAGEMENT PLANNING

A comprehensive traffic management plan (TMP) can be established for each project or set of projects within a given corridor. This would require assessing traffic-handling strategies and perhaps construction staging within project work zones. The extent of the development of this plan should be tailored to fit facility and project types. As indicated by Saag (1999), for reconstruction of major urban highways, a TMP is a critical component of the project development methodology. Part of the TMP is a comprehensive work zone analysis that considers the impacts of traffic diversion within a high-volume traffic corridor. An illustration of this type of iterative process is shown in Figure 2 (Krammes et al. 1989). Improvements to alternative routes will change their ability to accommodate additional traffic and, thus, affect the amount of traffic likely to divert to those routes. Once an estimate is made of how travel patterns may change because of the work zone, estimation of road user costs can proceed. The California Department of Transportation (Caltrans) has adopted a practice that supports this approach. This practice, "Traffic Management Plan on Major Urban Projects" (1998), is a comprehensive effort to accommodate traffic during construction. The impact to the *region* is assessed before construction and potential solutions are determined in a larger sense rather than localized remedies within the project limits (e.g., signing).

A simpler process for work zone road user cost analysis includes the following steps:

- Determine the traffic demand approaching the work zone.
- Estimate the reduced roadway capacity through the work zone.
- Compute changes in vehicle operating costs as they
  - slow down upon approaching the work zone,
  - oscillate through several speed change cycles as they pass through the traffic queue (if one is present), and
  - accelerate up to normal operating speeds once past the work zone.
- Compute additional motorist delays that are the result of slower travel speeds through the work zone and if traffic demands exceed the reduced work zone capacity, to any traffic queues that may develop upstream of the work zone.
- Compute the costs associated with the additional motorist delay using an estimated value of time.
- Compute changes in crash costs (if known).
- Sum up the individual road user cost components.

Generally, delays and vehicle operating costs caused by work zones are calculated on an hour-by-hour basis to capture the variation in traffic demands that occur over the course of a day. Manual procedures for calculating work zone road user costs do exist and have been documented elsewhere (Abrams and Wang 1981; Walls and Smith 1998). However, computerized analysis tools such as Queue and User Cost Evaluation for Work Zones (QUEWZ) or user cost models for the life-cycle cost analysis such as those developed by the University of Cincinnati, are also available to simplify the evaluation (Krammes et al. 1993; Arudi, Minkarah, and Pant 1997). These tools are particularly useful because they automate the rather tedious calculations needed to estimate the changes in road user costs through the work zone. Results of both manual and computerized tools should be used carefully, however, because they represent traffic only at a very simple level. In urban areas, traffic patterns are often quite complex, and changes to those patterns, because of a construction project, are even more difficult to predict. In some cases, more complicated traffic simulation or even network-based transportation planning models should be

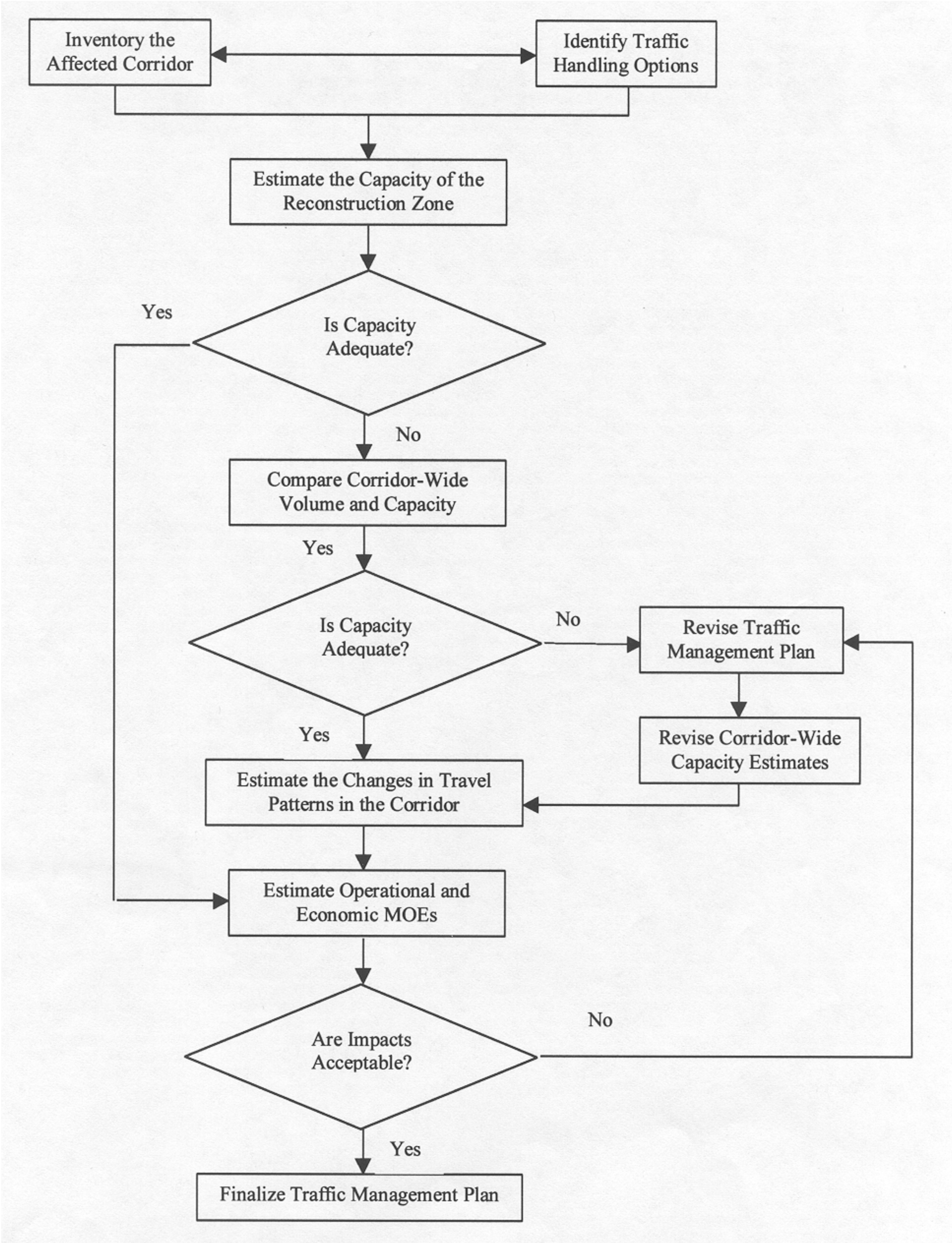

FIGURE 2 A corridor-wide approach to work zone traffic control (Krammes et al. 1989). MOE = measures of effectiveness.

used to help determine how drivers will respond to a project and how those responses will affect traffic operations and road user costs.

The step-by-step analysis approach described earlier is limited to the roadway on which the work zone is to occur. It is important to recognize that work zones on high-volume roadways will likely generate traffic diversion to alternative routes and change departure times and travel modes if the roadway capacity is severely restricted during peak travel times. The amount of diversion that occurs can be quite significant and can be considered in the road user cost analysis (Ullman 1996). If significant diversion is expected to occur, it would be necessary to use a network-based travel demand model to estimate how traffic may redistribute itself within the corridor when the work zone is present (Krammes et al. 1989; Saag 1999). Figure 2 illustrates the steps in this type of analysis process.

PROJECT PLANNING FOR APPLICATION OF TECHNIQUES

During the planning phase, agencies can evaluate the types of techniques necessary for reducing lane occupancy and mitigating the impact of lane occupancy on road users. In addition to those techniques related to traffic management and control, considerations can be given to other practices that would help reduce lane occupancy. These practices would include implementing constructibility reviews, evaluating the use of innovative materials and construction equipment, using alternate contracting methods, and applying partnering and value engineering during preconstruction. It is necessary to develop project-specific plans that incorporate these practices into design, construction, and maintenance operations. These plans would, however, be tailored to fit facility and project characteristics and need not be implemented at the same level of effort for every project.

Decision makers can also consider maintenance when designing highway facilities. Ceran and Newman (1992) proposed a process for including maintenance considerations in design. A decision tree was developed for a central design group and a district design. Many design features that could incorporate maintenance considerations are presented. For example, roadway design might consider providing skid-resistant surfacing in wet climates, which can be achieved by having grooves in concrete pavements and by placing an open-graded surface course over asphaltic concrete. Designs could consider future pavement resurfacing requirements when establishing vertical clearances and designing elements such as inlet grates and manhole covers. When considering bridge deck joint design, the number of expansion joints might be reduced. Perhaps designing for continuity and taking advantage of the flexibility of the structural system may be an approach to eliminating these joints. Designs that incorporate maintenance issues as a matter of policy can be enacted when planning a project. This policy would help reduce maintenance work, resulting in a reduction in lane occupancy and its adverse impact on road users.

During the project planning phase, consideration could be given to pavement or bridge design and material options that could accelerate construction, reduce maintenance, and provide the means for accelerating future maintenance or rehabilitation. The intent of such strategies is to reduce road user costs over the operational life of the facility and/or improve the efficiency of future rehabilitation work. As a consequence, lane occupancy may be reduced as the frequency and severity of maintenance activity decreases, and the adverse impact on road users over time may also be reduced. In many cases, the initial cost of such strategies may be higher when compared with other alternatives. The life-cycle cost (LCC) of the facility may be lower than other alternatives.

A workshop on pavement renewal for urban freeways, held in California in 1998, provided an excellent illustration of how a strategy could be selected for pavement renewal ("Get In, Get Out, Stay Out!" 2000). Four teams were assigned to develop solutions for a Caltrans project to reconstruct a portion of Interstate 710, also known as the Long Beach Freeway. The key objective was to provide a renewed pavement with a service life of at least 40 years, in addition to minimizing long-term user costs. Two teams were charged with producing an asphalt pavement design, and two teams a portland cement concrete pavement design.

The Superpave design and analysis system was considered the optimal choice for designing asphalt pavement mixtures. Innovations were proposed, such as stone matrix asphalt-base courses. Concrete designs considered fast-setting hydraulic cements and high-performance portland cement concrete. One concrete pavement design proposed full-depth outside shoulders tied to the new pavement to provide edge support. This could be particularly important because the lanes closest to the shoulders carry very heavy truck traffic. Each proposed pavement design and the required materials address the needs of pavements subjected to high traffic and, hence, could extend the life of the pavement beyond the typical 20-year service life. If successful, this general strategy for pavement design and materials selection could reduce lane occupancy during future maintenance operations and the impact lane occupancy could have on road users.

Another strategy to reduce lane occupancy during facility operation that might be considered during project planning is to design for rapid replacement of bridge decks. Tadros and Baishya (1998) identified three areas where modifications could be made to make deck systems more suited for accelerated replacement. The first area is the demolition process. Demolition often controls the rate of progress, because concrete removal is tedious and labor intensive. Provisions developed by the authors suggest that agencies should allow contractors the freedom to choose methods and equipment for deck removal. Performance-based specifications could be adopted to achieve this end. The second area is the design of the deck system itself. Adopting the AASHTO load and resistance factor design specifications reveals that a substantially reduced amount of reinforcement is needed, thus facilitating deck removal. The third area is the connection between concrete decks and concrete or steel girders. Use of a debonded shear key system for concrete girder-to-concrete deck connections or larger diameter shear studs for steel girder-to-concrete deck connections would facilitate deck replacement.

AGENCY PRACTICE

The survey sought to identify program-wide approaches that ensure that design, contracting, and construction techniques used to reduce lane occupancy during construction and maintenance are implemented effectively. Most responding agencies did not identify any specific program-wide approaches, although the New Jersey DOT is currently preparing a policy that addresses this issue. According to this agency's response, traffic volume is the key factor in determining allowable construction stages, working hours, and completion dates. In addition, methods of construction, types of materials, and alternate designs can be considered based on traffic volumes, capacities, and associated road user delay costs. These issues could be considered beginning in the planning phase and detailed during design.

In a similar context, the Oregon DOT views traffic analysis and identification of projects that are likely to have a high impact on road users as essential issues that must be addressed during planning. This viewpoint is being emphasized because the disruption of traffic due to construction activities is becoming one of the top concerns for this agency's stakeholders, including legislators. Minimizing traffic impacts is likely to become as important as minimizing construction costs.

The Pennsylvania DOT stressed constructibility and phasing of a project as a key consideration early in the planning process. Public education was also an important component of early project planning, especially when nighttime and weekend work is planned.

A fourth agency, the Michigan DOT, stressed that a corridor approach can be used. In this case, construction and reconstruction of both roads and bridges is planned by corridor. Another general policy adopted by this agency is to plan maintenance so that such operations can be completed within construction lane closures.

Finally, the West Virginia DOT emphasized relocation of traffic as an important technique. When alternatives for a proposed project are evaluated, an inherent advantage of relocation is the avoidance of maintenance of traffic through the construction area. This advantage can be considered and given proper weight in the alternative evaluation process. The potential loss of access to properties and business within the work zone is also recognized.

CHAPTER THREE

TECHNIQUES USED DURING DESIGN

A primary purpose of the design phase of a road project is to translate programming and planning concepts into a viable design that can be constructed efficiently. Decisions made during design will ultimately impact the effectiveness of the construction effort, especially with respect to reducing lane occupancy. When reducing lane occupancy during construction is a project objective, then techniques to reduce lane occupancy and mitigate its impact on road users can be incorporated into the design process. Specific areas of focus may include project phasing and traffic control, constructibility reviews, materials, construction equipment, and prefabrication of project components.

PROJECT PHASING AND TRAFFIC CONTROL

Construction and maintenance operations on highways disrupt traffic flow and pose safety hazards for motorists, pedestrians, and workers. Efficient and effective project phasing, construction sequencing, and traffic control through a work zone are likely to reduce the impact on motorists and improve safety for all involved. The project can be designed so that construction could be performed in a number of components that would be sequenced in a manner that minimizes the impact on the traveling public.

During the design phase, and on larger projects, traffic control plans (TCPs) are detailed based on a strategic policy direction and documented in a comprehensive TMP, as developed during project programming and planning. On smaller projects, standard practices for developing TCPs can be followed.

Background Literature

According to Graham and Migletz (1994), a TCP is needed for "handling traffic through a specific highway or street work zone or project." It is important to recognize early on that the temporal and spatial work zone requirements for a project will influence the ability of a contractor to reduce lane occupancy. Temporal requirements refer to the amount of time a given work zone needs to be in place each day (i.e., for a few hours, for the entire day/night, etc.), the total number of work zone days needed to complete the work, and the number of times the work zone must be set up and taken down during the project (i.e., each day, at the beginning and end of the project, etc.). Spatial requirements refer to the roadway space that the work zone needs for the specific work activity to be completed, and includes both lateral (i.e., roadway cross-section) and longitudinal (i.e., work zone-length) dimensions.

The purpose of the TCP is to minimize traffic disruption and eliminate safety hazards involved with work zones. A TCP may include traffic control strategies, construction staging requirements, specification of traffic control devices, and geometric design features, among other elements (Graham and Migletz 1994).

During design, data related to traffic volumes, travel patterns, and site characteristics should be collected and collated for the project. A site visit during data collection may help develop realistic TCPs. Meetings are often used as a means to obtain input from various experts involved with or influenced by the TCP, including traffic operations, construction, maintenance, and other design disciplines. Evaluating construction staging and sequencing in the context of traffic control is a key element in ensuring that a safe and effective TCP is adopted, especially when reducing lane occupancy is an objective. Items included in the TCP are usually covered in the contract documents (e.g., plans, notes, and special project-specific provisions).

For long-term reconstruction projects on high-volume freeways, agencies may choose to implement traffic control techniques and strategies that maximize the roadway capacity through the work zone. Some examples that have been used are (Ullman et al. 1989):

- Use of portable concrete barriers and paddle screens;
- Closure of entrance ramps within the work zone (or the restriction of their use to high-occupancy vehicles only);
- Widening and upgrading shoulders to be used as temporary travel lanes;
- Use of reversible lanes through the work zone to handle peak period, peak direction traffic; and
- Use of service patrols and/or tow truck services to quickly remove incidents that occur within or immediately upstream of the work zone.

Consideration has been given to the following issues when designing TCPs:

- Differences in traffic control/traffic management implementation costs,
- Increased road user costs, and

- Other factors such as public perceptions and business concerns that otherwise affect strategy acceptability.

Work zone traffic control requirements vary according to the type of roadway, duration of work, and the location of the work activity within the roadway right-of-way *(Manual on Uniform Traffic Control Devices* 1988). In general, work activities that take place within the existing travel lanes on higher-volume roadways require the most extensive degree of traffic control and can create extensive road user costs.

Work zone road user costs include the increased vehicle operating costs, delay costs, and crash costs (see chapter 2 for discussion on road user cost components). These costs are a function of:

- The temporal and spatial requirements of the approach being considered,
- The volume and operating characteristics of the traffic affected by the work zone, and
- The values assigned to vehicle operating characteristics, delays, and crashes (Walls and Smith 1998).

Table 2 provides examples of the temporal and spatial traffic control options for work zone activities in urban areas where traffic volumes are high. Experience suggests that work zone road user costs tend to be quite small in relation to other project costs when work activities can be completed without creating traffic queues *(Traffic Management Handbook...* 1999). Once queues develop however, motorist delays quickly cause road user costs to become significant.

Of the cost categories, crash costs are the most difficult to determine. Work is underway by several agencies to better define work zone crash experiences and prediction factors ("Work Zone Operations..." 2000). It is generally accepted that work zone crash rates at a given location are somewhat higher than the crash rate at that same location when a work zone is not present *(Summary Report on Work Zone Accidents* 1987). However, the magnitude of this increase can vary widely. Also, data suggest that work zone crash rates tend to increase by a greater percentage at night than during the day *(Summary Report on Work Zone Accidents* 1987; Ullman and Krammes 1991).

As TCPs are developed, a consideration that will affect decisions related to mitigating lane occupancy is that of public/business perceptions and concerns. A recent review of best work zone practices identified several DOTs that had adopted explicit policies that limit the amount of travel delay that a given project can cause *(Meeting the Customer's Needs...* 1998). Many policies also emphasize the importance of providing accurate and timely work zone information to motorists about current and upcoming detours, closures, and other related developments *(Meeting the Customer's Needs...* 1998).

TABLE 2

TEMPORAL AND SPATIAL WORK ZONE OPTIONS FOR HIGH-VOLUME ROADWAYS

Traffic Management Requirements	Options Available
Temporal	Daytime off-peak work (i.e., 9 a.m.-4 p.m.) Nighttime work (i.e., 7 p.m.-6 a.m.) Weekend work (i.e., 7 p.m. Friday-6 a.m. Monday) Intermediate-term work (overnight to 3 days duration) Long-term work (longer than 3 days duration)
Spatial	
Lateral	Lane shifts onto a shoulder or to temporary lanes Lane constrictions Lane closures Number of lanes closed Single lanes Multiple lanes Traffic-handling schemes Crossovers Interior (middle) lane or lanes Reversible express lanes Total roadway closures
Longitudinal	Full-length closure Advancing limited closure Leap-frogging limited closure

Developed from Dunstom and Mannering 1998; Ullman 1992.

TABLE 3
METHODS AND TECHNIQUES USED WHEN DEVELOPING TRAFFIC CONTROL PLANS TO REDUCE LANE OCCUPANCY

Method and Technique Area	Frequency (Times Cited)	High Impact	Medium Impact	Low Impact
Contracting	17	9	8	
Off-peak closures	13	9	3	1
Detouring	12	8	3	1
Coordinating tools	9	3	6	
Other closures	5	3	2	
Travel flow characteristics	5	2	2	1
Public perceptions/impact	4	I	2	1

Agency Practice

The majority of survey respondents (80 percent) stated that their agency specifically focuses on reducing lane occupancy when developing project phasing and TCPs. Each agency described the process/procedure used to develop and analyze these plans. Overall, the characteristics of these processes were similar to that described in Graham and Migletz (1994) and discussed in the background literature. For example, input to the process was traffic flow data, typically based on average daily traffic. Project phasing and construction staging plans are then developed, often with the aid of computer modeling and information from field inspections. Specific emphasis is placed on lane closures and the timing of the closures. Timing would include the use of off-peak hours, night work, and weekends. Alternate routes are examined for times when traffic capacity will create significant queues through the work zones. Public impact is also assessed. Advertising and other public awareness campaigns are considered, especially in high-traffic-volume situations. Constructibility analysis of phasing and staging configurations is frequently incorporated into the TCP development process. Contracting methods that promote the reduction of construction time are also considered to ensure that the contractor's time in a work zone is reduced or minimized. Finally, multidisciplinary teams are used to review the TCPs and other approaches to maintenance of traffic.

Methods and Techniques Associated with Traffic Control Planning

Survey respondents cited numerous examples of the methods and techniques used to develop and analyze project phasing and TCPs that reduce lane occupancy. As shown in Table 3, these methods and techniques are categorized in seven general areas. Interestingly, contracting was the area cited most frequently. The most frequently referenced contract methods were incentives and disincentives, cost-plus-time bidding, lane rental, and liquidated damages. Most respondents viewed these methods as having a medium-to-high impact on reducing lane occupancy and mitigating the impact on road users. More specific data and discussion of these contract methods is provided in chapter 4.

The use of off-peak closures and detouring were frequently cited as having a potentially high impact on reducing lane occupancy during construction. These two areas may not reduce a contractor's overall time occupying a lane; however, the impact on the road user may be less for two reasons. First, work is shifted to a time with lower traffic volume. Alternatively, traffic may not be substantially disrupted when using an alternate route or temporary road. Off-peak closures covered both off-peak hours during the weekday and at night and weekends. Decisions to use these techniques were based on attempts to avoid periods when traffic volumes were high, based on an analysis of hourly volumes. Special provisions and plan notes are often used to ensure that the contractor does not occupy lanes during certain hours. At certain levels of traffic volume, and when off-peak hours will not suffice, detours are used. Detours are established through the use of other roadways or by constructing temporary roads. Both of these approaches have impacts that must be evaluated; for example, the effect of more traffic being carried on the roadway than normal because it is being used as a detour route. Although temporary roads increase the cost of construction, they may be a way to maintain traffic flow at a level consistent with current capacity.

As shown in Table 3, "coordinating tools" is cited as a technique that might reduce lane occupancy. This category of techniques was labeled coordinating tools because the specific techniques identified would likely integrate a number of factors or issues related to phasing and traffic-control planning. For example, two respondents considered staging plans as a technique for reducing lane occupancy. Others concluded that reviews involving design, construction, and traffic personnel, including external experts, provided a good alternative. These multidisciplinary reviews would take into consideration the input of those effected by phasing and traffic control decisions.

Other types of identified closure techniques include more traditional techniques such as directional closures, crossovers, reduction of lane width, and temporary widening within existing right-of-way (ROW). These techniques were deemed appropriate when the roadway geometry allows for a lane closure approach that would maintain normal traffic flow through the work zone.

Integrating traffic volumes with lane configurations, queue lengths, and level of service can promote more efficient TCPs. Traffic flow characteristics can be considered when using other techniques for reducing lane occupancy. As shown in Table 3, techniques that focus on public perceptions and the impact of lane occupancy on both motorists and businesses were important. The impact on reducing lane occupancy was ranked as medium. However, from a road user's perspective, these techniques would likely have a higher perceived impact. Examples of techniques that focus on public perception include obtaining public participation when evaluating the impact of detours on road users, workers, and neighborhoods, and notification of the public when diversions will occur and what routes are available (Dunn et al. 1999). In addition, computer modeling of traffic flow and proposed detour routes could be used to select closure routes or staging plans that reduce lane occupancy.

Impact on Road Users

Responding agencies cited a number of methods for incorporating the impact of lane closure on the traveling public in their evaluation of project phasing alternatives, traffic control strategies, and TCPs. Road user costs, delay time, number of lanes effected, and use of off-peak work hours were among the most frequently cited criteria. Other criteria used include public communication, number of detours, accessibility issues, and queue length. Most agencies consider road user demands and expectations as their yardstick in selecting appropriate criteria. For example, road user costs and the number of lanes effected are weighed against time of construction lot an alternative versus expected public impact. The North Carolina DOT noted, "We evaluate user costs of road closures versus costs of temporary detours for our smaller bridge replacement projects. On larger projects, we determine the number of lanes that need to remain open. If a two-lane road must be closed to one lane we normally do these facilities during off-peak hours." The Iowa DOT reported that public convenience is always the primary consideration in every project. The Wisconsin DOT responded that delay times and queue lengths are determined using average daily traffic and design hourly volume data. The North Dakota DOT reported that it considers alternate routes for large traffic volume, truck traffic, and designated routes for wide loads.

Measures of Impact

Factors used to assess the impact of project phasing and traffic control planning decisions on safety, mobility, and travel efficiency commonly include road user costs, records of crashes and injuries, and the functionality of TCPs. Agencies generally estimate user delay time and costs associated with user delay to determine the intensity of the impact. Data on queue lengths and fuel consumption are also used. These data are an indication of the functionality of TCPs provided that the TCP is based on some planned queue length and associated fuel consumption estimate. Crash rates may be used as a measure of the functionality of the plans. When compared with historical averages, lower crash rates may be one indicator that the TCPs are working as planned. Public input is often considered. For example, the city of Edmonton Transportation and Streets agency reports that the number of telephone complaints suggests the level of effectiveness of TCPs. The FLDOT has prepared a "Plans Preparation Manual," which includes lane closure analysis worksheets that can assist a designer in determining the impacts of lane closures ("Plans Preparation Manual" 1998).

CONSTRUCTIBILITY

Transportation agencies recognize the need for contract documents that will ensure rational bids and minimize problems during construction projects. Such contract documents often incorporate a review process in the planning and design phases to assess project constructibility. This assessment is more critical on projects where reducing lane occupancy and mitigating its impact is essential.

Constructibility is defined as the optimum use of construction knowledge and experience in planning, design, procurement, and field operations in order to achieve overall project objectives ("Constructability: A Primer" 1986). The AASHTO Highway Subcommittee on Construction provides a more specific definition related to design, stating that it is "a process that utilizes experienced construction personnel with extensive construction knowledge early in the design stages of projects to ensure that the projects are buildable, while also being cost effective, biddable, and maintainable" ("Constructability Reviews and Post Construction Reviews" 1999).

Background Literature

Anderson and Fisher (1997a) compiled a list of critical issues relevant to the implementation of constructibility from the perspective of state highway agencies, design firms, and construction firms, several of which relate directly to lane occupancy. Traffic control was cited by all three entities as a critical constructibility issue. State transportation agencies reported the need to improve plans and specifications as a critical issue, whereas design firms indicated the need for better-coordinated timing, phasing, and scheduling. Construction firms also indicated a need for clear design plans and specifications and cited improved quality of scheduling and phasing of construction as critical constructibility issues. These different perspectives support the need for constructibility reviews in the areas of traffic control planning and execution.

Anderson and Fisher (1997b) developed a constructibility review process (CRP) for transportation facilities that can address these critical issues. The research also indicated the need to formally document the CRP and to increase the level of input of construction knowledge and experience during early project phases. A multidisciplinary team approach is an integral component of the CRP. These concepts are particularly important to developing plans that would reduce lane occupancy.

The Arizona DOT identified "improving the quality of project plans" as one of the key issues to investigate. The *Constructibility Guide,* compiled by Wright (1994), contains a detailed list of "constructibility concepts" (i.e., potential problem areas) grouped by construction activity or project consideration. These concepts can be used as a reference when evaluating construction issues and reviewing design plans. A more practical tool for a constructibility review would be a checklist derived from the constructibility concepts, which focuses on traffic control and sequencing of construction operations. Typical checklist items for traffic control include:

- Ensuring that detour design fits field needs,
- Considering staged construction and vertical elevation differentials for traffic lanes,
- Checking access for local business/residents,
- Ensuring that TCP is coordinated with job phasing,
- Checking if signing meets traffic needs in each phase,
- Determining if traffic conflicts can be reduced by using innovative haul routes,
- Checking that freeway closure information is clearly shown on plans, and
- Ensuring that work zones are large enough for equipment access.

A formal constructibility review process was implemented by Caltrans on all projects costing more than $25 million, beginning in July 1997, and on all major projects (more than $750,000), beginning in July 1998. Adopting the CRP as a best practice was expected to enhance construction effectiveness through better prepared plans, specifications, and estimates (PS&Es) with the intent of reducing contract time extensions and delay claims. Also, Caltrans expected overall project cost and construction time to decrease ("Formal Constructabililty Review Process" 1998).

Agency Practice

Most agencies (95 percent) perform constructibility reviews during the design phase. However, most of these reviews (70 percent) are performed on an informal basis; that is, no documented guidelines or procedures are followed. These results are consistent with similar results collected by the AASHTO Highway Subcommittee on Construction ("Constructability Reviews and Post Construction Reviews" 1999).

Table 4 identifies major constructibility issues that are typically addressed during design, which could reduce a contractor's time in work zones and the frequency at which each issue was cited. As shown in Table 4, scheduling, maintenance of traffic, and project phasing were cited as being the major issues addressed. Design features and material types and availability were the next most often cited. Construction methods and work time restrictions were also considered by several agencies. Most survey respondents considered that these issues would have a high impact on reducing lane occupancy.

Scheduling focused primarily on sequencing of construction activities, especially as related to ROW and utility work. Sequencing of activities should also be closely tied to project phasing and maintenance of traffic. Construction input in these areas during early design is critical to ensure that TCPs and other plans are realistic and can achieve reduced levels of lane occupancy.

TABLE 4
CONSTRUCTIBILITY ISSUES CONSIDERED WHEN REDUCING LANE OCCUPANCY

Constructibility Issue Area	Frequency (Times Cited)	High Impact	Medium Impact	Low Impact
Scheduling	15	10	3	
Maintenance of traffic	12	9	2	
Project phasing	12	9	2	
Design features	11	6	2	1
Material types and availability	9	6	2	
Construction methods	7	5	2	
Work time restrictions	5	5		

Note: Impact may not equal total frequency because some respondents did not always assess impact.

As the design is developed, specific elements can be evaluated from a constructibility perspective, such as the use of precast components and details of bridge structure elements, and equipment loading during construction. Pavement design would consider materials as well as elevation differentials, especially between a new pavement that is replacing an existing pavement.

Other considerations during design are the selection and availability of pavement materials, such as high early strength concrete, and construction methods. The type of equipment used, access to and from the site for materials handling, and specific methods of construction affect the time to complete construction activities. For example, instead of using an open cut replacement of existing culverts one option may be to insert plastic liners or jack new steel walled pipe into the existing culvert.

Work time restrictions can also reduce the impact of construction operations on motorists. These restrictions might include shift work, weekend work, nighttime operations, and the use of detours. Although time restriction may not necessarily reduce total time in work zones, they would enable the contractor to accelerate construction during periods of lower traffic.

Construction phasing, when combined with constructibility reviews, can reduce construction duration and avoid substantial traffic delays. At times, project phasing is developed by engineers who have limited access to construction expertise (Anderson and Fisher 1997a). Contractors often cannot participate or provide advice, because this may prevent them from bidding on the project. As a result, the proposed project-phasing scheme may not represent the most efficient approach to constructing the facility. Employing construction expertise for construction phasing and staging analysis can be highly beneficial. In the Buffalo Gap intersection project cited by Anderson and Fisher (1997b), constructibility reviews provided the necessary input for adopting a construction staging strategy that reduced the construction duration from 14 to 11 months. High early strength concrete was also used to allow for early opening of different sections of the intersection to traffic.

The constructibility review process was a key component in the accelerated reconstruction of an urban intersection (Anderson et al. 1998). In this type of reconstruction, the entire intersection is completed in one weekend. Typical construction staging would require repeated shifting of traffic to accommodate reconstruction of each stage of the intersection over a longer period of time. Anderson et al. (1998) formalized a process for accelerated urban intersection reconstruction and demonstrated it on a project that was completed in one weekend. The agency that sponsored the project reported that it would have taken 2 to 3 months if conventional construction staging practices were followed.

Saag (1999) studied project development methodologies for reconstruction of urban freeways and expressways. Constructibility was included as an important tool in the design process. A survey questionnaire revealed that a constructibility review was performed for more than one-half of the reconstruction projects. The importance of holding reviews early in the design process was stressed. The identification of critical issues and their dissemination to all parties involved was also an important premise for the constructibility review success. Saag states that constructibility reviews should be considered as a best practice for those types of facilities where reducing lane occupancy is critical, and especially to mitigate the impact of lane occupancy on the traveling public and local businesses.

MATERIALS

Three-quarters of the survey respondents cited the use of high early strength (or early-opening-to-traffic) concrete as a key material when an objective is reducing lane occupancy. This material allows for the opening of pavement to traffic within 24 h of placement and, therefore, is viewed as having a high impact on reducing lane occupancy (76 percent of the respondents assessed the impact as high). According to the Arkansas DOT, by using high early strength concrete (fast-track concrete in their terminology), the minimum strength required for opening to traffic was obtained within 6 h after placement.

Johnson et al. (1994) developed guidelines for the construction of intersections using high early strength (or fast-track) concrete. This research suggests that with proper pavement design, concrete placement procedures, and materials testing criteria, high early strength concrete can be used to construct concrete pavements in a shorter time than under conventional paving procedures. For example, appropriate methods to evaluate and test flexural strength should be used to predict strength gain under in-situ climatic conditions. By reducing placement and curing times, high early strength concrete allows for the opening of pavement sections to traffic much earlier and also reduces total project time.

Caltrans used a fast-setting hydraulic cement concrete to pave a portion of the I-10 Freeway in Pomona. This concrete achieved the required strength of 400 psi within 4 h. The reconstructed pavement section was approximately one and one-half miles and was completed over a weekend within the 55-h limit. Figure 3 shows this concrete being poured by direct chute.

Table 5 lists other materials cited by agencies as having a potential impact on reducing lane occupancy. As shown in this table, some respondents considered both movable barriers and precast elements as materials. These

FIGURE 3 Placing fast setting concrete on I-10 freeway in California (photo courtesy of the University of California at Berkeley and the Innovative Pavement Research Foundation).

TABLE 5
MATERIALS THAT MAY HELP REDUCE LANE OCCUPANCY

Material Item	Level of Impact
Soil stabilization with lime and cement	Medium
Using water to cool asphalt pavements on resurfacing projects	Medium
Flowable or lean mix concrete for backfill	High to medium
Use of hot asphalt with recycling	High to medium
Movable barriers	High
Precast components	High

items are discussed later under equipment and prefabrication, respectively.

CONSTRUCTION EQUIPMENT

As a general rule, most agencies would not specify equipment unless dictated by special circumstances. Most agencies (77 percent) do not specify construction equipment that would help minimize lane occupancy. When specific equipment is mentioned, movable barriers and paving machines were the most frequently cited. Tandem pavers were reported to have a medium-to-low impact on reducing lane occupancy. In one case, a special provision required the contractor to use a multiheaded concrete drill. Several agencies reported that the use of movable barriers would likely have a high impact on reducing lane occupancy, because it maximizes available space and the safety of both the traveling public and construction workers when it is moved. Figure 4 shows a moveable barrier as used on a pavement section on the I-10 Freeway in California. The use of special equipment to move the barrier (shown in Figure 5) may allow a smoother transition when closing lanes to traffic, because traffic can continue to move as the closure occurs, thus reducing queues at the time of closure ("Move Over Please" 1998). The system allows the barrier to be moved very quickly and without the closure of an adjacent lane for barrier-placing equipment. This makes the system feasible for closing a lane during off-peak periods and then opening the lane back up just prior to peak periods.

PREFABRICATION

Prefabrication is a practice where facility components are fabricated and assembled, if required, away from the project site and then brought to the site for installation. This practice is frequently used when site access is limited or, alternatively, when the agency seeks to reduce the impact of construction on traffic.

Approximately 64 percent of the responding agencies use prefabricated components, primarily for drainage

FIGURE 4 Movable barrier used to create a work zone on I-10 project in California.

FIGURE 5 Machine to place movable barrier in setting up a lane closure (Rathbone 2000).

structures and bridges, when an objective is to reduce lane occupancy. For drainage structures, box culverts and manholes/catch basins were the most frequently identified component and were reported to have a medium impact on reducing lane occupancy. The two most common bridge components identified were prefabricated beams and deck panels. The use of prefabricated bridge components is likely to lead to a greater reduction in lane occupancy than the use of prefabricated drainage structures. Because in many cases, the use of prefabricated drainage structures may not directly interfere with traffic, the actual impact on lane occupancy may depend more on the project conditions.

The New York State Thruway Authority replaced an 80-ft-long, 120-ft-wide, six-lane bridge in 5 months using prefabricated superstructure and decking. A temporary bridge was istalled on the northbound side of the thruway while contracts for design and construction were being prepared. While precast bridge segments were being manufactured, the contractor rehabilitated the abutments and approaches. Once the south side of the bridge was completed traffic was detoured to the newly completed section and construction began on the north side ("NYC Commuter Bridge Replaced in Five Months" 1998).

OTHER TECHNIQUES

A temporary bridge, as used by the New York State Thruway Authority, can be extremely beneficial in accelerating the reconstruction or rehabilitation of an existing bridge. Perhaps the most beneficial aspect of using temporary bridges is the ability to maintain traffic flow at or slightly below normal volumes during construction.

Another technique that is often considered when reducing lane occupancy is value engineering (VE). VE is often applied during the design process in conjunction with or in lieu of constructibility analysis (Anderson and Fisher 1997b). It relies on identifying alternative approaches to achieving the intended functional performance requirements. The objective of this analysis is to determine the most basic approach to fulfill the required functions of the facility. Once this basic approach is identified, all improvements are analyzed in reference to the cost savings. VE is a structured process that follows specific steps (Ceran and Newman 1992):

1. Selection of the project or item to study;

2. Investigation and information collection to determine the problem, costs, what is now accomplished, and what must be accomplished;

3. Speculation to identify and answer questions such as "what else will perform the function?";

4. Evaluation of alternatives, including how each alternative would work, what the cost would be, and whether each alternative would perform the function;

5. Selection of the most promising alternatives, determining total and life-cycle costs, and completing the evaluations;

6. Identification of the advantages and shortcomings of the recommended alternative for presentation and approval;

7. Incorporation of the approved alternative into the plans, policies, and standards for implementation; and

8. Monitoring the results.

Several agencies have identified best practices in VE. The Virginia DOT (VDOT) has a policy to value engineer all projects over $2 million to minimize construction time and road user costs ("Value Engineering to Minimize..." 1998). The Texas DOT (TxDOT) performs VE studies for major projects that evaluate traffic management control alternatives through work zones. VE is also used to analyze processes such as utility accommodation [Value Engineering (VE) Studies... 1998].

An engineering firm performed a VE study in conjunction with the TxDOT that had the specific goal of reducing lane occupancy and its adverse impact on the traveling public. This study was a part of a reconstruction project of 6.5 km (4 miles) of the IH-10 mainlines near the city of Beaumont, with average annual daily traffic of just over 70,000 vehicles. The VE analysis considered a temporary drainage system to eliminate the need for a lane closure when the system is installed.

PROJECT APPLICATIONS

To reduce lane occupancy, constructibility, certain materials and construction equipment, and prefabricated components can be used on any facility and project type. However, the survey data indicate that these techniques are better suited for some facility and project types (e.g., urban freeways and interchanges, rural freeways/highways where widening or realignment is involved, and bridge widening) than others. For example, the use of more innovative types of paving machines would be best suited for urban freeway facilities, whereas high early strength concrete is more frequently used on urban freeways, interchanges, and intersections.

The use of construction materials and prefabricated components, as previously discussed, would favor projects requiring restoration of existing pavements, bridge rehabilitation, or reconstruction projects. These projects would, perhaps, be better suited for high early strength concrete and prefabricated components such as bridge decks or drainage structures. The use of certain construction equipment may provide a better payoff for resurfacing and restoration projects especially in the context of using wider paving machines and moveable concrete barriers. Construction input during design for complex projects is vital to ensure that the most efficient project phasing and construction-staging plan is developed.

MEASURES OF EFFECTIVENESS

Most agencies do not measure the effectiveness of the techniques used for reducing lane occupancy discussed in this chapter. Only seven survey respondents reported that measurements were used. One state agency uses a postdesign review, and then follows with a second design review when construction is 30 percent complete. A standard list of questions is addressed during these reviews to ensure that the design has achieved its intended result. Other DOTs monitor the queue length and delay time of the motorist traveling through work zones to determine if the TCP is accommodating traffic flow as planned. Weekly meetings are frequently held on-site to evaluate the effectiveness of planned detours. Finally, in some instances public awareness is monitored, possibly through a hotline, where the frequency of calls and the type of issues addressed would indicate how well the TCP is working.

CHAPTER FOUR

CONTRACTUAL METHODS

The traditional competitive bidding system has served the public well. The foundation of this system is the principle of competitive sealed bids, with the award going to the lowest responsive bidder. The low bid system, however, does not always optimize construction duration. In recent years, DOTs have been under increasing pressure to reduce construction time and minimize the impact of construction on the traveling public and local businesses. In response to these pressures, several innovative modifications to the low bid system have been used.

Contract time estimating is one of the most important tasks in construction contracting. It influences not only construction project duration and, thereby, lane occupancy time, but also budgeting, resource planning, a project's impact on the local economy, and contract claims. Herbsman and Ellis (1995) investigated the determination of contract time for highway construction projects. They found that DOT engineers tend to estimate longer construction durations than are required. Contracting methods that require contractors to bid construction durations or that encourages them to accelerate construction time can reduce construction time. Thus, the use of some alternate contracting methods can often achieve more realistic durations for construction.

The AASHTO Highway Subcommittee on Construction has developed a catalog of contracting methods and procedures *(Primer on Contracting 2000* 1998). Among the specific techniques identified are several pertinent to minimizing lane occupancy. These include:

- Lane rental,
- Cost-plus-time bidding,
- Incentives/disincentives, and
- Flexible notice-to-proceed dates (or flexible start dates).

As shown in Figure 6, 94 percent of the agencies surveyed for this synthesis currently use incentives and disincentives (I/Ds), 76 percent use cost-plus-time bidding, and 52 percent use lane rental. These data are similar to the data published in the *Primer on Contracting 2000* (1998). Most agencies use a special provision to implement these contracting techniques.

Of the three contracting techniques, lane rental was believed to have the highest relative impact on reducing lane occupancy, as indicated in Table 6 (lane rental has the highest percentage of high impact citations). The use of I/Ds was viewed as having a moderate-to-high impact, whereas cost-plus-time bidding was reported by the DOTs surveyed as being slightly less beneficial.

Several other contract-related techniques were identified as influencing the level of lane occupancy. The three most frequently cited techniques were the use of critical path method for scheduling, variable start dates, and lane hour restrictions (e.g., specifying times when lanes cannot be closed). Lane-hour restrictions were cited as having the highest impact on reducing lane occupancy.

LANE RENTAL

Herbsman and Glagola (1998) analyzed the use of lane rental, both in the United Kingdom and for U.S. highway construction. Lane rental requires that the contractor pay for the time or right to use lanes during construction operations. This time component is converted to a cost to the contractor based on estimated road user costs.

The lane rental concept can be applied in a number of ways. Fees are assigned and determined by the type of application. Lane rental fees can be assessed based on work schedule (weekdays or weekends), work duration (hourly periods during the day), and lane location (left-hand lane, center lane). The fee can also vary according to the time period specified, such as a daily fee versus an hourly fee. Herbsman and Glagola (1998) found that the use of lane rental clearly could reduce construction time only if the correct procedures are used.

Lane rental was assessed by DOTs as having the highest potential impact on reducing lane occupancy. This is reasonable given its purpose and application; the purpose being to shorten the overall time required for lane closures, thus minimizing road user impacts during construction. Typically, a rental fee is included in the contract as a special provision. This fee is based on the estimated cost of delay or inconvenience to the road user during the time the contractor occupies or obstructs part of the roadway. According to survey respondents, application of lane rental requires the estimation of road user costs.

Lane rental rates are stated in bid documents in terms of dollars per lane per time period; i.e., by day, hour, or fractions of an hour. These rates may vary depending on, for example, whether one lane is occupied as opposed to a

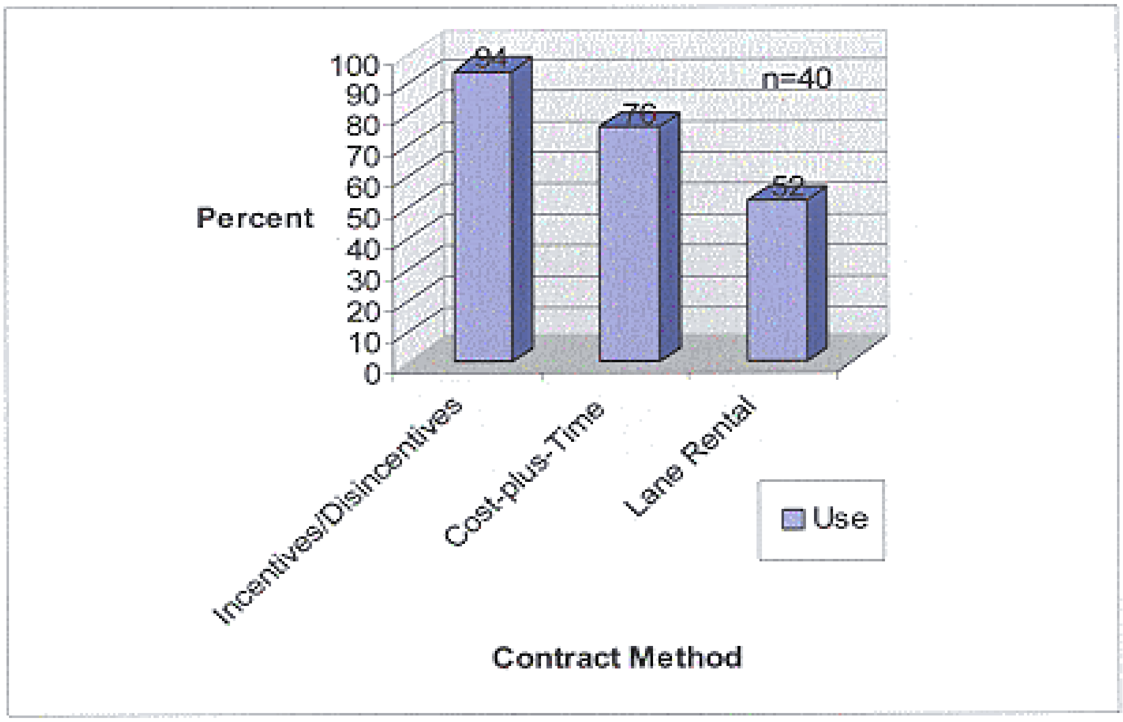

FIGURE 6 Agency use of contracting methods.

TABLE 6
IMPACT OF CONTRACT METHODS ON REDUCING LANE OCCUPANCY

Contract Techniques	High Impact (Times Cited)	Medium Impact (Times Cited)	Low Impact (Times Cited)
Lane rental	13	5	3
Cost-plus-time	15	11	4
Incentives/disincentives	18	15	5

TABLE 7
EXAMPLE OF LANE RENTAL FEE

Lane Type	Daily Fees (dollars/day)	Hourly Fees (6:30 a.m.-9:00 a.m.) (dollars/h)	Hourly Fees (9:00 a.m.-3:00 p.m.) (dollars/h)
One lane	20,000	2,000	500
One shoulder	5,000	500	125
One lane and shoulder	25,500	2,500	625
Two lanes	45,000	4,500	1,250
Two lanes and shoulder	50,000	5,000	1,375

lane and a shoulder. In addition, rental rates can be different depending on the time of day; that is, peak or off-peak hours. Several agencies tie rental rates to a time of day to encourage off-peak construction. The rental fee is assessed for the time the contractor actually occupies the lane or lanes and is deducted from the monthly progress payment. Lane rental is typically used for short duration projects. On projects of longer duration, agencies often use I/D provisions with lane rental as added incentive. Examples of fee structures and types of closure periods are provided in Herbsman and Glagola (1998), Saag (1999), and Rahman (1998). A typical example is shown in Table 7. In Table 7, fee structures are illustrated for different lane types such as daily rates (column 2) and hourly fees for rush hour (column 3) and nonrush hour (column 4) time periods.

Some states have used the lane rental concept in the determination of low bid. In this case, the contractor bids the time (e.g., hours, days, etc.) a lane(s) is required for the duration of the project, and the cost is then calculated using a predetermined rental fee structure. This cost is combined with bid prices to establish the overall combined bid and subsequently the lowest bidder. Other states have combined lane rental with cost-plus-time bidding to take advantage of reducing both lane closure time and the overall construction time (Anderson and Russell 1999a).

Lane rental has the highest potential for reducing lane occupancy during construction, especially on projects with high-traffic volumes. The Oklahoma DOT has adopted the "Construction Lane-mile Rentals" policy as a best practice. This practice was initiated to reduce user delay by encouraging contractors to work during nonpeak hours and to minimize the length of work zone closures. Limiting the length of work zones increases the public's acceptance of the work zone, because they no longer see miles of work zones with no construction activity ("Construction Lane-mile Rentals" 1998). The Oregon DOT has an aggressive lane rental specification, allowing lane rental in 15-min increments, with charges as high as $50,000 per lane per hour during peak use periods, with no fee during nighttime hours. This practice was adopted to minimize lane closures and make the contractor responsible for road user costs ("Lane Rental Specification" 1998).

The use of lane rental should be carefully planned for each project, and development of procedures for its application begins early in the design phase. This includes preparation and documentation of plans for the maintenance of traffic under various lane closure configurations and then carefully calculating the lane rental fee schedule. Implementation is very resource intensive, both in planning for lane rental use and monitoring lane rental assessments during construction (Herbsman and Glagola 1998).

COST-PLUS-TIME (A+B)

In analyzing specifications from many DOTs, Anderson and Russell (1999a) described cost-plus-time (A+B) bidding in terms of the following formula:

$$\text{Bid price} = A+B \times RUC$$

where

A = contract amount,
B = total calendar days bid by contractor to complete work, and
RUC = road user costs.

The successful bidder, as determined by the agency, proposes the lowest combination of A and B. The results of the survey indicate that the majority of state highway agencies have used A+B bidding, although the extent of application has varied. These results are consistent with other recent information on the application of A+B (Anderson and Russell 1999a; *Primer on Contracting 2000* 1998). Some transportation agencies, such as the NYDOT, which has used this bidding method on more than 65 projects, use this method often, primarily to reduce the duration of construction delays in urbanized areas. NYDOT reports having saved 8,500 contract days, based on the difference between the estimated contract time and the contract time bid, resulting in an estimated $100 million reduction in user delay costs ("A+B Contracts" 1998). The Michigan DOT (MDOT) uses A+B with I/D clauses as a best practice. In some cases, a disincentive is used with respect to lane closure. I/Ds and disincentive clauses typically reduce delay during critical high-traffic periods to minimize the time required to complete work, thereby reducing the level of traffic inconvenience ("A+B and Incentive/Disincentive Clauses" 1998).

Herbsman et al. (1995) analyzed 101 projects awarded using cost-plus-time bidding (A+B). Comparisons between the engineer's estimate and the time bid by the lowest combined bidder showed that for 92 projects bid time was less than or equal to the engineer's time estimate. An analysis of the 40 projects that were completed by the end of 1995 indicated that 33 were completed ahead of the contractor's time bid, 2 were completed on time, and 5 were completed behind schedule. In many cases where an I/D clause was used, the contractor received the maximum incentive amount allowed under contract provisions.

In the Herbsman study, approximately 75 percent of the projects analyzed involved restoration-, rehabilitation-, or re-construction-type projects. Such projects are often characterized as having substantial traffic control requirements, where motorists are frequently adversely effected by changing construction work zones. Therefore, accelera-ting the construction duration is desirable from a motorist perspective.

A+B bidding is generally successful for reducing overall construction time and work is often completed earlier than estimated by the contractor. This perhaps would reflect a reduced level of lane occupancy due to shortened construction durations. However, it must be recognized that under A+B construction operations are often performed using extended work schedules, including night and weekend work. This approach is often deemed necessary for the contractor to complete construction according to the time bid. Although the overall construction time is shortened, the duration of lane occupancy may not be shortened in the same proportion, if at all. However, when work is performed at night or over weekends, construction operations have typically less impact on road users.

A+B bidding is not necessarily suitable for every facility or project type (Anderson and Russell 1999a). Similar to lane rental, it can be resource intensive in terms of agency coordination and decision making in support of field operations. Projects typically need to be free of right-of-way problems, and it is best if utilities are cleared before construction begins. Satisfying these two requirements would prevent problems that may effect the time needed for a project and lead to claims for additional days.

INCENTIVES/DISINCENTIVES

Incentives and disincentives (I/D) are frequently used in highway construction to encourage a contractor to meet the contract's specified schedule. Liquidated damages, a form of disincentive, assess the contractor a dollar amount for each day the contractor is late beyond the maximum construction duration. The liquidated damage value is associated with those costs incurred by the agency in support of construction. Some states also incorporate road user costs as a basis for the value of liquidated damages because of the impact delays have on the traveling public. The TxDOT has used a value of $25,000 per day for liquidated damages on reconstruction projects with high-traffic volumes, where the impact on road users is substantial.

As the data in Figure 6 indicate, I/Ds are used by most agencies. The primary purpose of I/Ds is to motivate the contractor to complete construction early. This result was confirmed by the survey respondents (as shown in Table 8), as agencies used the goal of meeting construction durations or predetermined milestones as a basis for assessing I/Ds. Saag (1999) reports that incentives are used in construction contracting to reduce overall cost, to control time, and to increase support of specific performance goals, such as productivity and safety. In the highway industry, incentives focus almost exclusively on expediting completion of construction, with a net affect of reducing the duration of construction-related delays and the mitigating impact on motorists. In this way, I/Ds aid in reducing lane occupancy, although not as directly or at the same magnitude of impact as lane rental or A+B bidding.

TABLE 8
BASIS FOR ASSESSING INCENTIVES/DISINCENTIVES

Basis for Incentives/Disincentives	DOTs Use as Basis (%)
Meeting construction duration	76
Meeting predetermined milestones	57
Achieving given level of quality	26

Normally, incentives go hand-in-hand with disincentives. The value per day for the I/D calculation is based on road user costs applied equally to both incentives and disincentives. The FLDOT, for example, uses a range of user costs of between $2,000 and $6,000 for I/Ds. Anderson and Russell (1999a) found that most DOTs place a cap on the total incentives paid, determined as either a percentage of the total construction costs or the total number of days that can be earned for early completion, and that disincentives are rarely capped. Liquidated damages are often used in conjunction with I/Ds and are applied once the maximum construction duration is reached.

FLEXIBLE NOTICE TO PROCEED

Flexible notice-to-proceed dates (variable start dates) is an approach that gives the contractor the option of selecting, within a specified period, when construction can begin. Although the number of calendar days of construction time is specified, and the contractor may be required to bid time, a flexible start date is still allowed. Normally, the contractor begins work shortly after the "Notice to Proceed." With flexible starting provisions, the contractor is allowed to extend this period of time (usually up to 100 days) before starting construction *(Alternate Contracting Users Guide* 1997 and *Primer on Contracting 2000* 1998). FLDOT uses flexible start dates for two reasons. First, this technique reduces the length of time the public is exposed to construction conditions. Second, the probability of completing construction within the authorized contract time is increased.

Flexible notice-to-proceed, or variable start dates, are being used by several agencies. This technique provides the contractor with more time to plan and schedule the use of equipment and manpower prior to the start of construction. Scheduling problems that may delay contract completion are avoided and public exposure to adverse construction conditions is reduced. The Oklahoma DOT has found that, when flexible start dates were used with A+B bidding, the maximum allowable contract times specified in the bid documents were reduced by 25 percent ("Flexible Start Time Provisions in Contract" 1998). According to the Oklahoma DOT's best practice, the next generation of this technique will allow a specific amount of time for the contractor to complete the project, but also limit the time the contractor can impact traffic. However, those agencies estimate flexible start dates to have medium-to-low impact on reducing lane occupancy. One agency stated specifically that flexible start dates were not used for this purpose, although a "side effect" of using flexible start dates may be some reduction in lane occupancy.

OTHER CONTRACTING METHODS

The primary contracting methods that are expected to reduce lane occupancy are lane rental, cost-plus-time bidding, and I/Ds. Variations of these methods have been successfully used by DOTs. Other techniques that can reduce lane occupancy may include variations of A+B bidding, the use of best-value for contract awards based on performance and cost, no-excuse bonuses, and design-build. Each of these techniques will be discussed here.

Herbsman and Ellis (1992) evaluated the use of factors other than cost under the low bid system. In this study, the contract could be awarded based on the total combined cost of a few parameters, such as cost, time, and quality, with a weight assigned to each parameter.

Rahman et al. (1999) discussed different variations of A+B with I/D bidding used in current practice and proposed several innovative applications of this bidding technique. One application of the cost-plus-time bidding approach is to have the contractor bid items related to traffic control separately on a lump-sum basis. In the bid documents, a partial performance-related specification is provided for traffic control. The contractor formulates a TCP to optimize construction phasing and staging. Use of this modified method could, perhaps, allow the contractor to more effectively maintain traffic while providing a construction-staging plan that reduces time in work zones, the length of work zones, and the number of work zones. The Utah DOT has used this concept successfully (Rahman et al. 1998).

Anderson and Russell (1999b) proposed guidelines for implementing best-value contracting for construction projects. In highly complex and specialized projects best-value may be effective in selecting a contractor with the experience and resources necessary to complete a project in a timely manner. Best-value evaluates both the technical/management and price components of a project in awarding the contract. If reducing time is a key project objective, then this factor can be incorporated into the technical/management evaluation criteria. The best-value approach would require enabling legislation, because it is not compatible with the low bid system. The Oregon DOT has successfully used best-value for a bridge repair project that had an extremely short time period allowed for closure ("Contract Award..." 1998). Best-value contracting is further described in the guidelines developed under an NCHRP Project by Anderson and Russell (1999b).

Several states have used a variation of the incentive concept, termed no-excuse incentives (bonus), which gives the contractor a "drop-dead date" for completion of a phase of the work or the entire project. The contractor receives a bonus if the work is completed in advance of this date. However, no excuses, such as delays caused by bad weather, are judged as acceptable for not making the completion date. Alternatively, there are no disincentives for not meeting the completion date other than normal liquidated damages *(Primer on Contracting* 1999). The FLDOT is using no-excuse bonus provisions, which are included in the FLDOT *Alternate Contracting Users Guide* (1997). Other states are applying different versions of the no-excuse incentive clause. For example, the Iowa DOT is using a clause that provides for a $250,000 incentive for early completion of an I-35 reconstruction project. The provision simply states that "any delays due to weather, change orders, overruns of quantifies, utility delays, or any other delays will not be considered as justification to modify the calendar date." Provisions such as no-excuse incentives can accelerate construction and minimize road user costs, thus mitigating some of the impact of lane occupancy on the traveling public.

State transportation agencies have shown an increasing interest in design-build contracting as an alternate contracting technique. Under the design-build approach, the contracting agency identifies the end result parameters and establishes the design criteria for a project. The design-build contractor is responsible for both design and construction of the facility and develops a design proposal in agreement with agency requirements, which optimizes the contractor's construction abilities. Design-build contracting is particularly suited for projects that fit the design-build process, such as complex facilities that require creative design components. This contracting method typically shortens project delivery times (from design through construction). If agencies require reducing lane occupancy as part of design-build projects, the contractor can propose designs that reduce both lane occupancy and road user costs. Contract incentive provisions may also be used in conjunction with the design-build process to encourage designs and construction schedules that reduce time and lane occupancy, and ultimately road user costs.

PROJECT APPLICATIONS

Trauner Consulting Services (1997) performed research for the FHWA on contract management techniques for improving construction quality. According to this research, highway construction and 4R projects (resurfacing, rehabilitation, reconstruction, and restoration) affect existing traffic, inconvenience the traveling public, impact adjacent businesses and property owners, and increase safety concerns. State highway agencies are increasingly turning to contracting strategies designed to reduce project delivery time and to shift more responsibility for workmanship and quality to the contractor. According to this research, the use of I/Ds, A+B bidding, and lane rental are all contract techniques suited for 4R projects.

Although the contracting methods cited in this chapter can be used on most facilities and project types, there may be contract methods that are better suited for specific projects, as suggested by the survey data. For example, facilities involving urban freeways and bridge widening are, perhaps, the best application for lane rental. Urban interchanges, rural freeway/highway widening, and intersection improvements also might benefit from using lane rental. Lane rental may be best suited for restoration, resurfacing, and reconstruction projects as well. Although I/Ds and cost-plus-time bidding can be used for all facility and project types, the best application of these two contract techniques may be for reconstruction projects, especially reconstruction of facilities such as urban freeways and interchanges and bridges, either new bridges or bridges that require widening. Both the MDOT and the NYDOT reported that their recent experiences agreed with these applications of A+B with I/Ds.

MEASURES OF EFFECTIVENESS

The use of bidding and contracting methods that place greater responsibility on the contractor for determining construction durations have been generally successful in reducing contract time when compared with the DOT engineer's estimate. With the increased use of cost-plus-time bidding, agencies can better capture historical data with respect to actual construction durations and subsequently improve the engineer's time estimate by comparing actual time versus planned time estimates. Because construction duration is a critical issue in reducing and mitigating the impact of lane occupancy, the ability to more precisely determine contract time is a valuable asset. This is one way to ensure that the public and local business community will not endure unnecessary inconvenience.

In their research, Trauner Consulting Services (1997) rated different contracting methods according to a set of criteria, including quality, cost, time, risk, and legal/administrative. Each criterion was given a score of 0 to 10, with 0 being a negative impact, 5 being neutral, and 10 being a positive impact compared with the traditional method. Each criteria was evenly weighted. The highest total scores were obtained for contracting systems such as A+B bidding with I/Ds and a quality assurance attribute, or A+B with quality assurance based on LCC. However, the research reveals that there is no "best" contracting method that should automatically be used. The selection of a suitable contracting method depends on a number of factors including the project type and complexity, traffic conditions, objectives and experiences of the agency, and the experience of the contracting community.

The majority of the transportation agencies do not measure the effectiveness of contracting techniques in reducing lane occupancy. Only nine respondents reported that measurements were used. Six agencies relied on direct feedback in the form of comments from reviews, meetings, and the public, and two agencies used incentives achieved by the contractor as a measure of effectiveness. Measurements of effectiveness could show that the more incentive earned by the contractor the more likely the contractor finished early, which may translate into less time in work zones.

Evaluation of previous projects might give some indication of effectiveness. For example, comparisons between time bid and actual time to project completion will determine if time reductions are being achieved and the magnitude of these reductions (see the NYDOT analysis discussed earlier). The FLDOT has conducted such a comparative analysis of alternate contracting methods and found that cost-plus-time bidding has reduced contract durations for construction, as used on FLDOT projects, based on comparisons of the engineer's estimate of time, time bid by the contractor, and the actual time taken to complete construction *(Alternate Contracting Program...* 2000).

Also, user delay costs for completed projects can be compared with the cost of implementing a contracting technique. If the cost of construction is not offset by a reduction in delay time and, hence, road user costs, then the contracting technique may not be cost-effective. If an agency can consistently reduce user costs and contract durations, these data may be indictors that contract methods are reducing lane occupancy during construction.

CHAPTER FIVE

CONSTRUCTION PROCESSES AND PRACTICES

The primary concern of the construction phase of a project is how to translate the plans and specifications into a completed facility. The construction effort must be planned so that resources are used efficiently and effectively to meet the contract time and achieve a high-quality facility within the contractor's bid. The contractor must rely on construction methods and management techniques that will help achieve the project's objectives. When minimizing lane occupancy is such an objective, techniques to reduce lane occupancy should be incorporated into the construction process. To ensure that these techniques are successfully implemented, both agency and contractor personnel can focus on partnering, VE, and construction and testing methods.

PARTNERING

Partnering is defined as a method of transforming the contractual environment into a cohesive, cooperative project environment based on a single set of project goals and procedures (Rock 1992; Grajek 1995). Partnering, as implemented in the public sector, is more often performed on a project-by-project basis. Typically, a state agency begins the partnering process with a contractor after the contract is awarded. The basic goal of partnering is to create an atmosphere conducive to enhancing communication, minimizing disputes, attaining mutually beneficial goals, and sharing risk.

Background Literature

According to Saag (1999), partnering is a voluntary process where the agency and the contractor commit to working together at the beginning of a project. The process usually begins with a 1- or 2-day workshop, during which participants attempt to agree on a common mission and objectives for the project, identify potential problems, and establish procedures to address these problems as they might arise. TxDOT uses the term "Rocks in the Road" to describe potential problem areas, with the intent of addressing these problems before they arise. The workshop often concludes with a charter that documents key results, such as a project mission statement, project objectives, and potential problem areas. TxDOT implements partnering through special provisions to their standard specifications and procedures and guidelines for partnering workshops ("Partnering Special Provisions" 1996; "Partnering Workshop Guidelines" 1999).

The Iowa DOT identified major arguments for the use of partnering that include up-front team building; clear definition of common objectives; synchronized means for rapid dispute resolution; mechanisms to reduce costs, litigation, and stress of contract administration; and joint evaluation of the partnering process (Smith and McWaters 1995). Other transportation agencies, such as the Arizona DOT, have successfully incorporated partnering into their construction process. Their projects have regularly finished under budget, ahead of schedule, and with very few claims filed. Partnering was applied to specific areas such as traffic control and work zone safety. Subcontractors responsible for this work have a forum to voice opinions and contribute their expertise in the preconstruction planning of a project (Flynn 1992). Furthermore, an Ohio DOT (ODOT) study has documented that partnering has enhanced an already existing positive atmosphere of cooperation between ODOT and contractors (Chapin 1994). However, ODOT found that neither significant cost savings nor reduction in contract durations had resulted from the use of partnering. According to ODOT, formal partnering was not viewed as suitable for every project, especially small projects. Other studies support these experiences (Grajek 1995; Larson 1995; Gransberg et al. 1999).

The TxDOT currently uses partnering on many projects. According to Gransberg et al. (1999), for projects over $5 million, TxDOT partnered projects have outperformed nonpartnered projects in the following 12 different performance categories:

1. Cost growth,
2. Average cost per change order,
3. Average percentage increase per change order,
4. Average total change order per project,
5. Time growth,
6. Average percentage of additional days granted,
7. Average liquidated damages as percentage of total cost,
8. Average liquidated damage days as percentage of total time,
9. Percentage of projects with liquidated damages,
10. Percentage of projects with deducts,
11. Claims cost as percentage of original cost, and
12. Dispute cost as percentage of original cost.

A key conclusion is that partnering provides a mechanism to control two project performance parameters, cost growth (Final Contract Amount - Original Contract Amount divided by Original Contract Amount) and time growth [Days Charged - (Total Days Allowed + Additional Days Granted) divided by Total Days Allowed + Additional Days Granted]. This finding suggests that partnering contributes to the reduction of lane occupancy, especially if partnering practices tend to reduce time growth. On the average, partnered projects finished 4.7 percent earlier than originally estimated. Other studies have found similar results (Westen 1993; Grajek 1995; Larson 1995; Schmader 1995).

Agency Practice

Eighty-eight percent of the agencies surveyed use partnering with their contractors. Respondents identified a number of construction issues addressed during partnering sessions that can help minimize a contractor's time in work zones. Table 9 summarizes the identified construction issues.

Management planning pertains primarily to establishing communication and problem resolution approaches to help ensure that the contractor has competent and adequate personnel with clearly identified responsibilities, decision-making authority, and planning for approval of change orders. These planning issues may also address the problems associated with reducing lane occupancy and its impact on road users.

When conducting the partnering workshop, both agency and contractor personnel are likely to be better prepared to achieve the project objective. For example, a potential area where disputes are likely to impact work zone operations are changes in construction staging. Awareness of this problem area may prevent delays through quick problem resolution, if problems emerge.

Most of the specific issues underlying construction schedules, TCPs, and project phasing/staging, as identified in Table 9, focus on their integration to improve construction sequences and complete the project on schedule. Emphasis would be placed on potential problem areas and how to mitigate their impact. Problem areas often focus on interfaces with utilities or ROW requirements during construction. Specific scheduling issues viewed as potentially problematic are changes in critical path activities, delays in activities, and/or resequencing of activities. Work schedule considerations such as off-peak, nighttime, and weekend construction are among the issues affecting construction schedules and traffic control during construction. Attention to these issues will help reduce construction time in work zones.

VALUE ENGINEERING

Value engineering (VE) clauses are often included in construction contract documents to encourage contractor suggestions that may improve the cost-effectiveness of the design. If the suggestion is accepted by the agency and leads to cost savings, a portion of those savings is passed along to the contractor (Halpin 1998).

The majority of respondents (75 percent) reported that their agency uses VE incentive clauses in construction contracts. Four categories of construction areas that are often addressed through VE that could reduce a contractor's time in the work zone are shown in Table 10. These areas pertain to changes in project phasing and construction staging and changes in methods and materials. This suggests that these types of improvements can reduce lane occupancy, particularly in the area of construction sequencing.

Performing work in a different order or sequence than specified in the contract documents to aid in managing resources more efficiently is one example of VE. Revising detour strategies and plans to handle traffic through work zones more effectively is another example. The use of temporary bypasses was also suggested as an area where changing the traffic control requirements may improve construction efficiency by minimizing staging changes and shortening durations.

TABLE 9
CONSTRUCTION ISSUES ADDRESSED DURING PARTNERING TO REDUCE LANE OCCUPANCY

Construction Issues	Frequency (Times Cited)	High Impact	Medium Impact	Low Impact
Management planning	19	11	5	2
Construction schedule	11	8	1	2
Traffic control plan/execution	10	4	5	1
Project phasing and staging	10	8	2	
General preconstruction planning	6	3	3	
Work schedule	5	2	3	

Note: Impact may not equal total frequency because some respondents did not always assess the impact.

TABLE 10

CONSTRUCTION AREAS ADDRESSED THROUGH VALUE ENGINEERING CLAUSES TO REDUCE LANE OCCUPANCY

Construction Area	Frequency (Times Cited)	High Impact	Medium Impact	Low Impact
Project phasing and staging changes	15	9	3	2
Methods and material changes	12	6	4	1
Design changes	5		3	1
Propriety products	1	1		

Note: Impact may not equal total frequency because some respondents **did** not always assess the impact.

TABLE 11

AREAS OF APPLICATION AND METHODS TO REDUCE LANE OCCUPANCY

Preconstruction Planning	Construction Equipment/Methods	Materials
Traffic flow	Number and types of equipment	Maturity testing
Change traffic control method	Conveyor belt	
Phasing and staging	Dowel bar insertion	
Multiple shifts	Wider paver	
Work Restrictions-off-peak	Movable barrier	
Multiple operations	Mobile recycling plant	
	Precast components	

TABLE 12

KEY APPLICATION AREAS AND THEIR IMPACT ON REDUCING LANE OCCUPANCY

Area	Frequency (Times Cited)	High Impact	Medium Impact	Low Impact
Preconstruction planning	18	9	7	
Construction equipment/techniques	10	4	5	
Materials	2	2		

Note: Impact may not equal total frequency because some respondents did not always assess the impact

The use of alternate materials can also be addressed through the VE process. The Iowa DOT noted that the substitution of cast-in-place box culverts with precast box culverts occurred through VE before the start of construction. Reuse of existing aggregate subcourse gravel material instead of new subcourse material was proposed as a VE alternative. Reuse of materials and precast components can save construction time and reduce lane occupancy during construction.

CONSTRUCTION METHODS AND MATERIALS TESTING

Approximately 45 percent of the survey respondents indicated that contractors use innovative construction methods to reduce lane occupancy or mitigate its impact on road users. These methods were concentrated in three main areas: (1) preconstruction planning, (2) construction equipment and/or construction method selection, and (3) material selection. Specific areas of application covered under each category are shown in Table 11. Table 12 summarizes application results and their impact on reducing lane occupancy. As shown in Table 11, preconstruction planning includes such areas as changes to traffic control and construction staging and sequencing; the use of off-peak construction times including weekends, night work, and multiple shifts; and employing multiple operations under one lane closure at the contractor's discretion. These methods would have a medium-to-high impact on reducing lane occupancy depending on the project situation. Although there was an expectation that the main focus of the techniques would be on materials, equipment, and specific construction methods, preconstruction planning issues was cited most frequently. This suggests that planning is a key issue if reducing lane occupancy is a primary objective.

As delineated in Table 11, examples of equipment and construction methods cited by survey respondents include conveyer belts to transport excavated materials, mechanized dowel bar insertion, moveable barriers, wider paving machines, mobile and portable recycling plants, and precast components. The application of these types of equipment and methods was assessed as having a medium-to-high impact on reducing lane occupancy, as shown in Table 12. For example, use of portable crushing plants and concrete batching plants on-site helps reduce truck-hauling activities and site congestion, and may accelerate construction.

In the area of material selection, two respondents cited the use of high early strength concrete, although this material would typically be specified during design. Maturity testing, which is used to determine opening strengths for concrete pavements, was cited as a testing method that might aid in reducing lane occupancy. This method can help a contractor predict when the pavement has achieved the required flexural strength to allow for resumption of traffic. The concepts of high early strength concrete and maturity testing are often associated with early-opening-to-traffic or fast-track concrete paving (Secmen et al. 1996). This general technique is being used more widely to reduce construction time and lane occupancy.

Secmen et al. (1996) conducted a research project for the TxDOT to identify, develop, and refine techniques for accelerating urban highway intersection reconstruction. The findings suggest that successful fast-track reconstruction requires intensive planning beginning early in the project, particularly as related to selecting materials, construction equipment, and analyzing logistics in the work zone. A contingency plan is vital and should cover such items as backup construction equipment and batch plant preparations. Two main construction areas were identified as having a potential for time savings: the demolition of existing materials and the placement of concrete. Demolition is considered the most time-consuming activity, because it requires breaking existing materials into small pieces for hauling off-site. The guillotine breaker, a machine that drops an iron block continuously on the pavement (Figure 7) was found to be highly effective on concrete pavements. Once the breaker has finished breaking the concrete, the small pieces are removed by using a hydraulic excavator and dump trucks. The major risk of this technique is the possibility of damaging underground utilities or existing subgrade.

A second method, precutting of slabs, reduces the risk of damaging existing subgrade materials or underground utilities. This method involves cutting the pavement into 4- by 4-foot slabs prior to the start of reconstruction. Once the pavement is closed to traffic, the slabs are lifted and hauled off-site. This method is very effective and leads to time saving, but can sometimes be costly. Caltrans used this approach on the I-10 pavement reconstruction project (Figure 8). The subgrade was not disturbed and minimal effort was required to prepare the existing subgrade material for the placement of new concrete.

Concrete placement is the second construction area where time savings could be made. Three primary methods are in use: vibrating/air screeds, Bidwell screeds, and slip forming. Each of these methods has different labor and space requirements and different impacts on cost. Generally, the Bidwell screed and slip forming methods are best suited for long sections of pavement (open highways), whereas the vibrating/air screeds are adopted for smaller and denser areas (urban intersections). Pouring concrete using a direct chute is preferable. Pumping concrete

FIGURE 7 Guillotine breaker used on accelerated intersection reconstruction project.

FIGURE 8 Precut concrete slab removal on I-10 pavement reconstruction project (photo courtesy of the University of California at Berkeley and the Innovative Pavement Research Foundation).

can also be used when construction access is limited due to physical obstructions, such as a bridge structure, or concrete trucks cannot dispatch the concrete directly.

As part of the FHWA Quality Journey program, several states are working together to find common solutions to reducing lane occupancy and its impact on road users. Five states, Pennsylvania, Maryland, Virginia, West Virginia, and Delaware, have decided to implement accelerated construction techniques on 25 percent of their projects by the year 2000 ("Accelerated Construction Schedule" 1998). Their objective is to address the growing problem of motorist delay as a result of construction and/or maintenance operations within the five-state area. The main areas of improvement focused on accelerated construction techniques and innovative/high-quality materials. Based on the same concept, the Illinois DOT instituted roundtable discussions to develop new strategies for reducing the impact of the rehabilitation and reconstruction of freeways ("Roundtable Discussions on Urban..." 1998). A small group, comprised of a dozen subject experts, discussed the impact of urban freeway rehabilitation projects on traffic and businesses, shared experiences and potential solutions, and identified construction methods and materials to help accelerate construction and mitigate the impact of construction on the traveling public.

When using high early strength materials to accelerate construction time, transportation of rapid setting concrete to the site must be executed as expeditiously as possible. This usually requires good site preparation to allow construction traffic easy access and may require a retardant to slow the rate of hydration. Some modifications may need to be made with respect to the mixing, hauling, placement, and curing. It is apparent that transportation time must be well managed, because it influences workability and admixture requirements. Also important is the prevention of concrete deliveries from "stacking"' up at the discharge point to where a loss of slump occurs in the second load while awaiting discharge. Stacking tends to develop during the sampling of the first truck delivery of the day for various test specimens.

Regardless of the method of concrete placement (by using a vibrating wheel or roller screed, or where appropriate slip forming paving), the most important aspect of current construction techniques is, perhaps, related to the methods and practices of curing. Because patch repairs using high early strength concrete are often subjected to traffic immediately upon opening, curing time may only be effective for a short time.

Manpower requirements associated with high early strength concrete placements may consist of dispatchers, loaders, batchmen, drivers, field representatives, and a quality control supervisor. The cost of high early strength concrete construction may be greater than conventional placements due to larger construction crews and other special arrangements necessary to ensure the availability of the batch plant at odd times (weekends, etc.). Moreover, higher labor costs are incurred because of nighttime/weekend work, work-hour regulations for certain professions (e.g., truck drivers), and the short-term nature of high early strength concrete placements. These costs may be offset to some extent by the reduction in construction time and the associated impact on road users.

In the area of flexible pavements, a 10-mile section of a West Virginia turnpike was rubblized and reconstructed with a full-depth hot-mix asphalt (HMA) overlay. Rubblizing consists of breaking the existing concrete pavement to create a subbase. This turnpike in West Virginia, a vital north/south route for interstate commerce, business commuters, and tourists for the western third of the state, links Charleston with I-81 to the south. The state highway agency decided that the use of a straight HMA overlay on the existing pavement would not prevent slab cracking, joint deterioration, faulting, and other distresses of the existing concrete pavement. The agency decided that extensive breaking or rubblizing of the concrete pavement before the overlay with HMA would help reduce the potential reflective cracking of the new asphalt pavement. A multiple head breaker, capable of rubblizing a 12-foot-wide section of the concrete pavement in a single pass, was used. This work was completed at a rate of 1 mile per day in 4-day segments of rubblizing/paving/opening to traffic ("Rehab Work That Doesn't Take a Toll on Traffic" 1998). Thus, the agency was successful in minimizing the impacts on road users by considerably reducing lane occupancy. Advancements in rubblization technology could eliminate many traffic concerns.

PROJECT APPLICATIONS

When given a focus on reducing lane occupancy, partnering, VE, and the construction methods identified can be used on any facility and project type. There is some indication from the survey data, however, that these techniques are better suited for some facility and project types than others.

When reducing lane occupancy, partnering appears applicable to almost all types of facilities, slightly favoring reconstruction or new construction projects, although differences are minor. Partnering probably has a more universal project application (Gransberg et al. 1999). Conversely, VE may be more applicable to elevated structures such as urban interchanges and bridges, and it provides a higher payoff for more complex and larger-sized reconstruction or new construction projects. Construction methods would likely have a noticeable impact on reducing lane occupancy for urban freeways and elevated structures, particularly in the area of preconstruction planning. Data indicate that the use of construction methods, as presented in Table 10, is more suited for projects requiring the resurfacing of existing pavements or reconstruction. Such projects would, perhaps, require longer work zones and offer the opportunity for reducing lane occupancy through better preconstruction planning and the use of appropriate construction equipment/techniques (e.g., movable barriers and wider pavers).

MEASURES OF EFFECTIVENESS

The majority of the transportation agencies do not measure the effectiveness of the techniques discussed in this chapter in reducing lane occupancy; only three respondents reported that specific measurements were used. One state agency maintains records of all VE changes proposed and their impact. Another state prepares summary reports on nighttime work and A+B bidding. In the later case, comparisons between time bid and actual construction time are recorded. User delay costs for completed projects are compared with the engineer's estimate of user costs. The ability of the agency to consistently reduce user costs and contract durations indicates that some techniques employed during construction are appropriate in reducing lane occupancy.

CHAPTER SIX

MAINTENANCE TECHNIQUES

Many highway maintenance activities require the occupancy of traffic lanes, structures, and shoulders of a roadway by agency or contractor personnel resulting in the disruption of traffic. This problem is particularly acute on roadways and/or bridges with higher traffic volumes. Although highway agencies are concerned with the exposure of maintenance personnel to safety hazards, they also want maintenance activities to proceed in an orderly and efficient manner, with minimal delays to the traveling public. Thus, reducing lane occupancy during maintenance operations is an important consideration. The techniques that support this maintenance objective are discussed in this chapter.

MAINTENANCE DESCRIPTION

The term maintenance as used in this synthesis is defined as periodic activities whose primary function is to preserve existing pavements, bridges, and appurtenances so that these facilities may achieve their applied loading and design life. Maintenance activities are frequently referred to as normal, routine, requiring minor rehabilitation, and/or preventive. The types of activities that are considered as maintenance may vary from agency to agency. Some typical maintenance activities would include pothole repair; patching; crack and joint sealing; drainage cleaning/repair; repairs to culverts, shoulders, subbases, and spalls; erosion control; mowing; and snow removal. Other maintenance activities cited include resurfacing, crack sealing, pavement marking, bridge painting, chip seal coating, and striping. Maintenance activities are also determined by facility components, such as the type of pavement or bridge structure. Some maintenance activities, such as mowing, will have little or no impact on lane occupancy.

AGENCY PRACTICE

A comprehensive study was performed in the mid-1970s to evaluate techniques for reducing roadway occupancy during routine maintenance activities (Byrd, Tallamy, MacDonald, and Lewis 1975). The study concluded that promising materials and equipment, planning and management, and managing the entire maintenance activity were potential techniques for lane occupancy reduction. Many of the techniques discussed are still applicable today. Agency practitioners were asked to identify the different techniques used to reduce lane occupancy during maintenance operations and to assess the level of impact of these techniques on reducing lane occupancy. Table 13 summarizes the techniques in five generic categories.

Work restrictions focused on performing maintenance operations on weekends or off-peak hours during the week and at night. As shown in Table 13, the impact of employing work restrictions on reducing lane occupancy is medium to high. Also, respondents considered weekends and off-peak maintenance operations as having a greater (high) impact on reducing lane occupancy. Seven respondents reported that weekend or off-peak maintenance had a high impact on reducing lane occupancy, whereas two respondents reported that these two types of work restrictions had a medium impact.

A variety of techniques were cited under the category of traffic management and control of lanes. For example, the use of detours or retaining one open lane were among the strategies used in more heavily traveled areas when performing maintenance, such as replacing markers or re-striping. However, moving lane closures or shoulder closures may be used for specific types of maintenance activities, such as litter removal or herbicide spraying.

TABLE 13
TECHNIQUE AREAS USED TO REDUCE LANE OCCUPANCY DURING MAINTENANCE

Technique Area	Frequency (Times Cited)	High Impact	Medium Impact	Low Impact
Work restrictions	19	10	7	1
Traffic management and lane control	13	5	3	2
Methods and materials	13	5	7	1
Work planning	11	5	3	2
Public communications	9	2	2	5

Note: Impact may not equal total frequency because some respondents did not always assess the impact.

Employing traffic control personnel, such as flaggers, was another technique for traffic management.

Different types of materials and construction methods and equipment were identified that could help reduce lane occupancy during maintenance. These included very early strength concrete for patching, use of a pavement patching machine, and special-purpose mobile equipment such as a device that automatically places and retrieves cones. Arkansas uses a pavement-patching machine on high-volume roadways. Quick drying paint was cited by the Idaho mad Nevada DOTs as a material that can expedite striping of pavements and, therefore, have a high impact on reducing lane occupancy.

As an illustration of one material application, VDOT used a rapid repair technique on a bridge that carries 64,000 vehicles per day. Closing the bridge would have caused major problems. As a result, VDOT decided to use a very-early-strength latex-modified portland cement concrete overlay that allows traffic to resume on the bridge deck within hours after construction begins. The project was completed successfully within 8 h, and the overlay is performing very well (Jackson 1998).

In another example, the Delaware River Port Authority has used equipment to automate the placing and retrieving of cones during maintenance. The Port Authority maintains four bridges that carry about 95 million vehicles every year. Maintenance crews now use a machine that automatically places cones that close a lane of traffic along the entire length of the bridge, preventing these crews from interfering with the high traffic volumes crossing the Delaware River. The same machine automatically retrieves the cones when maintenance activities are completed. This machine uses a single operator who sits safely away from traffic (Kuenne 1995).

Work planning, as cited in Table 13, focuses primarily on maximizing maintenance efforts when closing lanes. One technique, cited several times, involved performing multiple work activities during a lane closure. Another approach is the use of specialized high efficiency crews for specific operations. According to the MDOT, assigning multiple crews for time critical operations, such as concrete repair work, can increase the speed of the work. The Wisconsin DOT suggests that a temporary suspension of work while waiting for materials is a technique that can be adopted by agencies to reduce the impact of maintenance activities. Other similar techniques included combining maintenance activities when lanes are closed (a maintenance "blitz"). The maintenance blitz allows several maintenance teams to pool their people, resources, and equipment and undertake work in a large area on an expedited basis. These last two techniques were viewed as having a high impact on reducing lane occupancy as related to maintenance.

Public communication is often viewed as a technique for reducing the impact of maintenance work on the traveling public. As shown in Table 13, this technique has a relatively low impact on reducing lane occupancy. Examples techniques cited include:

- Advanced signage/arrow boards (Minnesota DOT),
- Variable message boards (VDOT) to inform motorists in advance of delays,
- Road condition reports using an 800 telephone number,
- Road conditions reports obtained through an Internet web site,
- Public service announcements on radio and/or television in urban areas (city of Calgary) to inform the general public of the locations of maintenance work and recommendations for alternate routes, and
- Media blitz to inform motorists of upcoming work and possible delays (Kentucky and Virginia DOTs).

If these techniques reduce traffic volume through a maintenance area, agency personnel may be able to complete maintenance activities in a more efficient and expeditious manner, thereby reducing lane occupancy.

MEASURES OF EFFECTIVENESS

Most transportation agencies do not measure the effectiveness maintenance techniques have on reducing lane occupancy. Five respondents reported that some form of measurement was used. One agency ties peak hour traffic volumes to certain techniques. Another agency relies on input from the public through hotlines and informal discussions. A third agency performs a quality assessment of maintenance for each contract on a weekly basis. A fourth agency cited incentive programs that reward efficiencies, such as production achieved against a standard measure of production or work level of service. Most of these measures would be indirect indicators of an agency's success at applying a maintenance technique to reduce lane occupancy and its impact on road users.

CHAPTER SEVEN

INTEGRATION OF TECHNIQUES, METHODS, AND PROCESSES

The safe and efficient flow of traffic through construction and/or maintenance work zones is a major concern to all those involved in maintaining and improving highway facilities. One general strategy that may alleviate this concern is the application of various techniques to reduce lane occupancy and its impact on road users during construction and maintenance operations. Few techniques, however, accomplish this strategy directly. Most techniques would indirectly influence the time contractors and/or maintenance personnel occupy lanes while performing different operations. As presented in earlier chapters, many techniques were identified for use in different phases of project development. This chapter attempts to provide an integrated perspective for the application of these techniques, if implemented on a single project type.

The process would start during the project-planning phase, and can be driven by the clear understanding that the reduction of lane occupancy during construction is a concern. Decisions regarding pavement design and materials selection made during the design phase can reduce the level of maintenance required during facility operation. Other considerations include budget and time-related ones, and the involvement of the public at certain times during project development. Nevertheless, when reducing lane occupancy is a clear priority, engineers and decision makers should select those techniques that will address this concern.

PROGRAMMING AND PLANNING

During the planning and programming phase, an overall traffic management plan (TMP) for a project can be developed. The extent to which this plan incorporates a corridor analysis is a function of the volume of traffic, the facility type, the project type, and the required level of reduction in lane occupancy during construction. For example, if the reconstruction project is an urban freeway with interchanges, then it is likely that traffic may have to be diverted to alternate routes. Consideration could also be given to strategies that involve maximum use of off-peak hours, night construction, and/or weekends. A similar facility in a rural setting may not require as an extensive TMP if traffic volumes are less. As part of the plan, road user costs have to be estimated to determine the overall economic impact on the communities affected and, perhaps, the LCC of the facility. Furthermore, road user cost data are needed for analyzing specific project phasing and TCPs, as well as for the use of alternate contracting techniques. Public perception would be evaluated to assess the perceived impact that the project would have on motorists, local communities, and businesses. A public awareness campaign can be initiated to inform road users when potential delays will occur and what alternate travel routes will be available.

In addition to a TMP, the application of techniques used in other project phases could be evaluated and incorporated into an overall project plan. Some specific techniques that might be considered at this stage are constructibility reviews, prefabrication, innovative contracting methods, partnering, and VE. When focussing on mitigating the impact of lane occupancy, these techniques should be included in project procedures. Other techniques that might be considered during this planning and programming phase are the use of innovative materials and construction methods.

Finally, strategies that might affect future maintenance could be established during this phase. Designing to achieve extended pavement service life, selection of durable materials, and the application of different techniques to ensure that these designs can be successfully implemented could result in reduced lane occupancy ("Get In, Get Out, and Stay Out" 2000). The use of design techniques to allow rapid rehabilitation of bridge decks is another strategy that might be considered during this early project phase (Tadros and Baishya 1998).

DESIGN

Once the project proceeds into design and sufficient preliminary design data are available, project phasing and traffic control plans are developed. These plans would be developed within the framework established through the TMP. At this stage, specific techniques can be applied within design processes/procedures for TCP development to focus on reducing lane occupancy. The use of off-peak closures and detours was the most frequently cited technique having the highest level of impact on reducing lane occupancy.

As project phasing and TCPs are developed, constructibility review is an important technique that should be incorporated into the evaluation of these plans. Constructibility reviews can ensure that project phasing and TCPs reflect a realistic approach to construction sequencing.

Constructibility issues relevant to reducing lane occupancy are scheduling of operations, maintenance of traffic, and project phasing. Construction expertise, if input in these areas, would provide suggestions or ideas that would, perhaps, better integrate construction operations and resources with TCPs.

Constructibility input could also be used to modify design features to promote construction efficiency or recommend changes to designs to include implementation of innovative materials and construction methods. The intent of focusing on these constructibility issues would be to potentially reduce lane occupancy. The use of high early strength concrete is one material that can be considered during design. The application of this material can be thoroughly evaluated from a construction perspective. In some cases, certain traffic control and phasing strategies might require unique construction equipment, such as wider paving machines or movable barriers, or perhaps the use of prefabricated components for certain types of interchanges or bridge facilities. The use of temporary bridges may be a solution for certain projects. Construction input would be useful in evaluating the effectiveness of using these techniques in reducing construction time in work zones and minimizing the impact of construction on road users.

While designing TCPs, many agency professionals cited innovative contracting as an excellent technique to help ensure that TCPs reduce lane occupancy. Lane rental was cited as the most effective contracting technique. This technique, however, is probably more applicable to certain types of projects, such as resurfacing, restoration, and reconstruction. Cost-plus-time bidding and I/Ds were considered less effective in reducing lane occupancy. Both were believed to be more useful on reconstruction projects where complexity and impact on road users were high. All three of these contracting methods require estimates of road user costs for their application. Decisions concerning these contract methods can be made as TCPs are developed and reviewed from a constructibility perspective.

CONSTRUCTION

Once the design is complete, the project can be bid and the project awarded to the lowest responsible bidder. If techniques to reduce lane occupancy were incorporated into the design process at that time, partnering should be implemented to ensure that these techniques are pursued by the contractor during construction. Partnering can focus on issues related to the construction schedule and project phasing and staging in the context of reducing or minimizing overall time in work zones. VE incentive clauses can also be incorporated into the contract to promote innovative ideas with respect to project phasing and staging changes. This VE analysis frequently occurs during the preconstruction phase of the project. Finally, there may be some construction methods and materials that the contractor uses to minimize time in work zones. Tapping this expertise is an excellent idea and could be an integral part of preconstruction planning. Preconstruction planning should consider several key issues, such as changing traffic control methods, project phasing and staging changes, and the use of multiple shifts and work restrictions (off-peak hours). A contractor would need to evaluate these issues if the project is being contracted using cost-plus-time bidding, lane rental, or I/Ds.

SUMMARY

Transportation agencies apply a variety of techniques, methods, and processes to reduce lane occupancy and/or mitigate the impact of lane occupancy on road users. A summary of general technique areas is shown in Table 14. According to the data, only a small number of agencies use all of the techniques. This suggests that certain techniques are more useful and easier to implement then others. It may also indicate that opportunities exist for implementing a more holistic or systems approach to reducing lane occupancy encompassing all project phases. Facility and project type would likely play a role in the extent to which all these techniques might be applied on any given project and facility type.

TABLE 14
SUMMARY OF APPLICATION OF TECHNIQUE AREAS

Areas	Focus on Reducing Lane Occupancy (% using technique)
Design	
Constructibility reviews	97
Project phasing and traffic control plans	79
Materials	74
Prefabrication	64
Construction equipment	23
Contracting	
Incentives/disincentives	95
Cost-plus-time (A+B)	62
Lane rental	52
Construction	
Partnering	87
Value engineering clauses	76
Construction methods	44
Testing	9

Saag (1999) illustrates the integration of many of the techniques shown in Table 14 for the reconstruction of urban freeways and expressways. Early programming and planning of project development is critical to the project success of major reconstruction projects. These types of projects often use partnering and alternate contract methods such as A+B and I/Ds. Involving and informing the public is essential so that the public is continuously involved. Traffic management considers traffic handling strategies and strategies for construction scheduling and impact mitigation using alternate routes. Work zone traffic control is incorporated into TCPs and includes handling traffic during construction and the consideration of safety issues. Other issues considered important during the design process include constructibility reviews, VE, and LCC.

On a smaller scale, the Wisconsin DOT integrates several of the techniques presented in this synthesis in their selection process for freeway work zone traffic control methods. In this process, consideration is given to factors such as work zone length and width, construction seasons, measurement of the impact of projects on traffic flow, evaluation of user costs, and alternate contracting methods, including A+B and lane rental *(Freeway Work Zone...* 1997).

CHAPTER EIGHT

CONCLUSIONS

The literature review and surveys of transportation agency practices provided a basis for identifying techniques, methods, and processes that reduce lane occupancy and mitigate its impact during construction and maintenance. The techniques practiced are somewhat unique to the different phases of a transportation project, yet they are interrelated in terms of their focus. The three project phases that occur prior to construction are programming, planning, and design. Contracting bridges the gap between design and construction. In turn, construction has its own set of techniques. Similarly, there are techniques that are applied during maintenance operations. Several trends emerged as a result of studying these techniques and their application across different facility and project types and project phases.

Planning is a key technique area in reducing lane occupancy. Planning begins with project programming at a regional or system level, with a global focus on traffic issues in different geographical locations. A general agency policy can be established that will effectively focus programming and project planning on issues related to reducing and mitigating the impact of lane occupancy on road users. The development of a comprehensive traffic management plan may be the best approach to implementing this policy. Early public input and involvement is needed to ensure that this policy is implemented in the most cost-effective manner. If designing for maintenance can be incorporated into this policy as well, it can have a substantial impact on reducing lane occupancy during maintenance of transportation facilities. However, very few agencies have policies and subsequent program-wide approaches that integrate the various techniques used in design, contracting, construction, and eventually maintenance to reduce lane occupancy.

Typical agency design processes focus on reducing lane occupancy as project phasing decisions are made and traffic control plans (TCPs) are developed. Off-peak closures and detours are the principal techniques used when developing and analyzing these plans. Constructibility reviews are frequently practiced during design and are especially important for ensuring that TCPs are constructible. These reviews provide an effective tool for addressing construction issues that could help reduce lane occupancy. Key issues addressed include project phasing, scheduling, and maintenance of traffic, all of which are integral components of controlling traffic through work zones. Alternate contracting techniques such as cost-plus-time, lane rental, and incentives/disincentives (I/Ds) are viewed by design personnel as working in conjunction with off-peak closures and detours to ensure that lane occupancy is reduced and, perhaps, that the impact of lane occupancy on road users is mitigated to the greatest extent possible.

As project designs are developed, consideration may be given to specifying the materials and construction equipment that could reduce lane occupancy by accelerating construction times. High early strength concrete is frequently used on pavements to allow for early opening to traffic. Movable barriers provide an effective mechanism for rapidly setting up work zones and allowing workers a safe environment in which to work. Movable barriers can be specified by the agency to support specific TCPs and subsequent construction staging approaches. Prefabrication of facility components reduces construction time, especially for bridges and drainage structures. In addition, the use of temporary bridges can be an effective approach to maintaining traffic flow during rehabilitation or replacement of a major bridge facility.

Using nontraditional contracting methods is helpful in reducing lane occupancy and the impact of lane occupancy on road users. These methods are also integral in effectively implementing TCPs. Such nontraditional contracting methods include cost-plus-time (A+B) bidding, lane rental, and I/Ds. Of these techniques, lane rental has the highest and likely the most direct influence on reducing lane occupancy. However, lane rental is used less frequently because of more project and facility specific application requirements. A+B, I/Ds, and variable start dates can reduce overall project duration. However, work under these contract methods is often shifted to off-peak hours, nights, or weekends to accommodate schedule acceleration. This reduces the impact on traffic because work zones are occupied during periods of lower traffic volume. Finally, newer and emerging contract techniques such as A+B with traffic control, design-build, no-excuse incentives, and best-value contracting may provide DOTs with other contracting alternatives to aid in reducing lane occupancy and mitigate the affect of lane occupancy on the traveling public. A contract technique selected should be tailored to fit specific types of projects and their unique characteristics.

The majority of DOTs are using partnering on their projects. Partnering provides an excellent forum for the agency and contractor to focus on those construction issues that reduce lane occupancy. Some key areas of focus during partnering sessions include management planning of the project, project phasing and staging, and construction scheduling. These issues were deemed to have the highest potential impact on reducing contractor time in the work zone. Value engineering (VE) incentive clauses are also frequently used to encourage contractors to find ways to reduce work zone occupancy. Changes in project phasing and staging approaches, as a result of VE analysis, would have the highest impact, whereas changes in methods and materials and designs would have a lesser impact. These types of changes would likely reduce the cost of the project as well.

In addition to partnering and VE, focusing on construction methods and materials may reduce contractor time in a work zone. Preconstruction planning is often used to evaluate traffic control and its influence on construction sequences and the use of shifts or work restrictions. The use of certain types of equipment, such as conveyor belts, movable barriers, mobile recycling plants, and wider paving machines may help to reduce lane occupancy. The use of partnering and VE will encourage contractors to analyze construction methods and materials and, perhaps, suggest changes in these areas that will reduce the impact of construction work on road users.

Partnering and VE have a substantial impact on reducing lane occupancy on reconstruction and new construction project types and facilities involving urban freeways and interchanges, rural freeways and highways requiring widening and realignment, and bridges, both new and widening, and can be used on any facility or project type. They have the most universal application, and the results of their implementation on projects reduces construction time and cost.

Work restrictions, traffic management and control of lanes, methods and materials, and work planning are effective techniques for reducing lane occupancy during maintenance operations. Although all these techniques aid in reducing lane occupancy, the impact of any one method is not overwhelmingly high. The most frequently used methods are patching; repairs such as culverts, shoulders, and base material; resurfacing; and crack sealing. Many of the techniques used to reduce lane occupancy during construction were also considered viable for maintenance operations. Specific examples include certain contract techniques and partnering. There was little consensus, however, on which techniques were best suited for a maintenance application.

All the techniques identified in the study to reduce lane occupancy during construction can be used on any facility and project type. As expected, these techniques probably provide the most benefit to the agency when used on reconstruction projects and new construction projects subjected to high-traffic volumes. Also, as expected, facility types likely to receive the most benefit would include those in urban settings (freeways, interchanges, and intersections) and those in rural settings when a roadway requires widening or realignment. Special facility types such as new bridges or bridge widening offer excellent opportunities to use many of these techniques.

Few agencies measure the effectiveness of techniques to reduce lane occupancy used during the development of a transportation project. Most measures of effectiveness cited were very specific, such as measuring public perceptions, impact on road user costs, and flow of traffic through the work zone. As such, comprehensive agency policies on reducing lane occupancy are not widely implemented. This would indicate, perhaps, that the application of practices is not as extensive as indicated in this synthesis.

Reducing lane occupancy and minimizing its impact on road users can be a clear objective for many facility and project types. This would heighten awareness to implementing those techniques that would have the highest impact on reducing lane occupancy during construction and future maintenance operations. Transportation agencies can use a number of these techniques in combination. If effectively integrated into a comprehensive transportation project plan, the benefit in reducing lane occupancy could, perhaps, be higher than using the techniques on an individual basis. Some techniques, such as contracting methods, are viewed as important across the different phases of a project. All techniques can be applied to both traffic management and control and integrated into the development and analysis of plans for effective traffic management and control.

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APPENDIX A

Survey Questionnaire

NCHRP PROJECT 20-5 SYNTHESIS
TOPIC 30-12
TECHNIQUES USED TO MINIMIZE LANE OCCUPANCY DURING CONSTRUCTION AND MAINTENANCE

QUESTIONNAIRE

PURPOSE OF THE QUESTIONNAIRE

Construction and maintenance operations inevitably require work forces to occupy the roadway. With traffic demand at or near congestion levels on many roads, methods for reducing time on the road are being applied by State Departments of Transportation (DOTs) and many other agencies. These methods include agency programs and policies for planning, design, construction and maintenance processes for minimizing lane occupancy.

This synthesis will document techniques currently used to minimize lane occupancy during construction and maintenance. The study focus is primarily on techniques implemented in the following areas: design, contracting, construction, and maintenance. Consideration will be given to details relevant to the application of these techniques, and the types of facilities and/or projects that are best suited for their use. Finally, measures or approaches used to assess effectiveness of these techniques, as implemented by DOTs, will be reviewed.

Please complete the following request for information to aid in processing this questionnaire:

Agency: ______________________________
Address: ______________________________
____
City: ______________ State: ______________ Zip: ______________
Questionnaire Completed by: ______________________________
Current Position/Title: ______________________________
Date: ______________
Telephone: ______________ FAX: ______________
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PLEASE RETURN THE COMPLETED QUESTIONNAIRE BY **June 30, 1999.**

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Please contact Stuart Anderson if you have questions.

THANK YOU IN ADVANCE FOR YOUR HELP AND COOPERATION WITH THIS PROJECT

Please Write On The Back Of A ny Pages If You Need More Space For Your Response

BACKGROUND INFORMATION FOR COMPLETING THE QUESTIONNAIRE

Objective of Questionnaire

To identify planning, design, contractual, construction, and maintenance techniques, methods, and processes employed to minimize lane occupancy.

To determine evaluation methods employed to measure effectiveness of these approaches.

Distribution of Questionnaire

This questionnaire is separated into stand-alone sections corresponding to different divisions/groups within your agency. The sections are as follows:

Section I	-	Design
Section II	-	Contract Administration
Section III	-	Construction
Section IV	-	Maintenance
Section V	-	Planning/Programming

If desired, each section can be completed by the appropriate division/group. Each section of the questionnaire has page breaks for ease of distribution to personnel within an agency.

Definitions

For purposes of this questionnaire the following terms are used:

Maintenance—periodic activities whose primary function is to preserve the existing pavements or bridges so that they may achieve its applied loading (sometimes called normal, routine, minor rehabilitation, and/or preventive maintenance).

Construction— include activities whose primary purpose is to significantly extend the service life of an existing pavement or bridge such as through resurfacing, recycling, restoration, rehabilitation, replacement, and/or reconstruction. New construction may add capacity.

Techniques that reduce or minimize lane occupancy can potentially be applied during both construction and maintenance. Throughout the questionnaire you are asked to identify whether or not a technique can be used for construction and maintenance.

Techniques used by DOTs may have different levels of impact on minimizing lane occupancy during construction and/or maintenance. In an attempt to obtain information on the relative impact of these techniques, you are asked to assess the **Level of Impact** using a three category scale as described below:

- **High (H)** - technique leads to a substantial reduction in lane occupancy
- **Medium (M)** - technique leads to a moderate reduction in lane occupancy
- **Low (L)** - technique leads to a minimal or no reduction in lane occupancy

SECTION - TECHNIQUES USED DURING DESIGN TO MINIMIZE LANE OCCUPANCY

1. **Project Phasing, Managing Travel, and Construction Phasing -** Effectively integrating traffic control plans and construction phasing is a technique that can impact lane occupancy during construction.

   a. Does your agency focus on minimizing lane occupancy when developing project phasing and traffic control plans? Yes____ No____ *If no, go to Question 2.*

   b. Please briefly describe the process/procedure your agency uses to develop and analyze these plans?

   c. List up to three special methods/techniques that are used to develop and analyze project phasing and traffic control plans that minimize lane occupancy during construction?

      1.

      2.

      3.

   d. In your opinion, what level of impact (High, Medium, and Low) will using the methods/techniques identified in Question "c" have on minimizing lane occupancy during construction?

      1. H ____ M ____ L ____ 2. H ____ M ____ L ____ 3. H ____ M ____ L ____

   e. How does your agency incorporate impacts on the traveling public in the evaluation of project phasing alternatives, traffic control strategies, and construction traffic control plans?

   f. What measures are used to consider the impact of these decisions on safety, mobility, and travel productivity or efficiency?

   g. Please list those techniques identified in Question "c" above that are used on maintenance activities?

2. **Materials**

   a. Does your agency specify materials that help minimize lane occupancy during construction (e.g., high early strength concrete)? Yes____ No____ *If no, go to Question 3.*

b. If yes, list up to three types of materials used and briefly describe each material.

1.

2.

3.

c. In your opinion, what level of impact (High, Medium, Low) will using these materials have on minimizing lane occupancy during construction?

1. H ____ M ____ L ____ 2. H ____ M ____ L ____ 3. H ____ M ____ L ____

d. What types of projects/facilities are *best suited* for using these materials, especially when a project objective is to minimize lane occupancy during construction (Check those best suited)?

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
	____ Overlays	____ City Street Improvements
____ Reconstruction w/Recycling	____ Rural Freeways/Highways - New alignment	____ Other - Specify __________
____ New Construction	____ Rural Freeways/Highways - Widening or realignment	______________________

e. Please list those materials identified in Question "b" above that are used on maintenance activities.

3. **Construction Equipment**

a. Does your agency specify construction equipment that would help minimize lane occupancy during construction? Yes____ No ____ *If no, go to Question 4.*

b. If yes, list up to three types of equipment and briefly describe their application.

1.

2.

3.

c. In your opinion, what level of impact will using this equipment have on minimizing lane occupancy during construction?

1. H ____ M ____ L ____ 2. H ____ M ____ L ____ 3. H ____ M ____ L ____

d. What types of projects/facilities are *best suited* for using this equipment, especially when a project objective is to minimize lane occupancy during construction (Check those best suited)?

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
____ Reconstruction w/Recycling	____ Overlays	____ City Street Improvements
____ New Construction	____ Rural Freeways/Highways - New alignment	____ Other - Specify __________ ________________________
	____ Rural Freeways/Highways - Widening or realignment	

e. Please list those construction equipment types identified in Question "b" above that are used on maintenance activities.

4. **Prefabrication -** Facility components are constructed elsewhere and then installed when ready for placement.

   a. Is prefabrication of facility components specified when a project objective is to minimize lane occupancy during construction? Yes____ No____ *If no, go to Question 5.*

   b. List up to three types of prefabricated facility components that would help minimize lane occupancy during construction.

      1.

      2.

      3.

   c. When prefabricated facility components are specified, what level of impact will this approach have on minimizing lane occupancy during construction?

      1. H ____ M ____ L ____   2. H ____ M ____ L ____   3. H ____ M ____ L ____

   d. What types of projects/facilities are best suited for prefabricated components, especially when a project objective is to minimize lane occupancy during construction (Check those best suited)?

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
____ Reconstruction w/Recycling	____ Overlays	____ City Street Improvements
____ New Construction	____ Rural Freeways/Highways - New alignment	____ Other - Specify __________ ________________________
	____ Rural Freeways/Highways - Widening or realignment	

   e. Please list those prefabricated components identified in Question "b" above that are used on maintenance activities.

5. **Constructibility Reviews -** Constructibility reviews incorporate construction experience and knowledge into the design of facilities to enhance ease and efficiency of construction.

   a. Does your agency perform constructibility reviews during design? Yes____ No____ *If no, go to Question 6.*

b. If yes, is the review formal (follows documented guidelines/procedures) ____ or informal (follows no documented guidelines/procedures) ____ (Check one)

c. Identify up to three constructibility issues that are typically addressed during design that would minimize a contractor's time in work zones?

1.

2.

3.

d. In your opinion, what level of impact will addressing these constructibility issues have on minimizing lane occupancy during construction?

1. H ____ M ____ L ____ 2. H ____ M ____L ____ 3. H ____ M ____ L ____

e. What types of projects/facilities are *best suited* for constructibility reviews, especially when a project objective is to minimize lane occupancy during construction (Check those best suited)?

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
	____ Overlays	____ City Street Improvements
____ Reconstruction w/Recycling	____ Rural Freeways/Highways - New alignment	____ Other - Specify ______________________________
____ New Construction	____ Rural Freeways/Highways - Widening or realignment	

f. Can you provide a project example to illustrate the application of one constructibility issue?
Yes ____ No ____

g. Please list those constructibility issues identified in Question "c" above that apply to maintenance activities.

6. **Other Techniques Used During Design to Minimize Lane Occupancy**

a. Please identify and describe other techniques used during the design phase of a project that your agency implements to minimize lane occupancy during construction. *If none, go to Question 7.*

1.

2.

3.

b. In your opinion, what level of impact will using these techniques have on minimizing lane occupancy during construction?

1. H ____ M ____ L ____ 2. H ____ M ____ L ____ 3. H ____ M ____ L ____

c. What types of projects/facilities are *best suited* for use of these techniques, especially when a project objective is to minimize lane occupancy during construction (Check those best suited)?

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
____ Reconstruction w/Recycling	____ Overlays	____ City Street Improvements
____ New Construction	____ Rural Freeways/Highways - New alignment	____ Other - Specify __________ ________________________
	____ Rural Freeways/Highways - Widening or realignment	

d. Please list those techniques identified in Question "a" above that are used on maintenance activities.

e. Can you provide a project example illustrating the use of one of these techniques? Yes____ No____

7. **Evaluation of Effectiveness**

a. Does your agency have a process to assess the effectiveness of the techniques identified in this section, when they are used on projects? Yes____ No____ *If no, return this Section to the coordinator or go to Section II.*

b. If yes, list which techniques. How does your agency measure their effectiveness in minimizing lane occupancy? How does your agency determine if the measure of effectiveness is achieved?

SECTION II - CONTRACTUAL TECHNIQUES TO MINIMIZE LANE OCCUPANCY

1. Does your agency use any of the following construction contracting techniques:

Lane Rental	Yes____	No____
Cost-plus-Time (A+B) Bidding	Yes____	No____
Incentives/Disincentives (I/D)	Yes____	No____

If no to all techniques, go to Question 5.

2. For those contract techniques being used (Yes), please answer the following questions:

a. Do you use a special provision or a special specification to adapt the contract technique?

Lane Rental - ____ Special Provision or ____ Special Specification
A+B - ____ Special Provision or ____ Special Specification
I/D - ____ Special Provision or ____ Special Specification

b. What is the level of impact (High, Medium, Low) of using each contract technique on minimizing lane occupancy during construction?

Lane Rental - H ____ M ____ L ____
A+B - H ____ M ____ L ____
I/D - H ____ M ____ L ____

c. What types of projects/facilities are *best suited* for use of these techniques, especially when a project objective is to minimize lane occupancy during construction (Check those best suited)?

Lane Rental

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
	____ Overlays	____ City Street Improvements
____ Reconstruction w/Recycling	____ Rural Freeways/Highways - New alignment	____ Other - Specify __________ ________________________
____ New Construction	____ Rural Freeways/Highways - Widening or realignment	

A+B

Project Type	*Facility Type*	
— Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
	____ Overlays	____ City Street Improvements
____ Reconstruction w/Recycling	____ Rural Freeways/Highways - New alignment	____ Other - Specify __________ ________________________
____ New Construction	____ Rural Freeways/Highways - Widening or realignment	

Incentives/Disincentives

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
	____ Overlays	____ City Street Improvements
____ Reconstruction w/Recycling	____ Rural Freeways/Highways - New alignment	____ Other - Specify __________ ________________________
____ New Construction	____ Rural Freeways/Highways - Widening or realignment	

3. If your agency is using lane rental, please describe how lane rental is applied on your projects.

4. If your agency is using incentives/disincentives, what is the basis for assessing incentives/disincentives? (check those that apply):

   Meeting Construction Duration (time in calendar days) ____
   Meeting Predetermined Milestone Date(s) ____
   Achieving Given Level of Quality ____
   Other - Specify ____

5. Please identify and describe other contracting techniques used on your projects to minimize lane occupancy during construction (e.g., CPM Scheduling, variable start dates, etc.) *If none, go to Question 6.*

   1.

   2.

   3.

   a. In your opinion, what level of impact will using these techniques have on minimizing lane occupancy during construction?

   1. H ____ M____ L ____ 2. H ____ M ____ L ____ 3. H ____ M ____ L ____

   b. What types of projects/facilities are *best suited* for use of these techniques, especially when a project objective is to minimize lane occupancy during construction (Check those best suited)?

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
	____ Overlays	____ City Street Improvements
____ Reconstruction w/Recycling	____ Rural Freeways/Highways - New alignment	____ Other - Specify __________ ________________________
____ New Construction	____ Rural Freeways/Highways - Widening or realignment	

   c. Please list those contracting methods identified in Questions 1 and 5 that are also used for maintenance operations.

6. **Measures of Effectiveness**

   a. Does your agency have a process to assess the effectiveness of the techniques identified in this section, when they are used on projects? Yes____ No____ *If no, return this Section to coordinator or go to Section III.*

   b. If yes, list which techniques. How does your agency measure their effectiveness in minimizing lane occupancy? How does your agency determine if the measure of effectiveness is achieved?

SECTION III - TECHNIQUES USED DURING CONSTRUCTION TO MINIMIZE LANE OCCUPANCY

1. **Construction Methods**

   a. Do your contractors use innovative construction methods to minimize lane occupancy during construction? Yes ____ No ____ *If no, go to Question 2.*

   b. List up to three innovative construction methods and briefly describe each method.

   1.

   2.

   3.

c. In your opinion, what level of impact (High, Medium, Low) will using innovative construction methods have on minimizing lane occupancy during construction?

1. H ____ M ____L ____ 2. H ____ M ____ L ____ 3. H ____ M ____ L ____

d. What types of projects/facilities are *best suited* for applying these methods, especially if a primary project objective is to minimize lane occupancy during construction (Check those best suited)?

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
	____ Overlays	____ City Street Improvements
____ Reconstruction w/Recycling	____ Rural Freeways/Highways - New alignment	____ Other - Specify ______________________________
____ New Construction	____ Rural Freeways/Highways - Widening or realignment	

e. Please list construction methods identified in Question "b" above that apply to maintenance activities.

f. Can you provide a project illustration of the application of one method? Yes____ No____

2. **Testing Methods**

a. Does your agency use any special testing methods that would minimize lane occupancy during construction? Yes____ No____ *If no, go to Question 3.*

b. If yes, list up to three testing methods and briefly describe them.

1.

2.

3.

c. In your opinion, what level of impact (High, Medium, Low) will using these testing methods have on minimizing lane occupancy during construction?

1. H ____ M ____ L ____ 2. H ____ M ____ L ____ 3. H ____ M ____ L ____

d. What types of projects/facilities are *best suited* for applying these testing methods, especially if a primary project objective is to minimize lane occupancy during construction (Check those best suited)?

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
	____ Overlays	____ City Street Improvements
____ Reconstruction w/Recycling	____ Rural Freeways/Highways - New alignment	____ Other - Specify ______________________________
____ New Construction	____ Rural Freeways/Highways - Widening or realignment	

e. Please list those testing methods identified in Question "b" above that apply to maintenance activities.

3. **Partnering**

a. Does your agency use partnering with its contractors? Yes ____ No ____ *If no, go to Question 4.*

b. When implementing partnering, list up to three construction issues that are typically addressed during partnering sessions that would minimize a contractor's time in work zones?

1.

2.

3.

c. In your opinion, what level of impact will addressing these construction issues have on minimizing lane occupancy during construction?

1. H ____ M ____ L ____ 2. H ____ M ____ L ____ 3. H ____ M ____ L ____

d. What types of projects/facilities are *best suited* for partnering, especially if a primary project objective is to minimize lane occupancy during construction (Check those best suited)?

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
____ Reconstruction w/Recycling	____ Overlays	____ City Street Improvements
____ New Construction	____ Rural Freeways/Highways - New alignment	____ Other - Specify __________ ______________________
	____ Rural Freeways/Highways - Widening or realignment	

e. Please list any construction issues identified in Question "b" above that apply to maintenance activities.

4. **Value Engineering**

a. Does your agency use value engineering incentive clauses in construction contracts? Yes____ No____ *If no, go to Question 5.*

b. When implementing value engineering, list up to three construction areas often addressed through value engineering that would minimize a contractor's time in work zones?

1.

2.

3.

c. In your opinion, what level of impact will applying value engineering in these areas have on minimizing lane occupancy during construction?

1. H ____ M ____ L ____ 2. H ____ M ____ L ____ 3. H ____ M ____ L ____

d. What types of projects/facilities are *best suited* for value engineering studies prior to construction, especially if a primary project objective is to minimize lane occupancy during construction (Check those best suited)?

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
____ Reconstruction w/Recycling	____ Overlays	____ City Street Improvements
____ New Construction	____ Rural Freeways/Highways - New alignment	____ Other - Specify ____________________
	____ Rural Freeways/Highways - Widening or realignment	

e. Please list those areas identified in Question "b" above that apply to maintenance activities.

5. **Other Techniques Used During Construction to Minimize Lane Occupancy**

a. Please identify and briefly describe other techniques implemented during construction of a project that your agency uses to minimize lane occupancy during construction. *If none, go to Question 6.*

1.

2.

3.

b. For these techniques, in your opinion, what level of impact will they have on minimizing lane occupancy during construction?

1. H ____ M ____ L____ 2. H ____ M ____ L ____ 3. H ____ M ____ L ____

c. What types of projects/facilities are *best suited* for their application, especially if a primary project objective is to minimize lane occupancy during construction (Check those best suited)?

Project Type	*Facility Type*	
____ Resurfacing	____ Urban Freeways	____ Major Bridges - New
____ Restoration	____ Depressed Freeways	____ Bridge Widening
____ Reconstruction w/out Recycling	____ Urban Interchanges	____ Intersection Improvements
____ Reconstruction w/Recycling	____ Overlays	____ City Street Improvements
____ New Construction	____ Rural Freeways/Highways - New alignment	____ Other - Specify ____________________
	____ Rural Freeways/Highways - Widening or realignment	

d. Please list those techniques identified in Question "a" above that are used on maintenance activities.

e. Can you provide a project example that illustrates the application of any of the techniques identified above? Yes____ No____

6. **Measures of Effectiveness**

   a. Does your agency have a process to assess the effectiveness of the techniques identified in this section when they are used on projects? Yes____ No____ *If no, return this Section to coordinator or go to Section IV.*

   b. If yes, list which techniques. How does your agency measure their effectiveness in minimizing lane occupancy? How does your agency determine if the measure of effectiveness is achieved?

SECTION IV - TECHNIQUES USED DURING MAINTENANCE TO MINIMIZE LANE OCCUPANCY

1. Please identify and describe up to five techniques that your agency uses to minimize lane occupancy during maintenance operations. *If none, return this Section to coordinator or go to Section V.*

   1.

   2.

   3.

   4.

   5.

   a. For these techniques, in your opinion, what level of impact (High, Medium, Low) will they have on minimizing lane occupancy during maintenance operations?

      1. H ____ M ____ L ____ 2. H ____ M ____ L ____ 3. H ____ M ____ L ____ 4. H ____ M ____ L ____
      5. H ____ M ____ L____

   b. List the types of maintenance activities that are *best suited* for their application, especially if a primary project objective is to minimize lane occupancy during maintenance?

   c. Can you provide examples that illustrate the application of any of the techniques identified above? Yes____ No____

2. Does your agency have a process to assess the effectiveness of the techniques identified when they are used on maintenance operations? Yes____ No ____ *If no, return this Section to the coordinator or go to Section V.*

3. If yes, list which techniques. How does your agency measure their effectiveness in minimizing lane occupancy? How does your agency determine if the measure of effectiveness is achieved?

SECTION V - GENERAL ISSUES

Please identify program-wide approaches that must be implemented to ensure that the specific techniques addressed in Sections I through IV are successful. Briefly describe each technique and specify the areas affected, that is, planning, design, construction contracting, construction, and maintenance. *If none, return this Section to coordinator.*

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