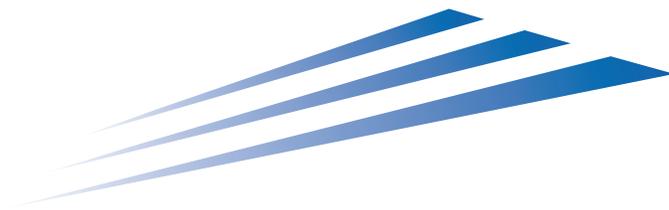


KENTUCKY TRANSPORTATION CENTER

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**INNOVATIVE RAPID CONSTRUCTION/RECONSTRUCTION
METHODS**



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KTC-05-14/SPR-283-04-1F**

INNOVATIVE RAPID CONSTRUCTION/RECONSTRUCTION METHODS

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In cooperation with the Kentucky Transportation Cabinet

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16. Abstract Innovative construction and reconstruction methods provide the opportunity to significantly reduce the time of roadway projects while maintaining the necessary quality of workmanship. The need for these "rapid" methods stems from the increase in traffic on Kentucky roadways coupled with the rise in conventional road and bridge construction methods. Conventional construction methods cannot maintain the demand for progress necessitated by the future needs of the Kentucky Transportation Cabinet, especially the current philosophy of "Get In, Get Out, and Stay Out." This research documents a series of case studies that examined past projects which used innovative rapid construction methods. This document also includes a decision making model based on road user costs and various project parameters which can broaden the Cabinet's awareness of the project options available for each venture.					
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EXECUTIVE SUMMARY

The purpose of this research project was to identify rapid construction methods and develop a decision-making system for selecting the most appropriate and effective method to expedite the construction of a project. The first task of the research project was to perform a literature review to identify and describe the proven methods for expediting construction and reconstruction projects. Next, a classification scheme to organize the methods was discovered. Then, the research team developed case studies as suggested during the project's first Committee meeting. The members of the Research Advisory Committee, composed of contractors, Cabinet officials, federal officials, and the academic research team met at least once per semester to review the research progress and suggest plans of action. Finally, the research project developed a scheme of conceptual user cost tables and a decision making system to assist the Cabinet of determining when and how to utilize rapid methods of constructions on a given project.

Based on observations from the case studies, major field innovations are initiated by the contractor on projects that contain unique design restrictions, such as time constraints and traffic control obligations, and monetary provisions. The Cabinet can encourage the contractor to develop innovative rapid construction methods by rewarding them for early completion and penalizing them for late completion. On projects offering monetary rewards, even if they do not develop innovative construction methods, the contractors are influenced to hire additional crews to simultaneously run multiple operations instead of working sequentially.

The contract is the Cabinet's most powerful tool to influence the contractor to use innovative rapid construction methods, especially when accurate project durations are established. The Cabinet's effort of establishing contract duration was especially effective on the Shawnee project. The Cabinet has the ability to influence the contractor to perform as many simultaneous operations as it is physically possible under the work site conditions and tasks at hand by providing monetary incentives in the contract. Incentives do influence a contractor to acquire a large work force of specialists, pieces of equipment with high productivity rates, and fast-installation materials in order to expedite traditional construction methods.

The Cabinet has been successful in using the A + B competitive bidding method with incentive and disincentive provisions and with maximum caps on their large projects. This

method works effectively on projects with many bidders because it allows the contractors to lower the contract duration at their own will in order for them to attempt bidding the lowest price to win the project. Establishing the maximum duration limit and the provision amounts so that they still can attract a large number of bidders is critical.

Employing engineers with experience in both highway design and highway construction during the planning stages of large urban construction projects is beneficial. This allows for CPM analysis reductions when estimating contract durations, which has proven successful in the past. Designers with the ability to think like contractors are best suited for accelerated critical path analyses to estimate how long it would take a contractor to complete the multiple jobs required on a project in the most efficient manner. They have the ability to analyze the project constraints, regional resources available, workdays available, and operations available for parallel work. It is important to use provisions with the A + B bidding method. In cases where they may be concerned about quality as well as speed, the Cabinet could also use the A+B-C bidding method. This method gives the contractor the opportunity to lower the total combined bid with a credit amount representing the lifecycle cost of the pavement.

Another expediting factor that was evident from the analysis of the case studies was the fact that the contractor was much more productive when working in a protected environment, away from the traveling public. In order to provide the most effective working environment for the contractor, the Cabinet should evaluate the possibilities of using lane shifting with protective barriers or applying full weekend closures before specifying the traffic control plans. The impact on local communities is greatly reduced by keeping the public well informed of such plans. Furthermore, as shown by the Shawnee Expressway Project, the use of police enforcement to impose reduced speed limits can drastically reduce the number of accidents in work zones, leading to fewer interruptions to the production of workers.

The Cabinet should continue to experiment with innovative field methods and materials through experimental projects to evaluate their potential ability to expedite future construction projects. When testing new methods, the Cabinet may want to consider using a working-day contract instead of a completion-date contract. By dictating an allowable number of working days instead of a completion date, the Cabinet is effectively accepting the burden of the learning curve for both parties. A working-day contract does not expedite the experimental project since the contract completion date may vary, but it allows both parties to become familiar

with the innovative method/material to be used and gives them time to develop an efficient approach. The use performance-based specifications instead of prescriptive specifications will also facilitate the use of innovative rapid methods and may also attract smaller contractors to become involved in the innovation process as well. In order to expedite each working day, the Cabinet could specify the use of incentives/disincentives or lane rental fees for lane closures. However, they would not specify which method to use during that timeframe. To be effective, the Cabinet could provide non-penalized practice areas where the contractor could adjust to using new equipment/material and they could work on improving their production rate. In that aspect, the Cabinet could require the contractor to reach a minimum production rate before allowing them to move into the areas with lane closures with provisions. This requirement would encourage the contractor to train their workers in the non-penalized areas before attempting to work on the areas with the lane closures and to acquire additional resources until they have the work force and equipment needed to reach the specified production rate.

When replacing full-depth slabs of concrete on interstates where one lane needs to remain open to traffic, the Cabinet could allow less than a twelve-hour window at nighttime and they could set lane rental fees if the contractor maintains the lane closure past the allotted time frame. The Cabinet could also provide specifications on using the concrete maturity testing method, where they could specify the use of the Arrhenius equation over the Nurse-Saul equation when dealing with high-early strength concrete mixes.

During the pre-construction meetings, it is also important for the Cabinet to utilize the contractors' experience and listen to their ideas of possible methods that could expedite the projects. This strategy will influence the contractor to assemble as many resources as need to perform simultaneous operations and/or to develop innovative methods, materials, and equipment to expedite the construction process.

The conceptual user cost tables could be utilized to identify a project's need to accelerate construction. The tables are based on variable value of time that exists within the different economic regions of Kentucky. There are tables designed for interstate travel and should be used regardless of which county a project is located; the interstate tables were developed based on the overall state's average value of time. Projects involving the state's parkways should consider using the project's county group value of time, since it is considered that most travel on the state's parkways involve local travel. Projects that overlap two economic

regions, should use the county with the higher value of time. The conceptual user cost tables could also be used internally regarding methods to be used for maintenance. However, the researchers strongly suggest that the conceptual user cost tables not be used to establish incentives/disincentives or liquidated damages. Instead the states existing method of determining detailed RUC should be used.

The Innovative Rapid Construction Method Decision Making System can be used to help the Cabinet identify a menu of rapid methods of construction for consideration during the project's early planning stages. The Innovative Rapid Construction Method decision-making model can be utilized by the Kentucky Transportation Cabinet to guide Engineers in Training (EIT) who are uncertain which methods to employ while working on a new project in development. Where more experienced engineers are typically familiar with many options available to a particular project, a young engineer may not recognize or be aware of the numerous contract options or methods that are available, such as A+B bidding, traffic phasing, nighttime work, incentives/disincentives, and certain innovative materials. This information and understanding of how justifications can be made to accelerate construction will assist EIT's during their early careers.

*** Note: The RUC Tables and Decision Making System are included with the project's CD ***

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1.0 INTRODUCTION

1.1 Necessity for Innovative Rapid Construction Methods

State transportation agencies face an ongoing challenge of maintaining, rehabilitating, and expanding the U.S. highway infrastructure. The aging infrastructure and the increases in traffic volumes have pushed state transportation agencies to build more highway construction projects in recent years. Due to societal demands of high quality roads put in place as quickly as possible, there has been a need to develop innovative rapid construction methods (Accelerated, 2004).

The new approach to highway rehabilitation has been to perform faster construction to save money and increase the safety of workers and motorists. In order to accomplish this, the state transportation agencies have pursued innovative rapid construction methods that would allow them to *get in, get out, and stay out*. This approach relies on the use of innovative rapid construction methods to complete the work in a quality manner and in a timeframe that will have a minimal impact on the traveling public. There are many advantages to using innovative rapid construction methods. By reducing construction time, these fast-track methods minimize delays, mitigate congestion, save money for state transportation agencies and the road users, and improve the safety of the motorists and the workers, without sacrificing quality.

1.2 Innovative Rapid Construction Methods

Significant costs are imposed on the public during roadway construction, including driver delay and disruption to local businesses. As a result, political and public pressures mount for roadway construction projects to become more efficient and require less time to complete. While pressures to expedite roadway construction increase, the public also reasonably expects high quality new roads to withstand decades of highway activity.

Innovative rapid construction methods (IRCM) provide a significant opportunity to reduce the congestion associated with roadway projects. These methods will lessen project durations while retaining the necessary quality. Opportunities for innovative methods are numerous. For example, pre-cast/modularization, alternative contracting strategies, and project incentives have shown that alternative methods can work. Although it may be uncertain which method to utilize on a specific project, some methods are immediately employable on many KYTC projects. Some

methods introduced by this report, which could have a substantial impact on expediting construction, will require changes in the Cabinet's project development process and/or changes in policy.

1.3 Federal Program Promoting Innovative Rapid Construction Methods

The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) created the Accelerated Construction Technology Transfer (ACTT) program to identify innovative techniques, planning strategies, and technologies that permit state transportation agencies to expedite highway construction projects. The ACTT initiative is to reduce construction time in order to reduce the travel delays and minimize the safety hazards associated with construction work zones. It promotes the use of innovative technologies and techniques to accelerate the planning, design, and construction of major highway projects for the benefit of the traveling public.

In order to notify the state transportation agencies about the innovative fast-track methods available, the ACTT program schedules accelerated construction workshops in various states. Any state department of transportation can make a formal request to hold ACTT workshops by contacting the FHWA. National transportation experts from state highway agencies, industry, academia, and FHWA head these 2-day workshops. During these workshops, there is a brainstorming session between the ACTT experts and the local participants in order to generate a list of rapid methods to use on a specific project in the works. Together, they evaluate all aspects of the project and develop practical recommendations to complete the project within budget, reduce construction time, and minimize traffic congestion to enhance quality and safety. The participants break into different skill set teams where the experts demonstrate how ACTT methods could be implemented to accelerate the project. The typical accelerating strategies addressed in the ACTT workshop include:

- Right-Of Way/Utilities/Railroad Coordination;
- Traffic Engineering/Safety/Intelligent Transportation Systems/Worker Health;
- Structures (Bridges, Retaining Walls, Culverts, Miscellaneous);
- Innovative Financing;
- Innovative Contracting;
- Geotechnical/Materials/Accelerated Testing;

- Long-Life Pavements/Maintenance;
- Construction (Techniques, Automation, Constructability) ;
- Environment/Context Sensitive Design;
- Roadway/Geometric Design; and
- Public Relations.

2.0 REPORT OBJECTIVES

2.1 Purpose of Research Project

The report describes a system to assist the KyTC in selecting the most appropriate method to expedite construction. This method attempts to efficiently utilize available funds and to minimize total road life cycle costs while also maintaining value and quality of new projects. Life cycle costs of new roadways include such factors as:

1. Construction costs,
2. User delay costs,
3. Expected accident costs,
4. Business impact cost,
5. Environmental impact costs such as pollutants and run-off,
6. Maintenance and rehabilitation cost, and
7. Minimum performance levels.

It is possible to estimate construction costs with relative accuracy, but the remaining costs are more difficult to estimate. These costs are affected by factors such as road user costs and the selected discount rates. The Kentucky Transportation Cabinet would experience significant benefits by selecting innovative rapid construction and reconstruction methods to reduce life cycle costs. Fortunately, there are many choices of innovative methods to expedite construction, which are not entirely restricted to the construction phase.

The purpose of this research project was to identify rapid construction methods and develop a decision-making system for selecting the most appropriate and effective method to expedite the construction of a project. The first task of the research project was to perform a literature review to identify and describe the proven methods for expediting construction and reconstruction projects. Next, a classification scheme to organize the methods was discovered. Then, the research team developed case studies as suggested during the project's first Committee meeting. The members of the Research Advisory Committee, composed of contractors, Cabinet officials, federal officials, and the academic research team met at least once per semester to review the research progress and suggest plans of action. Finally, the research project developed a scheme

of conceptual user cost tables and a decision making system to assist the Cabinet of determining when and how to utilize rapid methods of constructions on a given project.

The purpose of developing case studies on projects that used innovative rapid (re)construction methods around Kentucky was to obtain information on the effectiveness, benefits, and concerns of such practices. The team wanted to identify the Cabinet's experiences with fast-track methods to disseminate the successful practices and techniques used to expedite construction. After identifying many methods, input was collected from the Cabinet and contractors on the viability of these and other methods discovered during the literature review. Next, the researchers identified the essential elements of a decision-making process and associated them with road-user costs. These factors made it possible to develop a decision support system, based on project type and cost classification, to help in the selection of appropriate rapid construction methods for specific projects. The decision-making model, which incorporates road user costs, requires the user's input of some basic project elements. Such project elements include: whether the project is urban or rural, whether it is new construction or rehabilitation, and whether the project requires concrete or asphalt. The interface of the model is a series of questions leading to a set of appropriate methods for consideration.

2.2 Goal and Objectives of the Study

The goal of this study was to develop a knowledge base of best practices for rapid construction and reconstruction methods. The following objectives were identified for this study:

1. Identify the lessons learned from the Cabinet's previous use of rapid construction methods;
2. Identify construction methods and processes to expedite roadway construction;
3. Identify when the use of rapid construction methods are appropriate; and
4. Identify critical requirements to implement faster construction methods.

3.0 LITERATURE REVIEW AND METHODS IDENTIFIED

The first task of the research project was a literature review to identify all of the published innovative rapid methods successfully used to expedite construction and reconstruction projects. In order to find previous related research, the team explored the archives of several construction and transportation research associations, magazines, and journals. Publications from all 50 state transportation agencies were searched as well as the American Society of Civil Engineers (ASCE) and Transportation Research Information Services (TRIS) online archives, published research reports from other universities, and other sources including:

- National Cooperative Highway Research Program (NCHRP);
- Transportation Research Board publications (TRB);
- National Research Council (NRC);
- Turner-Fairbank Highway Research Center (TFHRC);
- Federal Highway Administration (FHWA);
- National Highway Traffic Safety Administration (NHTSA);
- Research & Special Programs Administration (RSPA);
- American Association of State Highway and Transportation Officials (AASHTO);
- Engineering News Record (ENR);
- Transportation Research Record (TRR); and
- other state transportation research centers.

From the literature review, it became possible to identify numerous rapid construction methods that had proven successful around the country. Some of the more popular methods included scheduling calendar day projects, using pre-cast components, using contractor milestone incentives, pavement type selection, standardizing planning approach, and evaluating multiple approaches to traffic control plans. For the full list of methods discovered through the literature review process, refer to Appendix A. In order to display the vast amount of information, the team imported all of the methods into Microsoft Access and created a form template (Appendix A). Though some methods belonged to more than one category, the team categorized all of the methods into 12 groups. The following is a list of applicable methods for each of the 12 categories:

1. Automation Equipment/Construction Technology:

- Avoid the need to relocate many utility lines by obtaining information using subsurface utility engineering (SUE) early in the design phase
- Maturity testing
- Perform faster inspection and construction monitoring: Software used for cable-stayed bridge
- Perform faster inspection and construction monitoring: Laser to monitor steel erection
- Use of automated construction technology: Geographical Positioning Systems, Laser-based positioning systems, and Compaction using automatic vibration control system
- GPS Controlled Production: Computer-aided earthmoving system, GPS-based grade control system (i.e. SiteVision), Laser-based grade control system (i.e. GCS21), and Automated compaction
- Application of 3D Machine Automation on Asphalt Pavers
- Innovative paver
- Pavers with Non-Contacting Sensors
- Automated Reflective Pavement Marker Placing
- Computer Integrated Road Compactor (CIRCOM)
- Automated Vibratory Compaction Using Onboard Compaction Meter
- Compaction Using Automatic Vibration Control System
- Perform faster inspection and construction monitoring: Microsensors embedded in concrete;

2. Information Technology:

- Application of Intelligent Transportation Systems (ITS): Freeway Management Systems
- Using Intelligent Transportation Systems (ITS electronic technologies) & work-zone traffic control
- Using the e-commerce system: project-specific web sites
- Exploit web-based team collaboration and project management system: Common e-Rooms and Web-based central project databases
- Use pilot demonstration projects for introducing new methods for expediting schedules
- Train selected field personnel in scheduling methods and scheduling claims
- Inform the public before and during construction

- Use of automated construction technology: Geographical Positioning Systems, Laser-based positioning systems, and Compaction using automatic vibration control system
- GPS Controlled Production: Computer-aided earthmoving system, GPS-based grade control system (i.e. SiteVision), Laser-based grade control system (i.e. GCS21), and Automated compaction
- Use InfoTech's Field Manager;

3. Innovative Contracting:

- Establish team concept: Right of Way, Utility, and Design Teams should coordinate issues and needs as early as possible.
- Limit the number of people contacting with the property owner
- Frequent coordination, cooperation, and communication (CCC) between each party to expedite utility relocation work
- Minimize relocation utilities by including incentives/disincentives in design-build contracts
- Utilize master agreement with the utility companies
- Design-Build with Bridging/Turnkey/Warranty/Maintain/Privatization Approaches
- Separate landscape contract
- Formal partnering with design consultants, contractors, local authorities, and regulatory agencies
- Develop Traffic Control Plans through partnering between DOT design and field organizations
- Have contractor prepare the Traffic Control Plan based on minimum requirements
- Incentivize Traffic Control Plan development with a contractor Value Engineering (VE) cost-savings sharing provision
- Increase amount of liquidated damages and routinely enforce
- A+B+C Bidding with Quality/Lifecycle/Safety/Past Performance
- Packaged multi-primes approach to contracting
- Incentivize contractor work progress with a lane-rental approach
- Warranty performance bidding
- "No Excuse" incentives
- Facilitate an innovative and equitable contracting environment
- Use performance-related specifications when using new technologies;

4. Innovative Field Methods:

- Shorten construction time by full closure instead of partial closure of roadway
- When doing concrete redecking of a bridge, place the deck in a continuous pour
- Maturity testing
- Employ methods for continuous work zones
- Perform faster inspection and construction monitoring: Software used for cable-stayed bridge
- Perform faster inspection and construction monitoring: Laser to monitor steel erection
- Using prestressed concrete panels for expediting pavement construction
- Using geosynthetic-reinforced and pile-supported earth platforms for embankments, retaining walls, and storage tanks constructed on soft soils
- Using post-tensioning in precast elements of bridges to provide durability and structural benefits to the system while expediting the construction process
- Develop two sets of standard sections and details for precast double-T beams for short-span bridges for use with a non-composite asphalt wearing surface as a viable alternative to voided slabs
- Use of automated construction technology: Geographical Positioning Systems, Laser-based positioning systems, and Compaction using automatic vibration control system
- Matec's AR2000 for Hot In-Place Recycling of Asphalt Pavement
- Build the structure top-down in environmentally sensitive areas
- Minimize field fabrication effort
- Perform faster inspection and construction monitoring: Microsensors embedded in concrete

5. Innovative Management:

- Designate a single individual as Project Manager (PM) from early planning to completion of construction
- Formal partnering with design consultants, contractors, local authorities, and regulatory agencies
- Packaged multi-primes approach to contracting
- Exploit web-based team collaboration and project management system: Common e-Rooms and Web-based central project databases
- Change management practices
- Use of windowed milestone

- Use pilot demonstration projects for introducing new methods for expediting schedules
- Train selected field personnel in scheduling methods and scheduling claims
- Study optimal approaches to crew shifts and scheduling
- Use InfoTech's FieldManager;

6. Innovative Materials:

- Using 100 ksi High-Performance Steel Box Girders to Build Bridge Structures
- Pavement type selection: using quick-curing concrete and using in-place recycling
- Precast/Modular components
- Using Donnacrete Superpatch for small concrete pavement repairs
- Using geosynthetic-reinforced and pile-supported earth platforms for embankments, retaining walls, and storage tanks constructed on soft soils
- Construct composite bridges with light weight composites and prefabricated elements
- Develop two sets of standard sections and details for precast double-T beams for short-span bridges for use with a non-composite asphalt wearing surface as a viable alternative to voided slabs;

7. Innovative Planning and Design Phase:

- Establish utility corridors and systematically locate facilities
- Use comprehensive standard tools to standardize planning
- Programmatic (Corridor) approach to planning, design, and construction
- CPM analysis reduction
- Formal partnering with design consultants, contractors, local authorities, and regulatory agencies
- Standardizing the environmental assessment and getting more local input during planning
- Standardization of design components
- Develop Traffic Control Plans through partnering between DOT design and field organizations
- Have contractor prepare the Traffic Control Plan based on minimum requirements
- A+B+C Bidding with Quality/Lifecycle/Safety/Past Performance
- "No Excuse" incentives
- Use of windowed milestone
- Use pilot demonstration projects for introducing new methods for expediting schedules
- Train selected field personnel in scheduling methods and scheduling claims

- Study optimal approaches to crew shifts and scheduling
- Build the structure top-down in environmentally sensitive areas
- Minimize field fabrication effort;

8. Innovative Software / Database:

- Using the e-commerce system: project-specific web sites
- Exploit web-based team collaboration and project management system: Common e-Rooms and Web-based central project databases
- Change management practices
- Perform faster inspection and construction monitoring: Software used for cable-stayed bridge
- Perform faster inspection and construction monitoring: Laser to monitor steel erection
- Use InfoTech's FieldManager
- Perform faster inspection and construction monitoring: Microsensors embedded in concrete;

9. Innovative Financing:

- Alternative funding methods: Grant Anticipation Revenue Vehicle Bonds & Highway Lease Revenue Bonds;

10. Public Involvement / Increased Awareness:

- Public input on phasing of construction
- Application of Intelligent Transportation Systems (ITS): Freeway Management Systems
- Using Intelligent Transportation Systems (ITS electronic technologies) & work-zone traffic control
- Inform the public before and during construction;

11. Relocation of Utilities:

- Frequent coordination, cooperation, and communication (CCC) between each party to expedite utility relocation work
- Establish utility corridors and systematically locate facilities
- Minimize relocation utilities by including incentives/disincentives in design-build contracts
- Utilize master agreement with the utility companies

- Avoid the need to relocate many utility lines by obtaining information using subsurface utility engineering (SUE) early in the design phase; and

12. Work Zone Traffic Control:

- Using lane shifts when widening and rehabilitating existing pavement
- Generate and evaluate multiple Traffic Control Plans
- Shorten construction time by full closure instead of partial closure of roadway
- Employ methods for continuous work zones
- Improve traffic flow in work zone: Law enforcement

4.0 CASE STUDIES

4.1 Methodology

Prior to the development of the case studies, the research team met individually with the Cabinet's Director of the Construction Division and the Director of the Cabinet's Highway Design Division. During each meeting, the research team explained how it was identifying roadway projects from around the state where innovative rapid construction methods were applied. The research team performed case studies on many of these fast-track methods in order to study their origins, their outcomes, and their feasibility for future usage by the Cabinet. Each director named several highway projects from around the state that had used innovative rapid construction methods to expedite their completion and identified methods from the projects that they believed would be of interest to the team. In addition, the Director of the Cabinet's Materials Division, informed the team of several innovative materials in use on projects around Kentucky.

For each of these selected projects, the research team contacted the project's engineers to set up interviews. During these meetings, the researchers collected detailed information about the projects and the rapid methods used. These data were used to identify all the factors that expedited the completion of the projects, and they were used to develop six case studies. Each case study was divided into several sections. The first section was an overview of the project that outlined the project description, location, cost, construction schedule, and contact information of the resident engineer, contractor, and designer. The next section was the core section of the study since it examined in detail the significant rapid construction factors used. In some cases, a lessons-learned section described the success of some Cabinet-initiated methods and what the Cabinet would do differently if these methods were used on future projects. The following six case studies were developed for the study:

1. I-264 Shawnee Expressway Rehabilitation Project;
2. I-65 Road Widening Project;
3. Blue Grass Airport Runway Paving Project;
4. Donnacrete Superpatch Product;
5. I-265 Gene Snyder Rehabilitation Project; and
6. I-64 Weekend Rehabilitation Project.

4.2 Project Description

The following section describes the projects that the research team used to identify and study various innovative rapid methods of construction. The team's goals were to identify the rapid methods employed on each project, evaluate the outcomes of their use, and determine whether these methods would benefit the Cabinet on future projects.

4.2.1 I-264 Shawnee Expressway Rehabilitation Project

This \$66 million project was the largest highway rehabilitation project undertaken in Kentucky. The project involved a 7.76-mile section of the I-264 Expressway in western Louisville, between Dixie Highway and Bank Street (Fig. 4.2-1). This part of I-264, also known as the Shawnee Expressway, handles over 65,000 motorists daily and is the main access to many neighborhoods in the western Louisville area.

Schedule: 500 days

- 12/20/2002 – Project let
- 03/21/2003 – Construction started
- 08/09/2004 – Construction completed
- 08/09/2004 – Contract completion

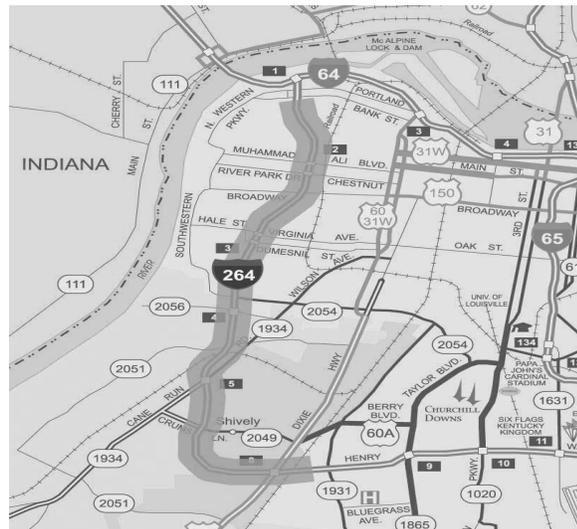


Fig. 4.2-1: I-264 Project Map

4.2.2 I-65 Road Widening Project

This project was broken up into 4 sections with separate contracts, each costing \$30 million, \$30 million, \$22 million, and \$19 million respectively. Over a 3-year period, 18.8 miles of I-65 were widened from a 4-lane highway to a 6-lane highway between Bowling Green and Rocky

Hill, Kentucky (Fig. 4.2-2). The major item of this project was the widening of the Barren River Bridge in the first section.

Schedule: 3 years

Section 1: Bowling Green to Bristow (4.4 miles)

- 09/29/2000 – Project let
- 10/23/2000 – Construction started
- 03/22/2003 – Construction completed
- 06/30/2003 – Contract completion

Section 2: Bristow to Oakland (5.8 miles)

- 12/15/2000 – Project let
- 01/15/2001 – Construction started
- 09/13/2002 – Construction completed
- 11/01/2002 – Contract completion

Section 3: Oakland to Smiths Grove (4.8 miles)

- 12/14/2001 – Project let
- 01/21/2002 – Construction started
- 06/02/2003 – Construction completed
- 09/30/2003 – Contract completion

Section 4: Smiths Grove to Rocky Hill (3.8 miles)

- 09/27/2002 – Project let
- 10/25/2002 – Construction started
- 10/01/2003 – Construction completed
- 10/01/2003 – Contract completion

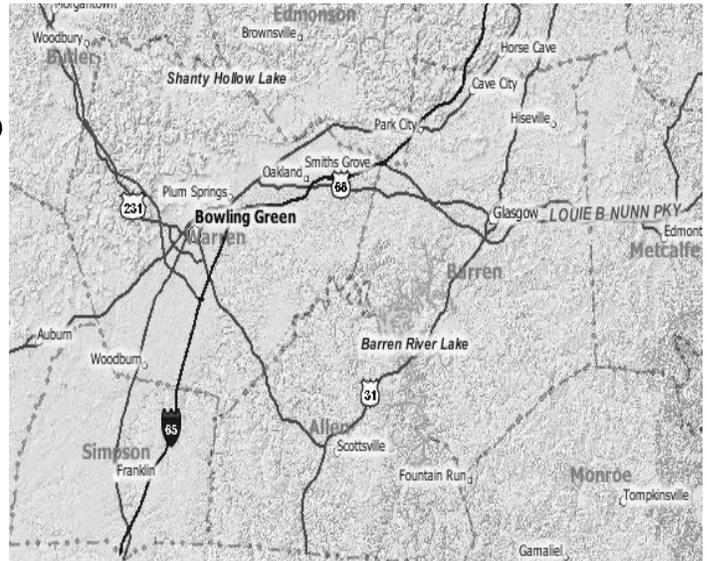


Fig. 4.2-2: I-65 Project Map

4.2.3 Blue Grass Airport Runway Paving Project

This was a unique project since it was the first time that an airport would pave its entire runway at one time. This \$4.5 million project required the first ever full closure of the Lexington Blue Grass Airport (Fig. 4.2-3) to allow for the 7003 feet long and 150 feet wide runway to be overlaid with a 3 inch deep asphalt layer. It required a significant mobilization of people, equipment, and materials. Overall, 1000 truckloads placed 24,000 tons of asphalt on the runway in less than 42 hours.

Schedule: 42 hours

08/26/1994 – Construction started at 9:00 PM

08/28/1994 – Construction completed at 3:00 PM

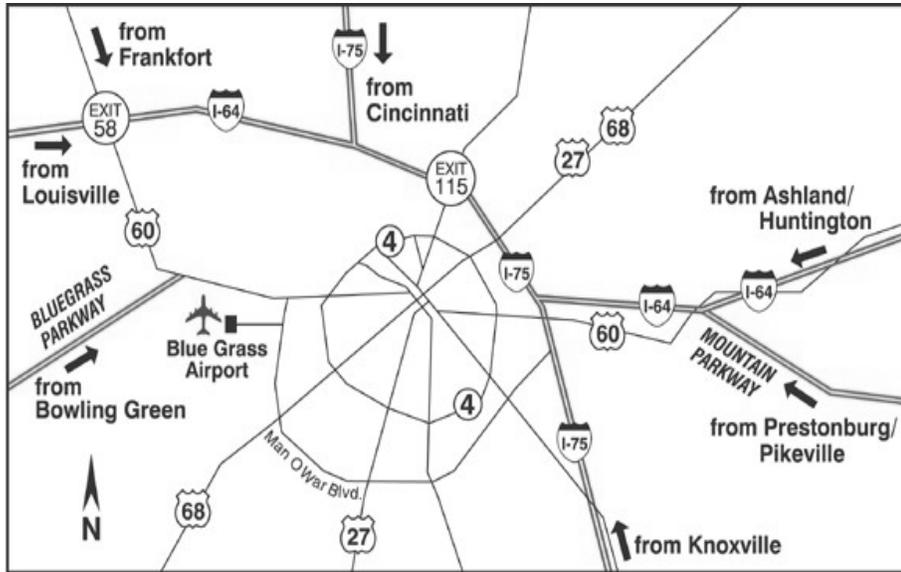


Fig. 4.2-3: Blue Grass Airport Map

4.2.4 Donnacrete Superpatch Product for Small Concrete Repairs

The Donnacrete Superpatch is a one component, rapid-setting, high early strength patching material designed for repairing concrete and masonry structures. This product is used to repair small areas of deteriorating concrete such as potholes in streets and bridges. In the past two years, the Cabinet has conducted trial patches to evaluate the effectiveness of this material. Soon, they will use this product to patch the cracks along the joints of a bridge deck overlay on a bridge leading into Paducah (Fig. 4.2-4).



Fig. 4.2-4: Donnacrete Project Map

4.2.5 I-265 Gene Snyder Rehabilitation Project

This \$3 million concrete pavement rehabilitation project, involving a 5.5 mile portion of the I-265 Gene Snyder Freeway in Southern Louisville, from I-65 to Beulah Church Road (Fig. 4.2-5) required over one hundred patches ranging from surface repairs to full depth slab replacements. The Cabinet wanted to use this project to test the maturity meter method and encourage the development of a high-early strength concrete mix to repave the deteriorated segments of the freeway. They wanted to become familiar with these two innovative rapid construction methods just before applying them on the high profile project to rehabilitate I-64. If these methods proved to expedite the project, the Cabinet would work towards implementing them on future fast-track projects as well.

Schedule: 149 working days

12/15/2000 – Project let

12/29/2000 – Project awarded

03/31/2001 – Construction started

06/29/2002 – Construction completed

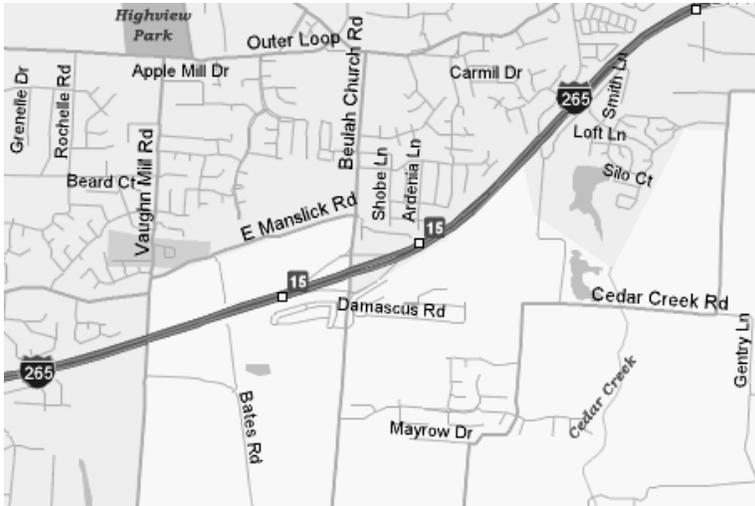


Fig. 4.2-5: I-265 Project Map

4.2.6 I-64 Weekend Rehabilitation Project

The purpose of this \$22 million project was to provide a smoother and safer roadway for a 3.3-mile section of I-64 in Louisville, between I-264 and Grinstead Drive (Fig. 4.2-6), that had never been paved since it opened in 1970. Aside from pavement rehabilitation, this project also included tunnel and bridge rehabilitations, barrier replacements, guardrail and drainage improvements, geometric improvements to ramps, shoulder widening, and landscaping. Since this urban section of the interstate accommodates a weekday traffic volume in excess of 100,000 vehicles per day, the Cabinet decided to run construction operations only on the weekends by closing down the entire section to motorists. As opposed to the traditional construction approach of keeping one lane open, this weekend-only construction schedule would make the project shorter and safer for the workers and motorists without interfering with the weekday commute.

Schedule: 15 weekends

- 07/27/01 – Project let
- 08/10/01 – Construction started
- 09/30/01 – Construction completed
- 11/19/01 – Contract completion

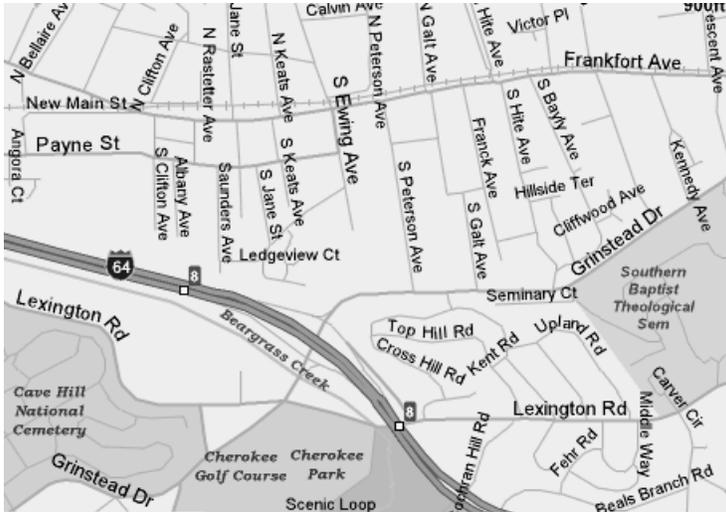


Fig. 4.2-6: I-64 Project Map

4.3 Analysis of Cabinet-Initiated Methods

The research from the case studies shows that the single most powerful tool that the Cabinet possesses to influence the actual duration of a project is the contractual agreement with the contractor. Though contracts differ from project to project, they all have the common power of setting the rules for the contractor to follow in order to get monetary compensations. Contracts have the power to influence the actions of the contractor by dictating such factors that affect productivity as time limits, performance expectations, methods of resolutions, and compensation amounts. However, the Cabinet can also expedite the duration of a project by specifying the use of certain construction methods, materials, and traffic control methods. In order to expedite construction projects, the Cabinet must carefully calculate the contract restraints and has to specify, or influence, the use of specific construction methods, materials, and traffic control methods. The above elements encompass what the research team refers to as Cabinet-initiated methods.

4.3.1 Innovative Planning Methods

4.3.1.1 Pre-Construction Changes to Project Scope

The key to expediting the construction phase of a project is to be well prepared prior to construction. On the I-64 Project, it was the budget restrictions that inadvertently accelerated the

final completion date. Initially, Cabinet officials estimated that the work in each direction could be completed in 800 hours at a total cost of \$20.7 million. After the lowest bidder of the early June letting estimated construction costs of \$25.5 million, the Cabinet was forced to make several changes to the scope of work in order to keep the project within budget. In the second round of bids on July 27, 2001, the \$20.9 million construction cost from the lowest bid was still higher than the Cabinet expected, but at least it was within the budget limit. The Cabinet officials decided to proceed without a third round of bids because there were no new bidders the second time, the project was a high priority, and there was no evidence to indicate a third round of bidding would reduce the bid prices. Conducting two rounds of bidding had already pushed the construction timetable into November, when colder overnight temperatures limit the times that asphalt can be laid (Bailey, 2004).

In order to reduce the original bids by \$5 million, the Cabinet significantly revised the scope of work. First, they removed the non-essential components of the project that only served aesthetic purposes. They decided to repair and clean the existing tunnel tile instead of installing new decorated enameled panels over the existing tiles. Although they decided to remove the decorative lighting on the tunnel entrances, they kept the new tunnel lighting system within the project scope. This innovative system would drastically improve the illumination inside the tunnel with its four intensity settings for different times of the day, and it would notify the maintenance workers via computer when a bulb went out. Another item that was removed was the 2-mile long and 4-foot high barrier wall of brick and mortar that would have required a minimum of 10 weeks to build and would have also interfered with the resurfacing operations (Bailey, 2004).

The Cabinet felt that they could reduce the drainage work that was supposed to take place in the tunnel by simply replacing a collapsed sewer pipe to alleviate most of the water pooling in the tunnel. Unfortunately, the Cabinet was also forced to remove the pavement warranty. They had planned to install a traffic monitoring system composed of weigh-in-motion sensors and traffic counters to collect Equivalent Single Axle Load (ESAL) counts. A review committee would have met biannually to examine the pavement and decide how to fix any problems during the pavement warranty period of 10 years or until 17,000,000 ESALs per lane, whichever would come first. This warranty was an expensive bid item since it required the contractor to buy a performance bond worth 50% of the cost of the pavement job (Bailey, 2004).

Another change made from the original bid was the increase in project duration, which would directly affect the amount of money that the Cabinet would receive in case of late completion or pay out in case of early completion. The Cabinet team worked hard studying how long it would take a contractor to complete the multiple jobs required in an efficient manner. They interviewed regional contractors, which all estimated that it would take at least 10 to 12 weeks to complete the project. The planners realized that over the last decade, projects launched during this time of year needed additional time because of weather problems, so they decided to add three weekends for the likelihood that time would be lost due to inclement weather. Therefore, the team set the original contract duration to 800 hours per travel direction. At the second pre-bid meeting, after the contractors indicated that the duration was too short, Cabinet officials decided to expand the allowable time to 1,000 hours per direction. The Cabinet felt that reducing the bidders' risk of facing a late penalty would encourage contractors to submit competitive bids. In addition, increasing the duration would increase the possibility of getting a bonus, which would make it more attractive for contractors to hire extra work force to complete the project earlier. In that case, the freeway would reopen earlier and the traveling public would not be excessively inconvenienced with detours (Bailey, 2004).

The Cabinet made formal partnering a requirement of the contract. They felt that successful partnering would be crucial to accomplish a fast-track project of this magnitude in the short timeframe given. Partnering would allow for concerns and issues to be addressed before and during construction. Extensive communication between the Cabinet and the contractor would be vital to a successful strategy heading towards the construction phase of the project. Thus, as soon as the lowest bid contractor was awarded the project, there was a pre-construction partnering meeting where members representing the Cabinet, the contractor, and the subcontractors, all met to express the problems they anticipated and discuss the possible ways to prevent them from occurring. During the partnering meeting, the contractor presented ideas that they believed would expedite traditional processes. For example, the contractor's asphalt manager expressed that they could expedite the project and get better control on grade by applying two 6-inch base lifts instead of the three 4-inch base lifts required by the pavement design. The Cabinet representatives approved the lift thickness change provided that the contractor would agree to stringent compaction requirements. As a result, the contractor was able to provide the agreed upon compaction and also expedite the project. The partnering relation between the Cabinet and the contractor created a bond that simplified dealing with problems as soon as they arose, so that

minimal time was lost. During the project, Cabinet representatives continually visited the project to answer the contractor's questions (Bailey, 2004).

4.3.1.2 CPM Analysis Reduction

The A + B contract method with provisions provides a monetary incentive for the contractor to accelerate construction, usually with the help of innovative rapid construction methods. The Cabinet wants the project to finish as soon as possible while paying a reasonable incentive for early project completion. The key to the success of this contracting method is to estimate a reasonable contract duration. To do so, the state has to conduct an efficient CPM analysis during the planning stages. For the Shawnee Expressway Project, the Cabinet hired a former engineer with experience in both design and 17 years of construction experience. The Cabinet felt this type of knowledge was need to estimate a contract time as accurately as possible (Jenkins, 2004).

The conventional way to calculate contract time is by looking at the production rates of a few items. However, with the use of incentive provisions, the contract time needs to be estimated as accurately as possible. The original CPM analysis of the Shawnee project yielded a project duration of 575 days. This initial analysis assumed the use of only 1 paving crew (Fig. 4.3-1) with 1 paving machine and 1 bridge crew (Fig. 4.3-2) with 1 crane operator, 1 foreman, 5 carpenters, and 4 laborers. In order to reduce the original calculated project duration, the project team first examined all of the constraints and made reasonable adjustments to as many of them as possible. The main constraint on this project was the fact that the Cabinet wanted to keep the highway opened during construction and therefore insisted on always having at least one lane of traffic open in each direction. This traffic maintenance constraint meant that the paving area was too small to move the paving equipment to the next section and therefore it could only house one paving train at a time (Newman, 2004).



Fig. 4.3-1: Bridge Crew



Fig. 4.3-2: Paving Crew

Next, the project team searched the Louisville area for bridge contractors and identified that a market capacity existed for two additional companies to be available to work on the project as subcontractors. This meant two bridge crews could be used in order to shorten the project duration. After analyzing the traffic maintenance and the crew availability, the project team looked at the work schedule. The project team ruled out the possible addition of a 2nd or 3rd shift, since pavement production typically decreases at night. Although it is possible to excavate and produce acceptable pavement strength quality, it is difficult to achieve good visibility with artificial light. Therefore, working at night would likely result in an uneven pavement, which was not acceptable for this project. Though the schedule could not be increased at nighttime, it could reasonably be increased during the daytime hours. In their CPM analysis reduction, the project team estimated 3 days of work per week during the off-season and 6 days of work per week during the on-season, while not counting holidays as available work days (Newman, 2004).

Lastly, the project team examined all operations to see which ones could be done in parallel since the original CPM analysis had been done with all operations in series. The project team used lag and lead times on some series operations to make the activities operate in parallel and shorten the overall project duration. In the end, the project team was able to reduce the original schedule by 100 days to get the total project duration of 475 days. They accomplished this by using their contractor knowledge and looking at the constraints set by the Cabinet, the regional resources available, the reasonable workdays available, and the operations available for parallel work. Even though they had no idea that the contractor would use a temporary conveyor system, the project team had anticipated that the contractor would set up some sort of onsite concrete batch plant, as was indeed the case. It was felt within the team that setting up a batch plant on site, especially in an urban area, would be a good investment since the plant would likely be used for future projects (Newman, 2004).

4.3.2 Innovative Contracting Methods

4.3.2.1 A + B Contract

An innovative contracting method that the Cabinet has been using lately is the A+B Contract, also known as Cost + Time bidding. This method requires contractors to bid on the construction cost (A) and on the user cost (B). The construction cost is calculated by multiplying the material and labor items by their corresponding unit costs. The user cost is calculated by multiplying the daily user cost incurred to the road users by the contractor's estimated duration of the project. The Cabinet calculates the daily cost of time lost by road users due to the work-zone-related delays and detours. The contractor with the overall lowest bid is awarded the contract, and the duration bid by the contractor in the B component of the bid becomes the contract duration. The A+B contract can be a very efficient competitive-bidding method, especially when it is combined with incentives for early completion and disincentives for late completion. It encourages fast completion, since the contractor has monetary reasons to finish the project early, which is what the state wants for highway construction in order to impose less inconvenience on the public. In the recent years, the Cabinet has been offering A + B bidding on one project every year. They have used this bidding method on both the Shawnee Expressway Project and the I-64 Project. This contracting method can be risky for the contractor, and it can be very effective for the Cabinet, when there are many contractors bidding competitively (Jenkins, 2004).

4.3.2.2 Incentives and Disincentives

In order to encourage accelerated construction, incentives for early completion and disincentives for late completion were used on the first three sections of the I-65 Project. The Cabinet offers monetary incentives to influence the contractor to finish the highway construction early and thus impose less inconvenience on the traveling public. The monetary disincentives discourage the contractor from slowing down while the monetary incentives encourage the contractor to use innovative methods to complete the project early. On the I-65 project, the incentive offered was a \$10,000 bonus for every day completed ahead of the contract completion date. However, the incentive was only offered for a certain amount of time, as a maximum incentive cap was implemented for each of the three sections. The disincentive imposed was also

\$10,000 per day. The Cabinet also allowed for a one-month leeway period before applying this penalty for every day of late completion (Carter and Proffitt, 2004).

The contractor completed the first section 100 days ahead of schedule to receive the maximum bonus possible of \$1,000,000. They finished the second section 50 days early to receive \$500,000 and they completed the third section 120 days early to collect an extra \$1,200,000. The Cabinet reduced their contract duration calculations after the first section and gradually reduced the contract time for the following two sections. The Cabinet issued a fixed-completion-date contract for the fourth section. That section, offering no incentive but rather liquidated damages only, was completed on the contract date set by the Cabinet (Carter and Proffitt, 2004).

4.3.2.3 Lane Rental Fees

On the Gene Snyder Project, the Cabinet decided not to expedite the completion date of the overall contract but rather to expedite each working day with lane rental fees. Their rationale was that since this was an experimental project where both parties were unfamiliar with the innovative methods to be used, both parties would have to spend some time with the processes before applying them on the jobsite. Therefore, the Cabinet wrote the contract as a working day contract instead of a completion date contract. This type of contract dictates an allowable number of working days as opposed to a contract completion date. The contract completion date varies over the life of the project, depending on unexpected events, such as bad weather, when the contractor can not work. Thus, this contract does not expedite the overall project. However, the Cabinet did not want to hurry the contractor through the process of developing a fast-track concrete mix nor through the process of developing accurate curves for the maturity meter method. They mainly wanted to use this project as a learning curve for their inspectors so that they could use their knowledge on the I-64 project that was beginning in August 2001 (Jenkins and Kissinger, 2004).

Instead of fully repaving that section of the freeway, the Cabinet decided to cut out and replace only the segments of concrete pavement that had failed. The pavement sections replaced were 12 feet wide, 10 inches deep, and anywhere from 10 feet to 500 feet long (Fig. 4.3-3). Many of these pavement failures were caused in part by the poor drainage of underground water (Fig. 4.3-4). Thus, in places where full depth lane slabs had to be repaved, the contractor dug out two-foot wide by ten-inch deep transverse trenches and filled them with gravel. Nonetheless, all

of the paving work took place during the night-time. The Cabinet allowed the contractor to use lane closures between 7 PM and 6 AM, during which the contractor would have to remove the broken slabs, replace them with fresh fast-track concrete, and reopen the lanes to the traveling public. There was a lane rental penalty assessed to the contractor for every hour that they kept the lane closed after 6 AM. The \$1000 per hour lane-closure fee was based on the road-user cost (Jenkins and Kissinger, 2004).



Fig. 4.3-3: Removal of Failing Pavement Slabs



Fig. 4.3-4: Poorly Drained Pavement Slab

4.3.2.4 A + B Contract with Incentives/Disincentives and Lane Rental Fees

The Cabinet proposes large incentives to stimulate innovation and large disincentives to encourage faster construction. In order to expedite the completion of the Shawnee Expressway Project, the Cabinet offered an incentive bonus of \$25,000 per calendar day of early completion. They also introduced two sets of disincentive penalties in case of late completion. Since this was an A + B project, the contract duration was actually set by the B component bid by the contractor who was awarded the project. The winning contractor actually bid the maximum duration allowed by the Cabinet – 500 days – and ended up working exactly that many days. Had the project not been complete by August 9th, 2004, the contractor would have been charged \$25,000 per calendar day. Furthermore, had the contractor still been working by October 1st, 2004, the charge would have increased to \$75,000 per calendar day until completion. There were also various sub-element disincentives inserted into the contract. For example, certain ramp closures were allowed for 4 to 5 weeks, after which lane rental fees were applicable. Also, there were disincentives for restricting access to US 31W (Dixie Highway) and for restricting access of the Shawnee Expressway during the week of the Kentucky Derby, when traffic volumes in the work zone spike tremendously (Jenkins, 2004).

Similarly, the I-64 Project used a contracting method that is a cross concept of the A + B bidding method with incentives/disincentives and lane rental fees. The project was awarded to the contractor who had the lowest total bid of the combined construction cost plus user cost. As usual, the construction cost included the material and labor costs. However, the original method used to calculate the user cost was a bit more complex than normal. Traditionally, the Cabinet calculates the daily cost incurred to the road users from the congestion delays of shutting down a lane, the contractor estimates the number of days needed to accomplish the task, and the total user cost is the resulting factor of these two numbers. Since the traffic control chosen for this project required to fully shutdown I-64 in at least one direction, the Cabinet had to calculate the hourly cost incurred to the road users from the delay of taking alternate routes instead. Also, since the Cabinet gave the contractor the option of shutting down the freeway during the evenings as well as the weekends, there were three different hourly road user costs per direction of travel. Thus, for the first round of bids, the contractors had to estimate six different durations of work. Instead of the simple A + B bid, they had to submit an $A + b_{1e} \cdot t_{1e} + b_{1w} \cdot t_{1w} + b_{2e} \cdot t_{2e} + b_{2w} \cdot t_{2w} + b_{3e} \cdot t_{3e} + b_{3w} \cdot t_{3w}$ bid where:

A = construction cost, including material and labor costs

b_{1e} = \$3,000/hr road-user cost of closing the eastbound lanes on weekday nights

b_{1w} = \$3,000/hr road-user cost of closing the westbound lanes on weekday nights

b_{2e} = \$9,000/hr road-user cost of closing the eastbound lanes on weekend days

b_{2w} = \$9,000/hr road-user cost of closing the westbound lanes on weekend days

b_{3e} = \$2,000/hr road-user cost of closing the eastbound lanes on weekend nights

b_{3w} = \$2,000/hr road-user cost of closing the westbound lanes on weekend nights

t_{1e} = number of hours the eastbound lanes would be closed on weekday nights

t_{1w} = number of hours the westbound lanes would be closed on weekday nights

t_{2e} = number of hours the eastbound lanes would be closed on weekend days

t_{2w} = number of hours the westbound lanes would be closed on weekend days

t_{3e} = number of hours the eastbound lanes would be closed on weekend nights

t_{3w} = number of hours westbound lanes would be closed on weekend nights

(Bailey,2004).

When the project was bid using the above equation, only two bids were submitted. Since this was a high profile project, the Cabinet wanted to find an easier way to bid the project with

incentives and disincentives. To make it easier on all parties involved in the second round of bids, the Cabinet decided to only allow weekend closures, using a weighted average user cost of \$4,500/hr/dir. In order to make sure that the Monday morning commute traffic would not be delayed, the Cabinet added a \$15,000/hr/dir lane rental fee that would begin at 6 a.m. if the contractor had not yet reopened the roadway to traffic. Furthermore, if the roadway was still closed by 7 a.m., there would be an automatic penalty of \$231,500/dir incurred. Thus, a late departure with dual directional closing at 7 a.m. would have cost the contractor nearly half a million dollars (Bailey, 2004).

The contractor who was awarded the project had bid the maximum number of working hours with a user cost of \$9 million ($2\text{dir} * 1000\text{hr} * \$4,500/\text{hr}/\text{dir}$), thus setting a contract duration of 2,000 hours. The firm would be paid a \$4,500 incentive bonus for every hour the project was completed ahead of the 2000-hour schedule. For every hour over the 2000-hour schedule, they would have to pay a \$4,500 disincentive penalty. The contractor had the option to only work on one direction at a time but they decided to proceed with a dual directional closing. They thoroughly planned all events ahead of construction and carefully coordinated the large numbers of manpower, equipment, and materials during construction. They also experienced only one day of rain instead of the two loss weekends the Cabinet had assessed. The contractor was able to finish the job in only 409.25 hours during eight consecutive weekends. Thus, they were rewarded with a \$5,316,750 bonus ($2\text{dir} * 590.75\text{hr} * 4500\text{hr}/\text{dir}$) for finishing the project 590.75 hours early and reopening the interstate earlier than expected. That amount is equivalent to the cost of time and disruptions that the motorists and area businesses would have incurred had the road remained closed as long as expected. It is the cost that would have been incurred by the public in lost business, added travel time, and added gasoline from the delays of taking detour routes for seven more weekends (Loftus, 2001).

4.3.2.5 Separate Landscape Contract

It is not uncommon for a general contractor to subcontract the landscape activities when a roadway is rehabilitated. However, for the Shawnee Expressway Project, the Cabinet took on the responsibility to issue a separate landscape contract. In order to let the roadway contractor focus solely on the rehabilitation of the Shawnee Expressway and its bridges, the Cabinet awarded a separate \$3 million landscaping contract along the same corridor. This project would enable a

faster rehabilitation of the roadway, since it would keep the contractor motivated to get mobilized and lead to a faster demobilization. The landscape project started towards the completion of the Shawnee Expressway roadway project. It included removing and replacing the right-of-way fence, doing the maintenance of the right-of-way, and doing minimal clearing and grubbing while leaving the original landscaping (Jenkins, 2004).

4.3.2.6 Measuring ESAL for Warranty

One concern of innovative rapid construction methods is that they sacrifice quality for speed. In order to test the quality of the pavement placed under rapid construction methods and to be compensated in case of bad quality, the Cabinet decided to award the third section of the I-65 Project using the A+B-C method. The C component in this case was a credit representing the lifecycle cost. Similar to the B component, the Cabinet set a pavement warranty cost per year and a maximum number of warranty years while the contractor bid on a number of years to provide warranty on the pavement. The contractor awarded this project bid the maximum lifecycle cost equivalent to a 10 year warranty or 23,000,000 Equivalent Single Axle Loads, whichever came first. By these terms, the contractor agreed to pay the cost of repairing this section of the highway for the next 10 years maximum, assuming traffic flow does not exceed 23,000,000 ESALs (Carter and Proffitt, 2004).

In order to measure the traffic volume, a scale was installed in the pavement of the outside lane of each direction. The contractor agreed to supply a 10 year warranty, as opposed to the traditional 3 and 5 year warranties, since the Cabinet agreed to install a scale to measure actual traffic volume. By installing the scales, the Cabinet was ensured to have good quality pavement for a significant amount of traffic flow. Even though using scales in the pavement is a great way to measure ESALs directly, it is difficult to calibrate them without interrupting the flow of traffic in the outside lanes. Regardless, the one million dollar installation of the scales was considered an effective way for the Cabinet to preserve the quality of the pavement through its warranty (Carter and Proffitt, 2004).

4.3.3 Work Zone Traffic Control Methods

4.3.3.1 Off-Duty Police Officers

After Labor Day weekend of 2003, a \$1 million change order was issued in order to reduce the number of accidents occurring in the work zone of the Shawnee Expressway Project. Off-duty police officers were used to enforce the posted 45 mph speed limit throughout the entire project by issuing traffic violation tickets. Starting in September 2003, approximately 3 police patrols, in marked and unmarked cars (Figs. 4.3-5 & 4.3-6), began patrolling the 8 mile corridor around the clock. On average, they issued 3500 citations per month, most of which were given for speeding through the work zone. By enforcing the 10 mph speed limit reduction, the number of accidents greatly decreased (Fig. 4.3-7), leading to a much safer work zone. Before the project let, this stretch of highway reported an average of 24 accidents per month. When the project started, the number of accidents consistently increased to reach a high level of 327 accidents in July 2003. However, after the introduction of police officers in the work zone, the accident rate decreased to an average of 32 accidents per month with a low of 13 accidents in January 2004. By reducing the number of accidents in the work zone, there were fewer construction interruptions in addition to the obvious improvement to the health and safety of the construction craft workers and the traveling public (Jenkins, 2004).



Fig. 4.3-5: Marked Police Car in Median



Fig. 4.3-6: Traffic Stop by Unmarked Police Car

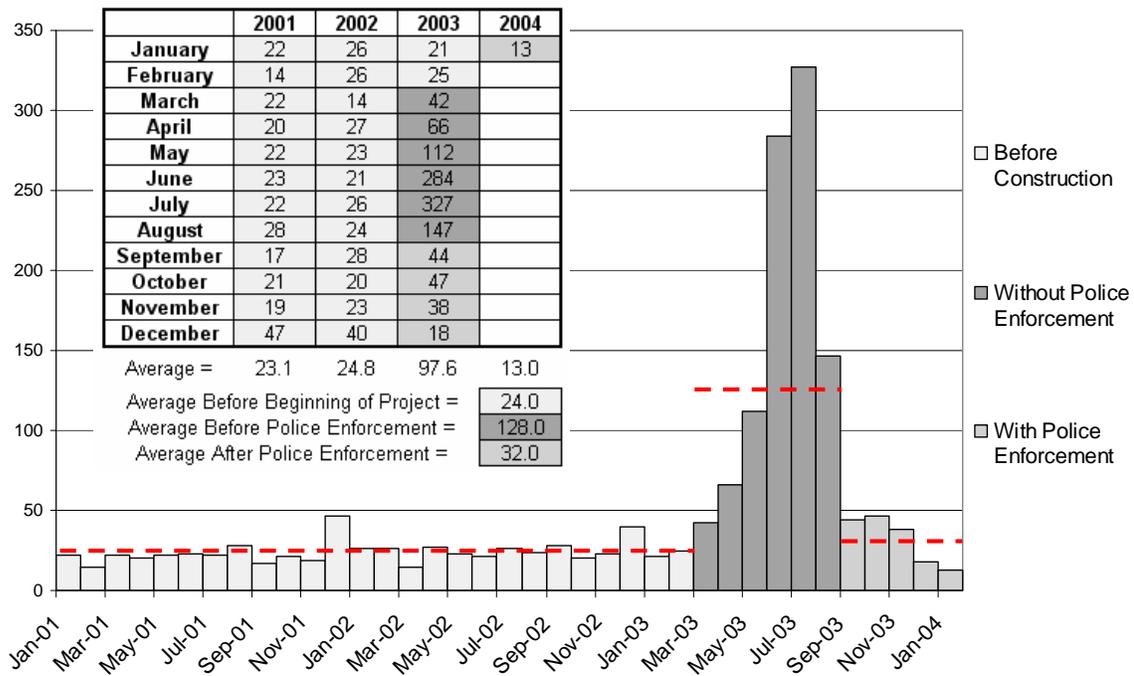


Fig. 4.3-7: Total Number of Accidents Per Month

There are three different dashed-lines in the graph above. The first dashed-line represents the average number of accidents per month before the Shawnee Project began. The second dashed-line represents the average number of accidents per month during the project, but before police enforcement was provided in the area. The third dashed-line represents the average number of accidents per month during the project after police enforcement was employed in area.

4.3.3.2 Extensive Public Involvement Campaign

In the case of the Shawnee Expressway Project, the public involvement campaign included getting public input early during the project development process and keeping the public informed about detours and closings throughout construction. Prior to the project, the Cabinet created a speakers' bureau, organized public information meetings (Fig. 4.3-8), and communicated with a stakeholders group (Fig.4.3-9) led by the area's elected officials and focus groups composed of local citizens in an effort to better understand the needs of those who would be affected. The stakeholders group, composed of business and community representatives, met monthly with the Cabinet and elected officials during the planning phase to share information about the project. In fact, the members of the group had a proactive role in sharing their ideas for

landscape and delivering project information back to the communities they were representing (Jenkins, 2004).



Fig. 4.3-8: Public Information Meeting



Fig. 4.3-9: Stakeholders Group

In the contract, the Cabinet insisted that the contractor could minimize disturbance through the work zone by leaving two open lanes of traffic in each direction at all times. This restriction forced the contractor to work mostly on weekends and weeknights, contrary to what the project team had assumed, to complete the westbound sections of the roadway and then redirect traffic to begin construction in the eastbound direction. However, the contractor had to occasionally impose daytime street and ramp closures to the public. Therefore, the Cabinet started an extensive advertisement campaign to communicate the latest traffic plans to the public. The Cabinet regularly sent the latest traffic plans to the newspapers, radio stations, television stations, local businesses, and to other individuals who had requested this information through the project stakeholder group meetings. The Cabinet also informed the motorists about the latest lane closures and detours by posting signs along the corridor and creating a website and a toll-free telephone hotline. As the traffic plans changed, the signs, website, and hotline changed as well to reflect the updated information (Jenkins, 2004).

The website was an interactive resource with up-to-date construction information that kept the public informed of the detours and lane closures occurring during construction. The public could access the daily traffic plans (Fig. 4.3-10) describing the lane closures along the corridor, the full closures of crossroads, and the full closures of the entrance and exit ramps. The public could also communicate with the Cabinet representatives by sending their comments and questions through links on the website (Fig. 4.3-11). Also, the site provided an overview of the project and a timeline with descriptions of the main events and meetings of the project.

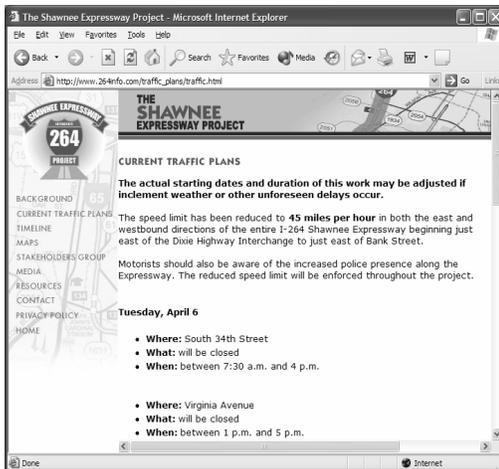


Fig. 4.3-10: Shawnee Website

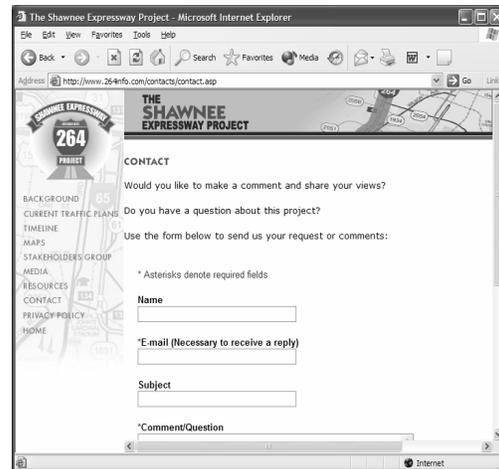


Fig. 4.3-11: Shawnee Website Contact Form

4.3.3.3 Lane Shifts

There were two sections of the I-65 Project that did not have to purchase additional right-of-way to widen the road from a 4-lane highway to a 6-lane highway. These two sections had a depressed grass median that could be paved over to create a median with a concrete barrier and two additional lanes. For these two sections, the Cabinet included a lane-shifting method in the traffic control plans designed to shift the flow of traffic onto the newly paved median lanes to rehabilitate the existing four lanes. This was an effective method that permitted widening and repaving the roadway without decreasing the number of traffic lanes. This method also decreased traffic disruptions and the need for human-supervised traffic controls. Therefore, the lane-shifting method accelerated construction since it allowed the workers to solely focus on the construction (Carter and Proffitt, 2004).

The lane-shifting method can only be used when widening the roadway by paving the existing grass median. In the case of the I-65 widening, the existing road was a four-lane highway with a depressed grass median. The first step of the process was to narrow the width of the lanes and shoulders by re-striping the road. Then, temporary medians were installed to separate the public traffic from the construction activity (Fig. 4.3-12). The next step was to install drainage box inlets and pipes at the centerline of the highway. Once the drainage system was in place, an asphalt base and overlay were paved over the grass median. Then, a permanent concrete barrier median was placed at the centerline, directly over the drainage system (Fig. 4.3-13). Once the median was paved, traffic from one direction was diverted onto the newly paved

lanes to allow for the construction crew to overlay the existing two lanes. However, the two lanes were split apart at the beginning of the permanent concrete barrier and were rejoined together at the end of the barrier as the traffic was redirected onto the existing two lanes (Fig. 4.3-14). Once the existing two lanes were rehabilitated, the traffic resumed on these lanes. The traffic shifting and splitting was repeated for the other direction in order to complete the paving of the roadway. Finally, the temporary barriers were removed and the pavement was re-striped to complete the widening to a 6-lane highway (Carter and Proffitt, 2004).

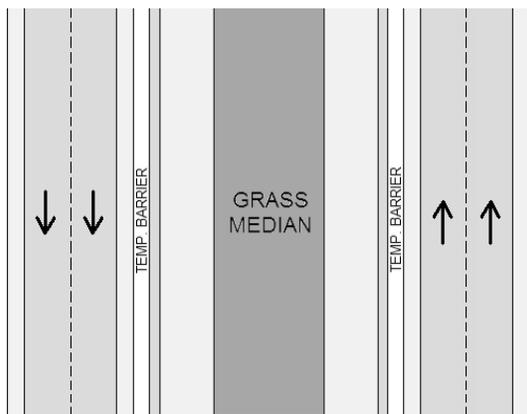


Fig. 4.3-12: Re-Striped Road and Installed Temporary Barrier

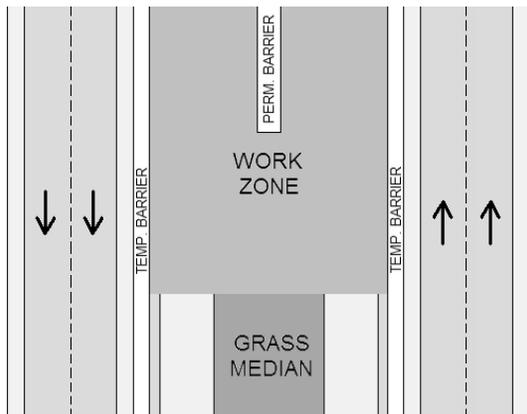


Fig. 4.3-13: Paved Median and Installed Permanent Barrier

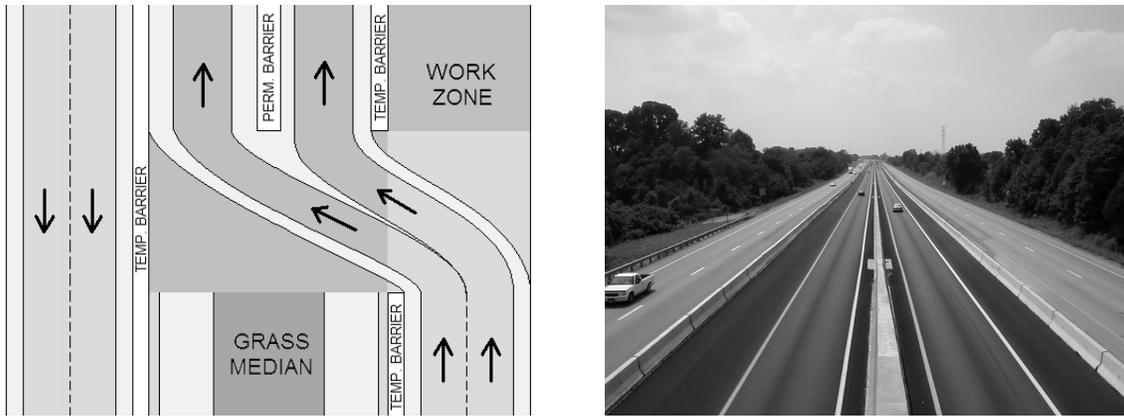


Fig. 4.3-14: Shifted and Split One-Directional Traffic

The lane-shifting method was used to widen and rehabilitate the roadway with minimal traffic interruptions. It allowed for the installation of drainage box inlets and the permanent barrier wall in only one phase. However, this method has a few shortcomings. For one, it requires the outside lanes to drive over the existing shoulders. That part of the pavement can possibly fail if it was originally designed to support smaller loads. There are also shortcomings to diverting one lane of traffic to the other side of the concrete median. Due to the permanent barrier, the left lane does not provide access to the exits of the section in construction. Therefore, the shift-and-split method creates an express lane which confuses drivers as they approach the split. There is a danger for accidents if these drivers are late to realize that they need to get in the right lane to exit. There is also a potential danger of driving over the permanent drainage sag (Fig. 4.3-15) and grates (Fig. 4.3-16) of the centerline to access the express lane (Carter and Proffitt, 2004).



Fig. 4.3-15: Drainage Sag



Fig. 4.3-16: Drainage Grate

4.3.3.4 Full Closure of Interstate

The 3.3 mile stretch of I-64, from the Watterson Expressway to Grinstead Drive, was built in 1970. Over the years, the Cabinet did a lot of spot work on the four-lane roadway to repair the cracks caused by the settlement of the 10-inch concrete slabs. Towards the end of the 1990's, the Cabinet realized that the useful life of the original pavement had expired and that this 3.3 mile section of I-64 would soon need to be repaved. Besides the vaulting of the concrete pavement, they also noticed extensive base failures, settlement of bridge approaches, bridge deck sprawling, and severe pavement deterioration inside the existing tunnels. Therefore, the Cabinet designed a \$22 million project to repair the existing concrete pavement of the entire section by resurfacing the pavement with asphalt and applying latex overlay on the eight bridge decks and the 840 feet pavement in the Cochran Hill Tunnels. The tunnels also needed drainage improvements, a new lighting system (Fig. 4.3-17), new barrier walls, and new tiles. In order to minimize the number of future interventions on that section of I-64, the Cabinet believed that they should also improve the safety of the roadway. They decided to also install new street lamps (Fig. 4.3-18), replace the guardrail and signing (Fig. 4.3-19), install new drainage systems in the median to reduce erosion, and add extensive landscaping (Bailey, 2004).

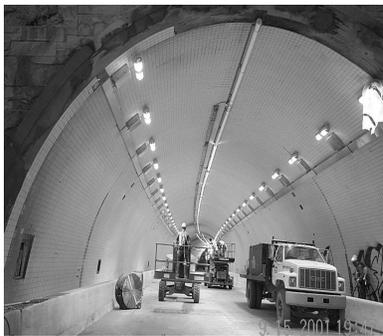


Fig. 4.3-17: New Tunnel Lighting



Fig. 4.3-18: New Street Lamps



Fig. 4.3-19: New Signs

The full closure concept is an innovative traffic control approach that had successfully been used the previous summer on the I-65 rehabilitation project in downtown Louisville. During that \$4 million project, the Cabinet rationalized that it would be better to inconvenience the 133,000 daily motorists with one major impact over a very short time period rather than subjecting the traveling public to a moderate impact over an extended period of time. Therefore, the Cabinet decided to shut down the roadway on weekends to rehabilitate the pavement in the smallest time possible. The contractor mobilized a large work force to successfully replace forty four bridge

expansion joints in only two weekend closures instead of impacting the traveling public for ninety consecutive days (Weekend, 2004).

For the I-64 project, the Cabinet looked at different construction methodologies to accomplish the task. Since there is an excessively large average weekday traffic volume of 100,000 vehicles, the Cabinet realized that during rush hour a car accident blocking one lane would create a six to ten mile backup. It would be difficult to complete this job in a timely fashion using traditional construction methods. The traditional continuous part-width rehabilitation of the pavement would have lasted 8 months and caused severe traffic congestion throughout each day of construction. The delays resulting from half the capacity taken away for construction would have virtually shutdown I-64 during the weekdays. However, the Cabinet had calculated that it would take the contractor, at most, 15 weekends to complete the job if they would entirely shut down both directions of I-64 on weekends, from 9 p.m. on Friday until 6 a.m. on Monday (Bailey, 2004).

It was the successful completion of the I-65 project, and its positive reception by the public and media, that gave the Cabinet confidence to attempt the same type of roadway closure on the much larger I-64 rehabilitation project. Since this section of I-64 serves mainly as a workday commuter route for residents of the eastern suburbs of Louisville, the traffic volumes are much lower during the weekends. Doing the construction work on weekends only, when there was a significant drop in traffic, was the most feasible option for this project, especially since a viable detour route existed that would only extend the overall driving distance by 3 miles. Weekend closures of the freeway would allow the crews to pave two lanes at once to form a better seal, which would reduce cracking by keeping out water and ice. The Cabinet scheduled the project for the end of summer, a time of the year that would cause the least disruption to the majority of people since most summer trips are over and many schools resume after their summer break (Full, 2004; Bailey, 2004).

The use of weekend closure was successful, since it shortened the duration of the traffic control and resulted in minor traffic delays for the detoured motorists. By removing traffic from the work zone, the Cabinet created a much safer working environment, which increased productivity and a higher quality of work from the contractor. Without public traffic in the middle of the work zone, the contractor had complete access to the construction zone and was able to eliminate construction joints by doing the rehabilitations across the full width of the road.

The detour routes seemed effective since there were no traffic accidents or congestion reported. It only took eight weekends of closure for the contractor to fracture the existing concrete pavement and overlay it with 135,000 tons of asphalt pavement designed with air voids to reduce traffic noise. The contractor's crews also placed 428 cubic yards of latex concrete overlay on bridges and in the tunnels. For all bridge decks, they milled the original asphalt surface layer, performed partial and full-depth patching, and placed a new latex overlay (Fig. 4.3-20). In the tunnels, the crews performed hydro-demolition of 2,800 square yards of concrete surface to remove the unsound concrete surface, just before overlaying 400 cubic yards of rapid set latex modified concrete (Fig. 4.3-21). They also installed 90 new street lamps, 10 acres of sod in the median, and approximately 30,000 feet of rust-colored guardrails meant to blend with the background (Kenning, 2001; Bailey, 2004).



Fig. 4.3-20: Placing Latex Concrete on Bridges



Fig. 4.3-21: Placing Latex Concrete in Tunnels

4.3.4 Innovative Field Methods and Materials

4.3.4.1 Bore and Jacking of New Cross Drains

For parts of the second and fourth sections of the I-65 Project, the Cabinet asked the contractor to bore and jack new cross drains. The bore and jack method uses a tunnel boring machine that drills a horizontal hole below the highway while the hydraulic jacking station pushes the pipe through the shaft to prevent the soil from caving in (Fig. 4.3-22). This method is an alternative to open cut trenching that does not disturb the pavement of the roadway and therefore does not interrupt the flow of traffic. The new cross drains were created with a significant time savings over the traditional method and without disturbing the traffic. To speed

up the process, the District Branch Manager requested using hydrated lime as an underdrain for the newly paved median to absorb moisture out of the clay and stabilize the soil (Carter, 2004).

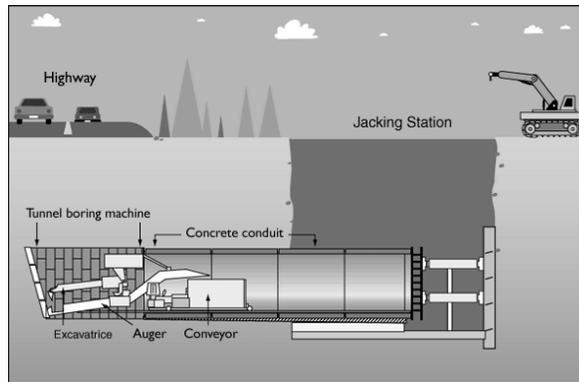


Fig. 4.3-22: Bore and Jacking a New Cross Drain Pipe

4.3.4.2 High-Early Strength Concrete Mix

The Cabinet’s strategy for the Gene Snyder Project was to give the contractor time restraints and let necessity be the “mother of invention.” By requiring the contractor to complete the job in a certain amount of time, the Cabinet indirectly pushed the contractor to invent a fast-track concrete mix that allowed them to finish the job faster and increase their profit. The contractor was required to develop a mix that would reach a compressive strength requirement of 3000 psi in 6 to 8 hours. The contractors had no other choice but to develop a fast-setting mix to realistically give themselves the opportunity to replace the typical 100-foot-long pavement slabs within the allotted 11 hours. Ultimately, after placing over 2300 cubic yards of concrete pavement and experimenting with two different mixes, the contractor was able to formulate a concrete mix with an accelerator that could consistently provide 3000 psi in 8 hours (Jenkins and Kissinger, 2004).

Typical fast-setting concrete mixes require a water to cement ratio below 0.35, over 750 pounds of type III cement per cubic yard, a high range water reducer, and a non-chloride accelerator to provide at least 3000 psi in 8 hours. For a starting base, the Cabinet provided the contractor with their 24-hour mix usually used for concrete pavement repair work. After altering the type III cement-based mix, the contractor was able to reach the required strength in 8 hours. However, the concrete was difficult to place as it would set too fast and frequently crack. Type III cement is specifically used to formulate high early strength concrete, but it produces inconsistent and unpredictable batches. Therefore halfway through the project, the Cabinet and

contractor decided to replace the mix design with a more consistent mix that was easier to place. They decided to switch to a type I cement, usually used for general purposes, in order to use less water reducer and more admixture to accelerate the gain of strength. This type I cement-based concrete mix also differed from the first mix (Table 4.3-1) since it had less sand, more aggregate, and more water (Mills et al., 2004).

Table 4.3-1: Concrete Mixes Used on I-265 Project

Material (per cubic yard)	Mix #1	Mix #2
Cement Type I		800 lbs.
Cement Type III	800 lbs.	
Natural Sand	1154 lbs.	1057 lbs.
Coarse Aggregate	1745 lbs.	1798 lbs.
Water	242 lbs.	264 lbs.
Air Content	6%	6%
High Range Water Reducer	80 oz.	48 oz.
Water Reducer and Retarder	12 oz.	
Non-Chloride Accelerating Admixture	400 oz.	720 oz.

As a result of the concrete-mix change, the contractor was able to obtain more consistent and controllable batches of concrete while attaining similar strength results. However, this second rapid-setting mix did not fully meet the contractor’s expectations because it consistently reached opening strength in 8 to 9 hours instead of the 6 hours that they had expected. In theory, the first mix, using type III cement, would have given results that are more consistent in less than 8 hours if the trucks could have had a shorter haul route between the batch plant and the jobsite. Type III cement-based concrete mixes can only work successfully if they are cast in place before they hydrate. However, these mixes generate a lot of early heat and hydrate very fast. Thus, when fast setting mixes are used on a project with long haul routes, they require more water reducer. On this project, the mixing truck could not reach the site within 5 minutes, since the plant was over 3 miles away, which prompted the contractor to use a retarder at the plant and add an accelerator at the jobsite. Unfortunately, when adding more reducers to the mix, it is less likely to reach strength in a consistent amount of time (Jenkins and Kissinger, 2004).

There are many other challenges to producing high-early strength concrete mixes. They are more expensive, more susceptible to cold weather, less workable, and less durable. An

accelerated concrete mix placed during cold temperatures develops a temperature gradient between the core of the slab and its surface. When the temperature difference is at least 35°F, it will be slower to set and more susceptible to internal cracking. These internal cracks occur when the temperature-induced tensile stress exceeds the tensile strength of the concrete. An accelerated concrete mix can also be sticky and hard to finish since the super-plasticizers do not allow much time before the mix sets up. On the Gene Snyder Project, the contractor had to water down the stockpiles to prevent the concrete from setting in the truck, which changed the design of the mix by altering the water to cement ratio. Accelerated mixes are expected to have shorter durability since the high heat of hydration greatly expands the slab and creates premature microscopic cracking throughout the curing stage. Even though these fractures increase in size through years of exposure to water, salt, and ice, the fast-setting concrete slabs are expected to last about 20 years (Mills et al., 2004).

4.3.4.3 Concrete Maturity Method

The maturity method is an alternative non-destructive testing approach for predicting the strength of in-situ concrete. The idea is that the hydration of cement is the major factor that controls the strength development of concrete. Since the hydration of cement produces heat, its progress can be observed by measuring the temperature of the concrete slab. It has been determined that the area below the time-temperature curve, hereafter called the time-temperature factor (TTF) or maturity index, has a direct correlation with the strength gain of concrete. By embedding sensors into fresh on-site concrete mass, maturity meters are able to measure the temperature history data of that mass and calculate the maturity index to predict the strength of the concrete. This method requires developing a strength-maturity relationship curve of the concrete mix prior to construction. From that curve, one can determine the maturity index that corresponds to the desired compressive strength. Once the concrete is placed on site, the contractor monitors the real-time reading of the maturity index until it reaches the desired TTF value. At that time, the concrete pavement will have reached the compressive strength required to allow the lane to reopen to traffic. State transportation agencies in Indiana, Iowa, Texas, Pennsylvania, and Minnesota have adopted the maturity method to determine the in-place strength of concrete in fast-track projects that necessitate early opening to traffic (Mohsen, 2001; Goodrum et al., 2004).

Correlating the maturity of the mix to its compressive strength is critical. Prior to the field application, the contractor has to develop a strength-maturity relationship with the concrete mix that will be used on the project. In order to do so, the contractor creates many cylinder specimens with embedded temperature sensors in at least two of the specimens. Over a period of time, the cylinders with embedded sensors are used to record the temperature history of the concrete mix while the other specimens are broken at various ages to record compressive strength. Since an 8-hour mix was used on the Gene Snyder Project, the contractor recorded the temperature history for ten hours while breaking two cylinders every hour. The next step requires plotting the temperature-time data (Fig. 4.3-23) and using the Nurse-Saul equation (Equation 4.3-1) to compute the area under the curve at any time a cylinder was broken (Mohsen, 2001; Goodrum et al., 2004).

Equation 4.3-1

$$TTF = \sum (T_a - T_o) \Delta t$$

where:

TTF is the Temperature-Time Factor (maturity index) at age t (°C·hr)

T_a is the average concrete temperature over a time increment (°C)

T_o is the datum temperature at which hydration stops (°C)

Δt is the time increment (hr)

The datum temperature T_o depends on how quickly the concrete gains strength. As a rule of thumb, T_o is set to 0° C for most applications, though it could be set as low as -10° C for highly retarded mixes and as high as 6.5° C for very early strength concrete. The easiest way to manage the data is to create a spreadsheet with the compressive strength values, at different ages of the concrete, and their corresponding maturity index values, calculated with the Nurse-Saul Equation. Then, the contractor can generate the strength-maturity relationship by developing a graph and using a logarithmic trend line to fit a curve through the data points (Fig. 4.3-24). The equation should be in the form $Strength = B \ln(Maturity) + A$ and should have an $R^2 > 0.95$ to justify a good fit (Mohsen, 2001).

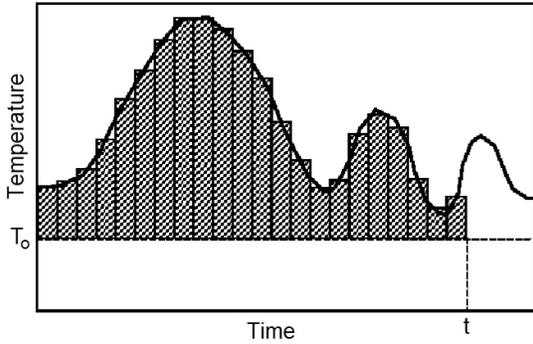


Fig. 4.3-23: Temperature-Time Curve

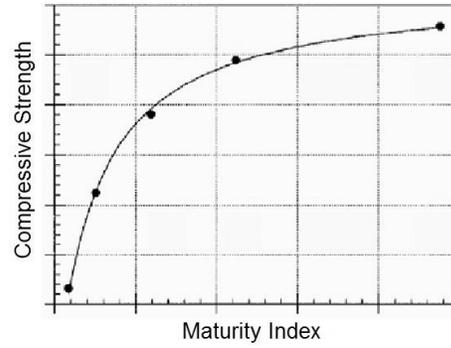


Fig. 4.3-24: Strength-Maturity Curve

Since the maturity method uses the observed thermal history of the concrete to determine the actual strength, the contractor has to embed a sacrificial temperature sensor in the concrete when it is placed on site. There are two types of sensors that can be embedded in the concrete. While each type uses a different maturity meter to output the data, they both connect to their respective reader through a wire that extrudes out of the concrete mass. The first type is a battery-operated logger that uses a sensor to record the temperature history of the concrete as it cures. Its microprocessor calculates the maturity index and stores it in memory until it is downloaded to a handheld maturity meter (Fig. 4.3-25). The other type of sensor is simply a thermocouple wire that extrudes out of the concrete. However, in order to collect data, it has to stay connected to a stationary meter (Fig. 4.3-26) during the entire curing process (Mills et al., 2004).



Fig. 4.3-25: Handheld Meter with Logger Sensor



Fig. 4.3-26: Stationary Meter with Wire Sensor

On the Gene Snyder Project, the Cabinet preferred to use the stationary H-2680 Humboldt Multi-Channel Maturity Meter over the handheld Nomadics IntelliRock Meter because it could record data at shorter intervals. At the time of this project, the Humboldt meter could display real-time data and record it once every hour as opposed to the IntelliRock meter which could only give readings every 4 hours. Using the stationary meter is cheaper to operate since the sacrificial

thermocouple wires are cheaper to lose than the \$25 loggers. The Humboldt's multi-channel feature allows temperature measurements in up to four areas at once, which minimizes the chance of getting defective data from just a single source of measurement. However, it can be inconvenient to leave this meter continuously connected to the thermocouple wire. Since it has to sit next to the pavement during the entire curing process, the meter has to be protected from the weather and jobsite hazards to avoid any loss of data from a potential disconnection (Fig. 4.3-27). Also, more than one meter would be needed to monitor areas on the jobsite that are longer than 50 yards. Conversely, the Nomadics meter can be carried around a large jobsite and save data from 200 loggers. Its data loggers have also improved greatly over the years as they can now record maturity readings at one-minute intervals (Mills et al., 2004).

Since the maturity method relies on a strength-maturity relationship developed in the lab with a different batch than the one used on the project, there is no assurance that the concrete used on site has the exact same mixture proportions. In order for this method to work, the contractor has to use the same concrete mix on the job as the one used to develop the curve in the lab. This means that they should use the same procedures with the same materials from the same suppliers, with the same proportions and the same equipment as was used in the lab. Therefore, the Cabinet requires the contractor to verify the strength through breaking a core sample or an accelerated-cured cylinder before reopening the roadway to traffic (Fig. 4.3-28). If the meter reading is outside of a plus or minus 5% tolerance from the specimen tested, then the contractor has to go through the process of redeveloping a strength-maturity curve before continuing work on the project (Mills et al., 2004).



Fig. 4.3-27: Protected Meter Next to Fresh Concrete

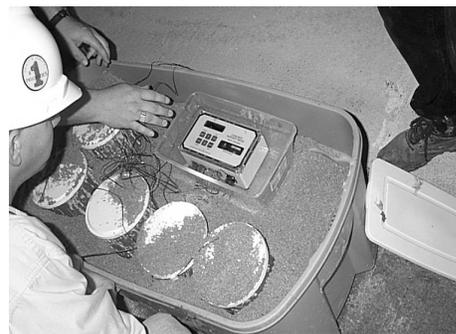


Fig. 4.3-28: Verification Cylinders to Break

The maturity method can be used through any weather that allows concrete placement. At the moment, many states are conducting research on this method. Some states have a protocol in place for its use and a few of those states even require mandatory use of this method as the

criterion to open the pavement to traffic. States such as Texas, Iowa, and Indiana are currently using the concrete maturity method for final project acceptance. Since November 2002, the Cabinet has allowed contractors to use this method to estimate the early strength of concrete pavements. Nevertheless, the Cabinet still prefers breaking 24-hour, 48-hour, 72-hour, and 28-day cylinders for final project acceptance (Mills et al.).

The Cabinet wanted to use the Gene Snyder Project to do experimental work with the maturity meter method and to assess its potential usage for future projects. Since the contractor was not familiar with the technique, University of Louisville researchers and Cabinet members worked together to collect data and document the process. They extracted cores from the pavement while it was curing to verify the effectiveness of the process. Furthermore, as soon as the meter indicated the maturity index corresponded to 3000 psi compressive strength, the crew would break a core sample to verify that they could safely open the pavement to traffic. As they expected, all the cores indicated approximately the same compressive strength as the maturity meter had predicted. On the other hand, the cylinder specimens reached 3000 psi two to three hours after the maturity meter had reached that point. If they are cured in the field with the same atmospheric conditions, directly on top of the big mass of concrete and covered the same way, the cylinders will cure faster than if they were cured off site or just next to the pavement. The main reason that cylinder specimens cure slower than the in-situ specimens is that they lack the heat generated by the large concrete mass. Therefore, no matter how they are cured, cylinders will always experience slower hydration and thus take longer to strengthen (Mills et al., 2004).

There are many advantages to using the maturity method to estimate the compressive strength of concrete. It is an accurate and non-destructive mean of testing concrete. This method provides real-time readings of the strength gain, right on site, which can help the contractor detect problems occurring during the curing phase. The maturity method provides cost and time savings over the traditional method of breaking cylinders. A contractor placing concrete every day with the same mix would break ten times fewer cylinders using this method since they would only have to test the last structure placed each day for verification. However, if they were starting to get disparities in the results, the savings would disappear as the contractor would have to start breaking cylinders at every placement of the day until they reach consistent results (Jenkins and Kissinger, 2004). Most importantly, though, the maturity method has the potential of being more accurate than the conservative representation of strength from cylinders since it estimates the concrete strength in situ by measuring data from the material itself instead of measuring data

from a representation of the material. It will always indicate a higher strength than the cylinders since, under similar curing conditions, bigger masses of concrete always achieve strength before smaller masses. This instantaneous accuracy allows the contractor to reopen the pavement to traffic earlier or to remove forms and move on to the next phase of construction faster. By allowing the project to move along ahead of schedule, this method saves money to both the public and the contractor.

However, the maturity method has some disadvantages. This method requires good quality control at the plant in order to maintain a consistent reproduction of the concrete mix and continue using a single curve. This is especially true for fast-setting concrete mixes, which, as proven by this project, can produce inconsistent curves (Jenkins and Kissinger, 2004).

There was a 600-foot portion of the I-64 Project where the existing concrete was completely removed and replaced with 14-inch deep concrete slabs. This section was located at the east end of the project, from Browns Lane to the bridge over the Middle Fork of Beargrass Creek. The Cabinet decided to replace the concrete pavement of that section because it is an area that had deteriorating concrete pavement due to trapped water. Since this is a short section next to a bridge, more than half of the pavement had to be removed for a digout anyways. Thus, it made sense to go ahead and completely repave the section with concrete. It also provided a good opportunity for the Cabinet to experiment with the maturity method (Bailey, 2004).

The Cabinet decided to use the fast-track concrete mix (Table 4.3-2) previously developed on the Gene Snyder Project and improved on the National Turnpike Project. This mix could develop the opening strength requirement of 3500 psi in less than 12 hours. Coincidentally, the contractor was from Indiana, where the maturity meter method had already been incorporated into their testing for two years. Thus, they had already been introduced to this testing method and had actually used it extensively on previous projects. Ultimately, since the maturity method had not yet been accepted as an acceptable testing method for opening strength verification in Kentucky, the concrete cylinders were used as the true opening method. This project gave the Cabinet the opportunity to use the maturity method at the same time as breaking cylinders to compare the results from both methods and further examine the validity of the maturity method (Mills et al., 2004).

Table 4.3-2: Concrete Mix Used on I-64 Project

Material (per cubic yard)	Concrete Mix
Cement Type I	800 lbs.
Natural Sand	1053 lbs.
Coarse Aggregate	1791 lbs.
Water	264 lbs.
Air Content	6%
High Range Water Reducer	36 oz.
Water Reducer and Retarder	20 oz.

The Cabinet provided the contractor with the curves previously developed for this particular mix design so that they would not have to completely redevelop them. Given that the same producer supplied the concrete, the contractor simply had to run a test to make sure the supplier could reproduce the mix to match the curves. During Labor Day weekend, the contractor placed 8 passes of concrete using a slip-form paver while making 10 cylinders for each pass. Since the maturity method is very sensitive to variations in the concrete mix, which is a major problem when dealing with high-early strength mixes, the contractor had to wait for the pavement to reach a conservative maturity index of 650 °C·hr to claim it had reached a compressive strength of 3500 psi. The concrete reached the 650 °C·hr index in 10 hours, but since the maturity index was very conservative, the road opened according to the cylinder breaks which reached 3500 psi in 9 hours. Therefore, the maturity method was not able to expedite the project due to the utilization of the fast-track design mix (Mills et al., 2004).

4.3.4.4 Breaking and Seating

In order to expedite the I-64 Project, the Cabinet specified the use of the breaking and seating method to rehabilitate the roadway pavement. By using this rapid rehabilitation method, they repaired the roadway faster and cheaper than by removing the existing concrete pavement. Since concrete is a lot stronger than dense grade, the Cabinet knew they could extend the service life of the existing concrete pavement and use it as a base. Before overlaying the pavement with asphalt, the contractor had to mechanically crack the concrete pavement into small segments (Fig. 4.3-31) using a heavy drop hammer with a sharp point (Fig. 4.3-32) to decrease the size of the concrete

slabs. If the contractor did not fracture the concrete pavement, the asphalt overlay would experience reflective cracking at the joints of the concrete slabs as the slabs would settle over time. Then, the contractor used rubber-tire rollers to seat the cracked pavement and ensure its settlement. Next, the contractor applied a tack coat bond breaker before overlaying the three lifts of hot mix asphalt. Once the concrete pavement was cracked and seated, the contractor placed a leveling and wedging layer of asphalt. Finally, the contractor overlaid the two 6-inch-thick base lifts followed by a 1.5-inch riding surface lift (Bailey, 2004).



Fig. 4.3-29: Cracked Concrete Pavement

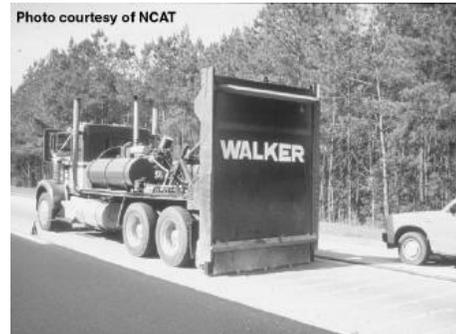


Fig. 4.3-30: Drop Hammer

4.3.4.5 Donnacrete Superpatch

Traditionally, the Paducah District has used three different methods to repair deteriorating pavement surfaces: cold mix asphalt, Duracal Brand Cement, and Emaco T415. The application of cold mix asphalt is the most temporary method they use. However, most surfaces are repaired with longer term mortar style materials. These materials are not structural patches but rather they are small patches that will prevent the cracks from worsening. These small preventive-type patches do not require any field testing of strength gain because the Cabinet only uses materials that were proven to achieve high early strength according to the ASTM C 109 testing method. A few years ago, the Cabinet began using Duracal Brand Cement, a high yield, fast setting, and high compressive strength concrete patch material. They were impressed with its ability to reach high compressive strengths in the first hour of the curing process (Table 4.3-4). However after using this product a few times, they realized that it was temperature-sensitive and would not last more than three months before cracking (Gibson, 2004).

Table 4.3-3: Compressive Strengths (in psi) of Conventional Pavement Repair Products

	Final Set (min.)	Curing Time Needed to Reach Strength				
		1 hour	2 hours	3 hours	6 hours	1 day
Duracal Brand Cement	35	4100	-	4100	5100	8100
Emaco T415	20-36	-	1500	-	-	4500

For the past couple of years, District 1 started using Emaco T415, since it had better durability in cold temperatures. Even though it took about three hours to harden and was a bit more expensive than Duracal, this product proved to be somewhat more successful. However, the patches only lasted six months before requiring repair. Both the Duracal and the Emaco products are mixed with water to develop into a mortar-like material and both of these products require a five to six hour lane closure to allow time for the mixing, placement, and setting of the mixture (Gibson, 2004).

Quadex is the company that developed Donnacrete and is also the only company that is able to apply this product since it requires their proprietary equipment. Currently, Quadex has demonstrated this product in Arkansas, Tennessee, Oklahoma, and Missouri. The Arkansas State Highway and Transportation Department has created a special provision for their contracts in order to allow the use of pneumatically placed mortars such as Donnacrete. This material is placed using the dry shotcrete method where the dry materials are mixed together first, forced through a hose, and then mixed with water at the nozzle. Hydration begins as soon as the water interacts with the dry materials, thus the material rapidly gains strength immediately after placement (Gibson, 2004).

Donnacrete takes less time to cure than Emaco T415 but it reaches greater compressive strength faster. As Table 4.3-4 demonstrates, Donnacrete reaches 3790 psi within the first hour of cure, compared to the 1500 psi that Emaco 415 attains in two hours (Table 4.3-3). Though Donnacrete is relatively more expensive than conventional methods, it lasts longer. However, since this product is a non-aggregated mix, it is only suitable to use as a surface repair mechanism and cannot be used to place full-size structural slabs. Actually, it is an ideal product to patch two to three foot wide areas on high volume roadways. Since it does not use any chlorides to accelerate the cure time, it does not corrode steel and thus it is suitable to use on reinforced concrete pavements such as bridges (Gibson, 2004).

Table 4.3-4: Flexural and Compressive Strengths (in psi) of Donnacrete Superpatch

	Final Set (min.)	Curing Time Needed to Reach Strength				
		1 hour	3 hours	1 day	7 days	28 days
Flexural Strength	35-37	-	-	1020	1275	1715
Compressive Strength	35-37	3790	4160	6020	6450	7100

Unlike conventional patches, the greatest duration requirement using Donnacrete is not the setting time, but rather it is the preparation time of the patching area. The surface must be prepared by first removing the deteriorated section with a concrete saw and a jackhammer. It is recommended to cut an additional six inches of the existing surface around the deteriorated section to allow the new material to tie into the existing surface. Though it is not necessary, District 1 also tries to penetrate below the steel reinforcement because they feel it provides more strength to the patch. Next, the crew removes the loose concrete and air blasts the section to clean out the rust, dust, and other chemicals. Then, they spray the surface with water, which is the only primer required. The next step makes use of the Quadex Spray Master proprietary trailer (Fig. 4.3-31) that was specifically designed to mix and apply Donnacrete. This piece of equipment holds the sixty-pound bags of Donnacrete and is equipped with a generator, a water tank, and a batch mixer. The crew dumps the dry Donnacrete material into the mixer and then the mix is hydraulically sprayed in very small overlapping layers (Fig. 4.3-32) until it patches the holes (Gibson, 2004).



Fig. 4.3-31: Quadex Spray Master Trailer



Fig. 4.3-32: Quadex Crew Applies Donnacrete

The crew removes the high spots of the mixture in-place with a sharp trowel and levels it with a screed (Fig. 4.3-33). Next, the application area is covered with damp burlap to minimize the evaporation of the water in the mixture (Fig. 4.3-34). Insulating the area helps to retain the heat of hydration, during which the mixture gains strength as the water and the Donnacrete combine chemically to produce a strong bonding paste. Finally, if the Donnacrete patch is applied over a

joint, the crew returns a day later to see a joint in the patch. For a two-foot wide by ten-foot long and three-inch deep patch, the described procedure requires approximately one and a half hours of work. This means that traffic would only be interrupted for two hours compared to the three to five hours of lane closure needed when using a conventional method (Gibson, 2004).



Fig. 4.3-33: Trowel and Screed Finishing



Fig. 4.3-34: Damp Burlap Used For Curing

The US-60 Bridge over the Tennessee River was built in 1931 to connect Paducah to communities such as Ledbetter and Smithland, located on the north flank of the river. The bridge is used in large part by the residents of these communities who commute daily to their jobs in Paducah. In 1998, it sustained an average daily traffic (ADT) of 26,400 vehicles. Since the bridge is an important gateway to Paducah and is very old, the Cabinet plans to replace it in the next five to six years. Due to poor conditions of the original pavement, the Cabinet was forced to repave the driving surface with a latex overlay in the early 1980's. However, since then, that overlay has deteriorated. Instead of overlaying the entire surface with a costly new latex overlay, the Cabinet decided to repair the existing overlay before the winter with Donnacrete (Gibson, 2004).

The inch-and-a-half thick latex overlay placed two decades ago is similar to conventional concrete except that a latex emulsion admixture is added to the mix to make it waterproof. This impermeable latex concrete is used to repair the wearing surface overlay of bridges since it increases the lifespan of concrete decks by protecting them from the infiltration of salts. Latex-modified concrete creates less transverse deck cracking than conventional concrete and is the most economical solution to repair an entire deteriorated bridge deck. It is a very fast-setting material that is batched on site and placed in one continuous operation in order to avoid cold joints. Unfortunately, when the new overlay was placed on the four-inch-thick concrete slabs two decades ago, the paving crew did not see a joint above the centerline joint of the deck. Over

time, the deck slabs started working independently and have allowed water and salt to penetrate through the centerline of the overlay. Through the years, the water trapped in the overlay has experienced the annual freeze and thaw stress enough times to cause significant cracking along the centerline of the overlay (Gibson, 2004).

The current problem is that the Cabinet sends crews five to six times per winter to do spot repairs on the overlay. These frequent visits to the bridge cause a nuisance to the traveling public, and the repair crews are exposed to a hazardous work zone. The smaller cracks are frequently repaired by the maintenance crew with cold mix asphalt (Fig. 4.3-35). The asphalt patch is very temporary, and may in fact only last about a week during the winter. The bigger cracks are patched by the bridge crew using a Duracal-Brand-Cement-based mix or more recently using an Emaco rapid-setting mortar. These conventional rapid-setting patches usually take five to six hours of lane closure and they only last three to six months before requiring additional repairs. The longer the Cabinet waits to repair a pothole, the more it will grow into a full-depth hole (Fig. 4.3-36). A full-depth patch is more labor-intensive due to the form that needs to go under the deck, tied onto the concrete deck's exposed steel reinforcements, to cast the material in place.



Fig. 4.3-35: Small Crack Patches Along Centerline



Fig. 4.3-36: Full Depth Crack Patch

In order to cause fewer burdens to the public and less danger to the repair crews, the Cabinet chose to use Donnacrete in order to accelerate repair time and minimize maintenance until the new bridge is built (Gibson, 2004). The Cabinet will hire a contractor to apply a two foot wide patch down the entire centerline of the latex concrete overlay surface and along the transverse joints as well. The contractor will work from 8:00PM-6:00AM when traffic volume is low, using lane closures, and they will fully reopen the roadway to traffic during the daytime. They will continue doing the operation on subsequent evenings until the whole bridge is patched. However,

since Donnacrete is applied faster than the bridge crew can prepare the section, the bridge crew will have to cut out the sections ahead of time. Then, during each evening shift, the crew will jackhammer a few sections down below the steel and clean them out before the contractor places the material. Traffic will be allowed back onto the bridge within an hour of applying the material (Gibson, 2004).

Earlier this year, a group of engineers from the Materials Office in Frankfort traveled to Paducah to core the deck and measure the compressive strength of the existing concrete that was still in satisfactory condition. They wanted to identify what kind of adhesion they would get between the existing concrete and the Donnacrete. The three-inch-deep cores revealed that the concrete deck could withstand an excess of 4,000 psi. District 1 now has approval from the Cabinet to proceed with this project, which will last no longer than ten days and is expected to cost about \$200,000. This will be a turnkey contract since the Cabinet will not participate in any work, but at the end of the project the Cabinet will inspect the work and pay the full amount of the contract. In comparison, a complete overlay of the bridge would cost anywhere from \$300,000 to \$400,000 and would completely close the bridge and force commuters to drive a 30 mile detour (Gibson, 2004).

4.4 Analysis of Contractor-Initiated Methods

The choices the contractor makes during construction can obviously expedite construction projects. The research from the case studies proves that the fast completion of a project relies on effective pre-construction planning and scheduling of all construction operations. For example, the contractors from both the Blue Grass Airport Project and the I-64 Project used similar tactics to finish earlier than expected. During the pre-construction meetings, both contractors were able to convince the project owners to allow them to use innovative rapid construction methods instead of the conventional methods specified in the plans. Also prior to the construction phase of the projects, both contractors mobilized large amounts of resources that allowed them to perform simultaneous operations. They would make sure to provide the most productive machines to the specialized work force they hired. Moreover, another factor that helped the contractors expedite their projects is the fact that they were able to store their equipment and materials adjacent to the work zone.

4.4.1 Innovative Management Methods

4.4.1.1 Pre-Construction Planning and Scheduling

The Blue Grass Airport Project began early in 1993 when the Lexington-Fayette Urban County Airport Board (LFUCAB) met with their design consultants to create a plan to pave the airport runway. Some airlines were threatening to leave the airport if the weather worn runway was not fixed since the last major paving was the 8 inch asphalt layer laid two decades earlier over the 10 inch concrete base built in 1943. The original plan for rehabilitating the airport's runway was to mill out the 8 inch hot mix pavement before repaving the runway in sections at different times. At first, all contractors overbid the 4.5 million dollar budget that the Federal Aviation Administration (FAA) had allowed for runway's repavement. However, Mountain Enterprises suggested to the Airport Board and their consultants that they could stay within the FAA budget by only repairing and leveling some parts of the old asphalt pavement and then overlay 3 inches of asphalt at one time on top of the entire runway (Fig. 4.4-1). Mountain Enterprises developed a plan after partnering with the Allen Company of Winchester, giving them enough asphalt plants located near the airport to accomplish the task. Since the original design plans were complex, it took one month of negotiations between the Airport Board, its consultants, and the Mountain Enterprises team to agree on a final redesign, paving plan, and contract (Annis, 2004).

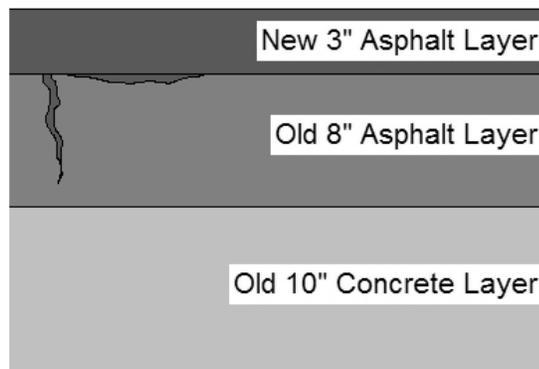


Fig. 4.4-1: Proposed Runway Cross Section

This project was an example of team partnering among the contractors and designers. Both the Airport Board team and the Mountain Enterprises team agreed on a contract to renovate the entire pavement of the airport in one weekend. However due to the contractual rain contingency which would force the Board to compensate the Mountain Enterprises team in the event of

rainfall, the airport engineers picked the historically driest and slowest air travel weekend of the year for the construction. Unfortunately for the Mountain Enterprises team, that weekend allowed only 5 weeks for planning and preparing the operation. During that short planning period, the contractor had to obtain the materials, equipment, and other resources needed to pave the new asphalt surface over the runway. They also had to organize haul routes in order to minimize conflicts between the trucks coming from other plant locations (Annis, 2004).

The main purpose of this \$4.5 million renovation project was to lay 20,000 tons of asphalt on the runway and to install a \$1 million lighting system in the centerline of the runway to improve visibility along the runway during bad weather. In addition, the contractor had to paint the runway striping and markings if the paving was completed at least 12 hours before the airport reopened. Otherwise, the painting would take place during the following weeknights, between 10:00PM and 6:00AM, when the team planned to return to completely repave the turnoffs and to seed and mulch the shoulders along the runway. In the weeks preceding the weekend operations, the Mountain Enterprises team did some preliminary work at night without interfering with the normal airport operations. They surveyed the runway to mark the runway centerline and also mark location spots for the mobile light plants. Additionally, a couple of nights before the weekend paving, their partnering team from the Allen Company pre-placed rows of dirt in preparation for work on the runway shoulders (Annis, 2004).

As a result of these planning efforts, the project was completed faster than expected and without any equipment breakdown, except for one flat tire. Mountain Enterprises calculated that the runway could be paved in 27 hours. They hoped to finish the runway paving in no more than 30 hours in order to have adequate time to paint the runway during the weekend operations. In reality, the runway was totally paved and compacted by 8:30PM Saturday evening, only 22 hours after it had started and 19 hours ahead of schedule. The additional time allowed the crew to complete the striping in time to let the paint dry before the first plane landed. Also, the crew was able to perform the work that was only planned to take place in the nights of the following week. The turnoffs were milled and completely repaved by 8:30AM on Sunday morning. Furthermore, the Allen Company had time to grade up the soil wedge to create a 3-inch tall by 4-foot wide shoulder along the edges of the runway. By noon on Sunday, once the seeding and mulching was completed, the entire crew demobilized away from the tarmac, and the first plane was able to land at 3:02PM (Annis, 2004).

Similarly, the early completion of the I-64 Project can also be attributed to the extensive planning and scheduling completed by the prime contractor before construction. The contractor established traffic control plans for the workers, picked key locations for storage and waste dumping areas, acquired enough equipment for the large work force, and coordinated all of the subcontractors. They also continued their detailed organization once the construction phase started. During the week, when construction work was halted, the contractor stockpiled the materials, assigned personnel, and developed a work plan for the following weekend. They were able to finish the job seven weeks early, because they were well prepared and developed a successful strategy (Bailey, 2004).

In order to work efficiently and safely on the I-64 job site, the contractor developed a traffic control plan for the large array of workers and their equipment. This project called for the addition of two 6-inch base lifts of asphalt over the existing concrete pavement of the roadway but not over the bridge decks. Thus, it required the full-depth removal of over 250 feet of existing concrete pavement at every bridge end to lower the surface of the asphalt down to the surface of the bridge decks. Since these bridge end digouts made the bridge structures unusable to traffic, the contractor completed all the digouts in one direction before performing the same operation on the adjacent bridges. That way, the adjacent bridges and temporary crossover lanes in the median remained operational (Fig. 4.4-2), (Bailey, 2004).

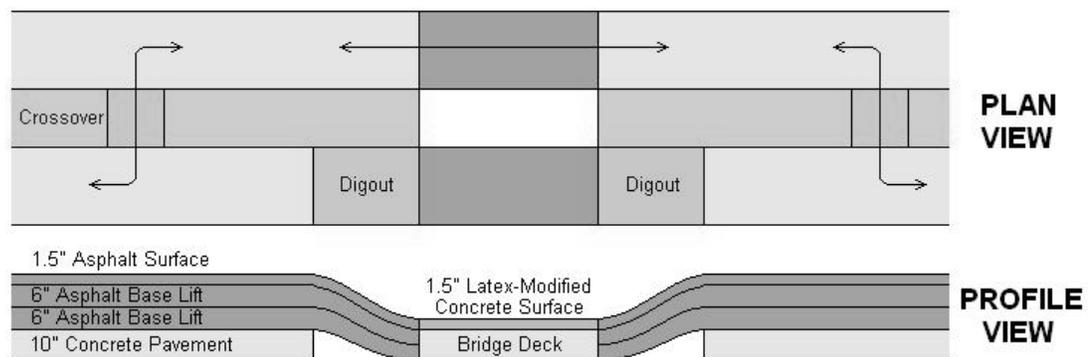


Fig. 4.4-2: Traffic Control During Digouts (Plan) and New Pavement Layers (Profile)

To efficiently manage the traffic throughout the jobsite, the contractor developed a traffic control plan with temporary traffic control devices. They continually maintained two operational lanes in order to deliver concrete and asphalt while hauling out truckloads of debris. However when there was only one lane available in the tunnels due to the crew installing the new lighting system, the contractor installed a temporary traffic signal at the entrance (Fig. 4.4-3), which was

more efficient and safer than the traditional operation of using two flaggers. The contractor also installed signage such as speed limits, overhead hazards, and stop signs. Added safety measures were also taken by appointing a specific safety and wellness crew that would visit each workstation to distribute rain gear and water bottles (Bailey, 2004).



Fig. 4.4-3: Temporary Traffic Signal

4.4.1.2 Performing Simultaneous Operations with Numerous Resources

On August 26th 1994, as soon as the Blue Grass Airport runway was officially shutdown, the Mountain Enterprises team applied grade SS1H emulsified asphalt tack coat before starting the overlay. They also moved in 24 light towers pulled by pickup trucks that would be used for mobile lighting (Fig. 4.4-4). Once the tack coat was applied, four paving trains began to place the asphalt overlay in a specific paving sequence. Behind each of the 4 paving machines, there were 3 dual-drum vibratory asphalt compactors moving at a rate of 2 to 3 mph (Fig. 4.4-5). All pavers and rollers were equipped with lights as well. Following the rollers were technicians who used a nuclear density meter to test for the asphalt quality every 100 feet of the paving lane (Annis, 2004).

There were 10 dump trucks assigned for each paving machine, all of which were marked with the same color flag as their respective paving machine. Two drivers per truck would alternate every 10 hours until the pavement was complete, thus there were 80 drivers for 40 trucks. Also, in case of an equipment breakdown, Mountain Enterprises had brought backup equipment to the jobsite. There were 2 spare paving machines, 4 spare roller compactors, and spare welders stationed adjacent to the runway. Ultimately, there were over 300 people directly involved in the airport paving project. In 23 hours, 1000 truckloads supplied the 24,000 tons of asphalt needed to lay the 1 million square feet of runway (Annis, 2004).



Fig. 4.4-4: Light Tower

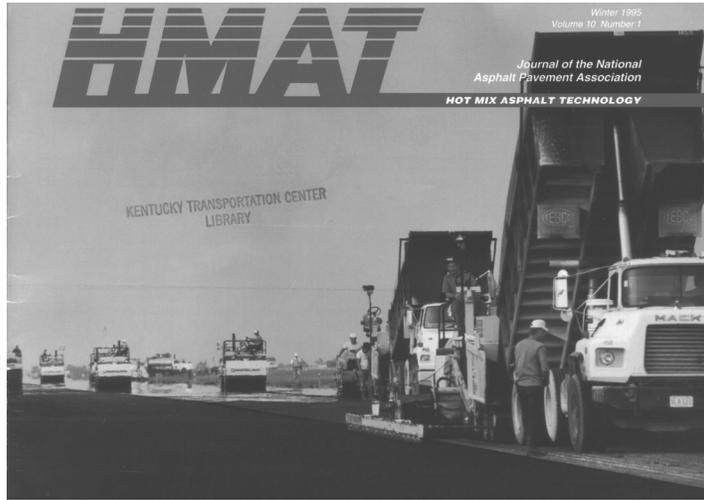


Fig. 4.4-5: One Paving Crew of 1 Paver & 3 Compactors

On the I-64 Project, the contractor coordinated over 500 workers, using in excess of 150 pieces of equipment, to simultaneously perform a variety of tasks. They were able to succeed with a great deal of planning, great coordination with their equipment suppliers, and strong commitment from the subcontractors. For example, the contractor required their suppliers to provide them with only new equipment that had less than 100 hours of previous use to minimize mechanical breakdowns. Still, the contractor had an on-site repair crew at all times and was even prepared to exchange any piece of equipment by having backup pieces kept in the storage yard (Bailey, 2004).

The contractor understood that the key to expediting this fast track project was to perform as many simultaneous operations as possible. They followed an extraordinary production planning strategy by hiring a large number of specialized subcontractors for the smaller items on the project. Similar to an assembly line, each worker was assigned a specific task that they would perform repeatedly. This strategy allowed the contractor to use a variety of subcontractors to work simultaneously on multiple operations in one day instead of only using one crew working sequentially on the same operations over multiple days. The contractor subcontracted the work for the breaking and seating of the pavement, the latex modified concrete in the tunnels and on the bridge decks, the guardrails, the electrical work in the tunnels and on the interchanges, the pavement markings, the shoulder edge drain and edge walls, the erosion control, and the landscaping. The crews were so specialized that, for example, there were two specialized pavement markings crews. Typically there would only be one crew who would perform all of the

tasks for pavement marking. On this project, however, one crew would place the tubular markers and barrier wall delineators while the other crew would place the thermal plastic pavement striping (Bailey, 2004).

4.4.1.3 Strategic Location of Project Resources

Mountain Enterprises suggested the idea of paving the entire Blue Grass Airport runway at once because they had access to many hot mix asphalt (HMA) plants in the surrounding area of the airport, by partnering with the Allen Company of Winchester. Mountain Enterprises possessed 2 HMA plants in downtown Lexington that they had built for previous projects. These two plants, located near one another on Old Frankfort Pike and Manchester Street, were both approximately 4 miles away from the airport (Fig. 4.4-6) and could each produce 250 tons of the asphalt mix per hour. Mountain Companies also owned a HMA plant next to the Allen Company's HMA plant on Catnip Hill Pike at the entrance of Jessamine County. These plants were further away from the airport and slower as they would require an 8 mile haul distance and produced 200 tons of asphalt per hour each (Annis, 2004).



Fig. 4.4-6: HMA Plant Locations

Mountain Enterprises decided to subcontract the Allen Company to operate both Catnip plants during the project, while they would handle their two Lexington plants. According to the Project Manager, coordinating the truck delivery from the right plant to the right paving train was

the key to success. The critical aspects of this process were to keep the trucks flowing with hot mix asphalt, to provide the least amount of traffic contact between the two truck teams, and to ensure a continual flow of the asphalt mix into the paving trains. In order to minimize traffic delays, the haul routes were designed so that the trucks managed by Mountain Enterprises would enter a gate on the east side of the runway and exit through another eastern gate. Alternatively, the trucks operated by the Allen Company would enter the central gate of the airport and exit through a southwestern gate (Annis, 2004).

The I-64 Project is another example where the contractor gave careful consideration to the location of critical project resources. One very important reason why the contractor was able to expedite this project was the fact that the laydown area and the waste dumping area were located on the jobsite. Before this project, the contractor worked for the regional airport authority on a runway extension and revitalization program at Bowman Field, just a few hundred feet from the Cannons Lane on-ramp to I-64 (Fig. 4.4-7). The contractor received permission from the airport authority to utilize the laydown yard they had created for the previous project. The contractor was able to utilize this vast staging area next to the interstate to store over 150 pieces of heavy equipment, including trucks, rollers, backhoes, trackhoes, cranes, pavement breakers, and edge drain trenchers. This proximity to the jobsite allowed for a quick and easy deployment of the equipment and materials into the project and minimize interaction with public traffic. In order to expedite the deployment on Friday evenings, the contractor would use trailers, on Friday mornings, to transport the critical pieces of equipment to the large grassy areas next to the ramps. This allowed the contractor to start work once the roadway closed. Overall, the contractor maintained a safe construction operation by making sure that the trucks and other equipment would never be on the roadway at the same time as public traffic (Bailey, 2004).



Fig. 4.4-7: Laydown Yard Right Next to Project

Another well-planned factor that helped expedite the I-64 project was the short haul time it took the dump trucks to carry the waste material to an on-site dumping facility, at the interchange of I-264 with I-64. A lot of the material that was removed during the job was brought to these two ramps and benched into the existing 1:3 slopes of the ramps to lengthen them to 1:4, 1:5, and 1:6 slopes. Since the slopes were now safer, it allowed the Cabinet to remove the existing guardrails and thus reduce the Cabinet's long-term cost of maintaining them. Most importantly, this on-site dumping facility allowed the contractor to haul the waste in a short 15 minute round trip instead of the 1 hour round trip they would have had to make to their quarry in Sellersburg, Indiana. Besides the construction entity and the quarry, the contractor also owns a hot-mix asphalt plant in Sellersburg, adjacent to I-65. Thus, they had the freedom to open the quarry at 3:00 a.m. without trouble and they had good access to the jobsite, only encountering public traffic for about 15 miles on I-65. Once the asphalt trucks crossed the Ohio River and entered Louisville, they entered the work zone since the eastbound lanes of I-64 were shutdown to traffic starting at the I-65 ramp. As can be seen from the project information map published by the Courier-Journal to inform the public (Fig. 4.4-8), the westbound lanes of I-64 remained opened from Grinstead Drive to the downtown intersection with I-65 (Bailey, 2004).

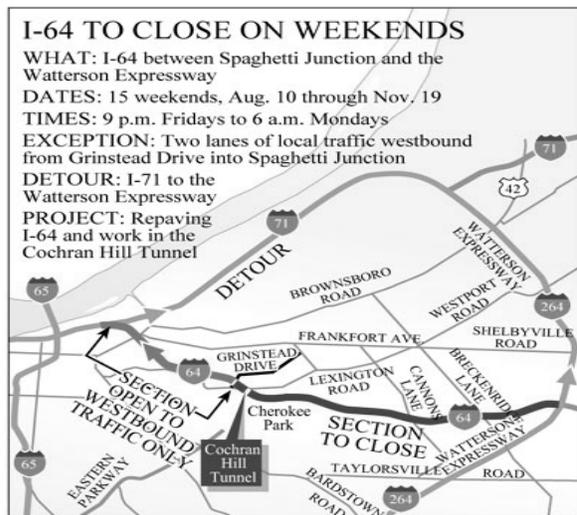


Fig. 4.4-8: Published Project Info

4.4.2 Innovative Field Methods and Equipment

4.4.2.1 Simultaneous Paving Sequence

The contractor of the Blue Grass Airport Project decided to use one paving crew per HMA plant because keeping the same asphalt per lane would facilitate asphalt isolation during testing. When they realized that all four paving trains could lay more asphalt than their corresponding plant could produce, they decided to adjust the paving speed to the plant production rate. They also decided to keep the paving speed constant in order to pave continually and thus produce a better pavement. Since the paving trains have screeds that could extend from 10 feet to 18 feet and that the runway to pave was 150 feet wide, the contractor decided to perform 10 passes (lanes) of 15 feet of width. As previously mentioned, Mountain Enterprises was responsible for the two closest and fastest asphalt plants. The two Lexington plants they were operating were located only 4 miles from the airport and could produce 250 tons of asphalt per hour. Thus, since Mountain Enterprises' pavers could pave at a faster speed, they would do 6 passes while the Allen Company pavers would do the remaining 4 passes (Table 4.4-1). Since the Mountain Enterprises trucks would haul more tons of asphalt per hour by making more trips of a shorter haul distance, each team would use the same number of trucks to continually feed asphalt to their pavers (Annis, 2004).

Table 4.4-1: Summary of Plant-Truck-Paver Relationships

Plant Owner	Company in Charge	Plant Location	Plant Distance from Airport	Plant Output	Trucks Used	Paver Supplied	Paver Passes
M. E.	M. E.	Lexington	4 miles	250 tons/hr	10	#1	3
M. E.	M. E.	Lexington	4 miles	250 tons/hr	10	#2	3
M. E.	Allen Co.	Catnip	8 miles	200 tons/hr	10	#3	2
Allen Co.	Allen Co.	Catnip	8 miles	200 tons/hr	10	#4	2

Originally, the Federal Aviation Administration asked the contractor to start paving the runway from one edge to the other in case that half of the runway was needed for an emergency landing. This method required operating all four pavers at the same slower speed so that the pavers would not cross paths on their return passes. However, Mountain Enterprises was able to convince the airport authority that starting the paving from the centerline, and working their way

leading paver around while making sure to never cross paths on the same joint (Fig. 4.4-10). The paving trains were staggered 300 feet for truckload-dumping purposes and to maintain an effective rolling pattern. This paving sequence developed by the contractor allowed the four combined plants to produce identical FAA asphalt mix at their maximum rate of 900 tons per hour (Annis, 2004).



Fig. 4.4-10: Two Same-Team Paving Crews Staggered by 300 Feet

Similarly, the same paving sequence was used on a smaller scale during the I-64 Project. Each weekend, the contractor used two pavers (Fig. 4.4-11) to simultaneously pave two lanes to eliminate the cold joint in the middle. During the week, the asphalt material of that lift would have time to stabilize and cool until the next lift would be placed the following weekend (Bailey, 2004).



Fig. 4.4-11: Simultaneous Use of Two Asphalt Pavers to Eliminate Centerline Cold Joint

4.4.2.2 Temporary Conveyor System

Before the public announcement of the Shawnee Expressway Project, the Kokosing Construction Company acquired a well-located piece of land next to the Shawnee Expressway. Once awarded the project, Kokosing immediately submitted letters and submittals for approval of a conveying system. The proposal was approved and a temporary concrete batch plant and conveyor were built on the acquired property located off Camp Ground Road. In the event that Kokosing was not awarded the contract, the company had put themselves in position of selling the property to the winning bidder. A piece of land located next to the project right-of-way could be used as a storage area (Jenkins, 2004).

In the end, this land proved to be very valuable. The conveyor (Fig. 4.4-12) transported concrete from the batch plant (Fig. 4.4-13), over two directions of traffic, and into trucks waiting in the inside lanes to deliver the concrete to the paving operation. The conveyor maintained a clearance of fifteen and a half feet above open traffic lanes and had shielding installed to prevent any material from falling onto the vehicles passing under it. The conveyor reduced the cost for trucking and allowed for accelerated construction by decreasing the cycle time from the point when concrete was batched to the point it was placed. The conveyor also improved safety by reducing the chance of truck accidents since exposure of trucks entering and exiting the work zone was reduced. The trucks stayed in the inside lanes and never had to enter or leave the construction zone. At one point, when the contractor was working on the westbound direction, the conveyor spanned about 250 feet over active traffic. However, since the conveyor belt blocked the Exit 5A cantilevered sign (Fig. 4.4-14), the contractor had to temporarily put up a similar sign on its post (Fig. 4.4-15) to help the traveling traffic (Jenkins, 2004).



Fig. 4.4-12: Conveyor System



Fig. 4.4-13: Concrete Batch Plant



Fig. 4.4-14: Extended Conveyor (Blocks Sign)



Fig. 4.4-15: Shortened Conveyor

4.4.2.3 Mi-Jack Travelift Rubber Tire Gantry Crane

In order to widen I-65 over the Barren River, the contractor came up with an innovative way to accomplish the task faster and with minimal traffic disruptions. Since the widening of the road approaching the river consisted of paving over the grass median to add two extra lanes, the widening of the two existing bridges required connecting them with a third bridge to create one uniform bridge with two extra lanes in the middle. The typical way to build the connecting bridge is to place a fixed crane on one of the bridges and thus shut down traffic lanes. Alternatively, the contractor decided to leave the fixed crane on land and use a mobile rubber tire gantry crane, as wide as the existing median, to carry the materials in between the existing bridges. To do so, the contractor had to re-stripe narrower lanes over the bridge and build temporary barriers on the inside shoulders to separate traffic from the gantry crane and the construction workers. The traffic slowed down through this work zone, but the two lanes of directional traffic remained open on each bridge (Carter and Proffitt, 2004).

The gantry crane was brought on site for the completion of the drilled shaft footings. It was used to lower the reinforcement cages into the shafts and lift the steel casings out of the shafts (Fig. 4.4-16). It was also used for the following process of casting in-place piers. However, its main use was for the building of the superstructure of the new bridge (Fig. 4.4-17). The crane lifted the I-beams from the on-land median and carried them into place over the river. It also lifted into place all of the other materials needed to install the beams, such as steel reinforcing cross bars, and it was used for the placement of the concrete deck. Overall, the gantry crane allowed for a faster and easier placement of the beams and concrete than the standard fixed-crane placement. It also minimally disturbed the traffic since two lanes of traffic in both directions remained open at all times (Carter and Proffitt, 2004).



Fig. 4.4-16: Using Crane to Build Foundations



Fig. 4.4-17: Using Crane to Build Superstructure

4.4.2.4 Pre-cast/Cast-in-Place Hybrid Barrier Walls

The contract of the I-64 Project called for the placement of cast-in-place barrier walls in the tunnels. One of the requirements was that the Cabinet wanted to have a large footer for these barrier walls. The contractor thought it would be difficult to cast an odd cross section in one continuous unit in the field. Therefore, they would have had to dig out and pour the footers in one weekend, let them cure during the week, and then cast the barrier walls in the following weekend. The contractor suggested to the Cabinet that they could expedite this process by pre-casting the footers offsite using the cross-section layout. Then, all they would have to do in the field would be to set the pre-cast footers in place, tie the top cage of steel on them, and pour the cast-in-place wall right on top. Due to the strong partnering bond they had achieved with the Cabinet, they were allowed to use this combined pre-cast/cast-in-place hybrid barrier concept, which helped them expedite the installation of the walls by at least a week (Bailey, 2004).

4.4.2.5 Complete Airport Shutdown

In order to pave the entire Blue Grass Airport runway at once it had to be non-operational to the planes and fully available to the contractor for 42 hours. At the time of this project, the conventional approach of building an airport runway was to pave shorter sections of the runway at night over a lengthy period of time to keep the airport operational. The downside of this traditional method is that it produces lower quality asphalt due to the extra cold joints it creates. However, by paving the entire runway in one setting, this problem was avoided. The contractor was allowed full access to the runway, enabled the construction of a smoother and better-quality

runway. Also, mobilizing the airport for a shorter period of time is more economical. If the FAA would have used the traditional method on this project, it would have taken 6 months to complete and would have cost at least \$1 million dollars more due to the lengthy mobilization of resources.

4.5 Lessons Learned

4.5.1 Full Closure of Interstate

Full roadway closures are best suited for major roadway rehabilitation projects in urbanized areas. They are a good traffic control alternative for projects where time is of the utmost importance and when there is a viable alternative route able to adequately handle the added traffic volume. Furthermore, completely closing a major freeway requires a good public relations campaign. By informing the public ahead of time about the roadway closure and the alternate detour routes, the traveling public has the choice to use these alternate routes or to even avoid the construction area during the weekends. During the I-64 project, the motorists were very accepting of this traffic control method, since they were informed in advance about the detour available. Compared to the traditional traffic control through a construction work zone for an extended period of time, the public seemed to prefer this innovative approach of a shorter construction operation. This traffic control system is a safer alternative for both the drivers and the traveling public. Overall, the full-closure method results in shorter inconveniences to motorists, minimal work zone accidents, minimal traffic congestion, a more productive work zone, and ultimately a higher quality product that will require less maintenance in the future (Full, 2004).

4.5.2 Incentives and Disincentives

The research team gained valuable insight with regards to the usage of incentives/disincentives on the I-65 and I-64 projects. If the Cabinet offers incentives on a project, the contractor will find ways to finish early, including using innovative rapid construction methods to build faster than usual. Furthermore, if Cabinet decides to use a maximum incentive cap, the contractor will find ways to schedule the work to finish construction on that day and no earlier. The Cabinet should calculate reasonable contract durations and reasonable bonuses for its highway construction projects. Mathematically, if the Cabinet was to maintain the same

incentive caps for all projects, the projects with lower road user costs would provide more early-completion-bonus days and thus they would likely result in faster construction. This is the reason why the contract duration should be especially calculated with care for roadways with high road user costs. If the contract duration, road user costs, and incentive caps are well coordinated, all parties will benefit from the contract. The contractor will finish early; the Cabinet will award a publicly-acceptable bonus; and the public will receive quicker access to the roadway without a work zone.

4.5.3 High-Early Strength Mix

Anytime a project needs to be accelerated, such as for early opening to traffic or early formwork removal to continue the sequential work, such as bridge piers, the Cabinet can consider time constraints to push the contractor to use an accelerated concrete mix. The Cabinet would recommend using fast-track mixes on large highway repair jobs in areas such as downtown Louisville, Covington, and Lexington. These areas are so saturated with traffic flow that the high road-user costs warrant the use of time constraints and the incentives/disincentives to try to get the job done early. Since accelerated mixes are more expensive than traditional ones, they are not beneficial to use when time is not a constraint. Therefore, fast-track mixes are not used on new roadway projects since these projects do not hold up any traffic (Mills et al., 2004).

In recent years, the Cabinet has stopped prescribing precise concrete mixes to the contractors. Instead, they started specifying wider ranges to allow the contractors to develop their own fast-setting mixes. This approach allows the Cabinet to hold the contractor responsible for the performance of the concrete and assess penalties if the mix fails to provide the specific strength within the allotted time. In fact, the Cabinet is now looking into possibly prescribing the use of third-party concrete mixes into their future contracts. In June 2004, after watching other states such as West Virginia use Master Builders' 4x4 Concrete System mix successfully, the Cabinet decided to run trial batches of the product to see if it could possibly work for them. This particular product is advertised to reach 400 psi of flexural strength (approximately 4000 psi of compressive strength) in only 4 hours. Unfortunately, this product underperformed, probably because the Cabinet did not add any chloride accelerator. Unlike some states, the Cabinet does not allow the addition of chloride accelerators into their concrete mixes because it corrodes the reinforcement in the pavement of bridges and the dowels at the joints of the non-reinforced roadway pavements (Mills et al., 2004).

The main lesson learned from the Gene Snyder Project is that high-early strength concrete is unpredictable. However, there are certain precautions that a contractor can follow to prevent most variable reactions. For instance, a contractor should never add water to a mix after the accelerator has started to bond with the cement. If water is added to the mix, there is no way to predict the concrete's reaction. The rapid hydration of fast-track mixes is also a cause for concerns. These mixes do not have good longevity as they become more brittle and crack sooner than regular mixes over time. The rapid hydration cause more internal cracking, which cuts down the durability of the structure. Even though compressive strengths are met, the flexural strengths may be weaker. In order to maximize the durability of the fast-track concrete, the contractor needs to minimize the internal cracking by using cooling measures such as surface insulation (Jenkins and Kissinger, 2004).

4.5.4 Maturity Method

When estimating in-place concrete strength, the concrete maturity method is an accurate technique. Concrete cylinder specimens do not accurately depict in-place concrete strength because they have a different temperature history, or maturity, which is directly related to strength gain. The cylinders retain less heat due to their different volume, shape, and curing conditions. Thus, they provide a conservative representation of in-situ concrete strength. On the other hand, the maturity method is unaffected by any of these factors since it collects in-situ data. As long as there is good quality control throughout the process, from developing the strength-maturity curve to producing consistent concrete mix, the maturity method has been regarded as a more accurate approach to estimating in-place concrete strength (Jenkins and Kissinger, 2004).

Over time, contractors will gain experience with the technique and they will have accumulated enough historical lab and field data for their mixes to enable them to use this method on most projects. The Cabinet has contacted the Kentucky Association of Highway Contractors, the Kentucky Ready-Mixed Concrete Association, and other organizations to inform all contractors of the region about the opportunity to use this method (Mills et al., 2004).

Unfortunately, the maturity method is very sensitive to variations in the concrete mix, which can be a problem when dealing with inconsistent high-early strength concrete mixes. For these

rapid mixes, the method does not work as well because the strength-maturity curve is approximately a straight line during the first 4 hours of the setting process. Instead of using the Nurse-Saul Equation to calculate the maturity index values, the Arrhenius Equation (Equation 4.5-1) should be used for more accurate early time estimates.

Equation 4.5-1

$$t_e = \sum e^{-Q\left(\frac{1}{T_a} - \frac{1}{T_s}\right)\Delta t}$$

t_e is the equivalent age (maturity index) at a specified temperature T_s (hr)

Q is the activation energy divided by the gas constant ≈ 5000 K

T_a is the average temperature of concrete during time interval Δt (K)

T_s is the specified temperature = 296 K arbitrarily

Δt is the time interval (hr)

Also, since high early strength mixes are very temperature-sensitive, contractors should use core samples for verification rather than cylinders. Nonetheless, regardless of the type of mix used, the temperature sensors should consistently be placed at the mid-depth of the concrete mass and preferably at the centroid. This practice is used to best represent the conditions at which the curves were developed in the lab. The main reason for this practice is the fact that sensors are placed at the core of the cylinders when developing strength-maturity prior to construction (Mosen, 2001; Jenkins and Kissinger, 2004).

It may also be worthwhile for the Cabinet to look into the new wireless concrete maturity systems available. For instance, the IRD Concrete Maturity Monitoring System developed in Canada by International Road Dynamics Inc. and Identec Solutions Inc., and manufactured in the United States by Wake, Inc., has worked successfully for states such as Iowa, Michigan, and New York. The system uses Identec's Intelligent Long Range Radio Frequency Identification (ILR RFID) sensor tags to emit concrete temperature data to a handheld radio frequency device such as a laptop, pocket PC, or PDA (Fig. 4.5-1). The RFID sensor tags collect temperature data at user-defined intervals that is wirelessly communicated to the handheld receiver through radio-frequency signals. This system eliminates the problems caused from stringing wires that other maturity method systems have. Each transponder tag can be embedded 8 inches into the concrete

and can emit the in-situ temperature data to a read range of about 20 feet. With an 8KB memory and a 5-year battery life, each tag can store a large amount of data that can be accessed for many years (Intellirock, 2004).



Fig. 4.5-1: Wireless Maturity Meter System

4.5.5 Donnacrete Superpatch Product for Small Concrete Repairs

A few years ago, Quadex representatives from Little Rock, Arkansas, contacted the Maintenance managers in the Central Office to inform them about the fast setting Donnacrete product. The Cabinet granted them the opportunity to demonstrate their product around Paducah, Kentucky on a bridge with low traffic volumes and on an interstate with high traffic volumes. In the morning of Tuesday April 30th 2002, the Quadex crew first went to a site on I-24 in Trigg County, between mile markers 66 and 67, to patch a concrete section of roadway that had cracked after the failure of the base. This interstate, built in the early 1970's, has concrete lanes with asphalt shoulders. A few years ago, a ten-foot concrete slab of the outside lane started to settle after a subsurface problem, most likely due to water saturation in a badly compacted area of the base. By the time the Quadex crew had cleaned the deteriorating area next to the joint of the lanes, the hole had a triangular shape with six foot long sides and was at least six inches deep (Fig 4.5-2). It only took a two hour lane closure to clean up the area, patch it up, and reopen the lane to traffic (Gibson, 2004).

Today, the patch is carrying an average daily traffic (ADT) of 16,500 vehicles and it is still holding up very well as it does not have a disintegrated surface yet (Fig. 4.5-3). In the past two years, the patch has settled down a bit due to the ongoing settlement of the outside lane concrete slab in that area. The resulting change in elevation of the outside lane, and not a failure of the

Donnacrete, has caused the patch to split in half. Besides the addition of a bit of asphalt a year ago to cover up that fracture, the material itself has not broken anywhere else but it also did not bond well with the existing pavement. The small cracks, between the separated patch and the existing concrete, had to be filled with a tar-based sealer (Gibson, 2004).



Fig. 4.5-2: Cleaned I-24 Hole Before Patch



Fig. 4.5-3: I-24 Patch Two Years Later

Once they finished the I-24 patch, the Quadex crew drove fifty miles northwest to the Smithland Bridge in Livingston County. Similarly, to the Ledbetter Bridge, this US-60 Bridge was built in 1931 and had a recent latex overlay added on a pair of concrete slabs. At the time these two bridges were built, it was not unusual to separate the concrete slabs for each lane with a joint in the centerline. Like the Ledbetter Bridge, the overlay of the Smithland Bridge was placed in a single monolithic pass, from one transverse joint to another, without a centerline joint. Likewise, the movement of the slabs, particularly at the joints, has allowed the water and salt to penetrate and deteriorate the overlay. The only difference between these bridges is that the Smithland Bridge crosses over the Cumberland River instead of the Tennessee River (Gibson, 2004).

In the afternoon of that Tuesday, April 30th 2002, the Quadex crew did not have to jackhammer as deep as the I-24 patch, although they did have to penetrate a bit below the steel reinforcement of the concrete deck slabs (Fig. 4.5-4). Again, it took no longer than two hours of lane closure to clean the area, apply the patch, and reopen the lane to traffic. Two years later, the patch is almost undetectable (Fig. 4.5-5). Its surface is still intact and its bond with the existing surface is so good that there has not been any crack surrounding the patch area. The only visible fracture on the surface is the joint that the District sawed at the centerline of the whole overlay. One of the reasons that the patch is doing so well may be because it does not carry much traffic. In 1999, it sustained an average daily traffic (ADT) of only 3,900 vehicles. However, since the centerline of the overlay is in such a bad condition, the Cabinet may still patch the entire centerline with Donnacrete if the September project of the Ledbetter Bridge is successful (Gibson, 2004).



Fig. 4.5-4: Cleaned Bridge Cracks Before Patch



Fig. 4.5-5: Bridge Patch Two Years Later

Kentucky is a state that has moderately cold winters with average temperatures hovering around the 35°F mark. Thus, it is common to see the nighttime lows fall below freezing while the daytime highs rise just above freezing. That type of weather allows water from a cold rain shower, or from melting snow, to infiltrate the porous concrete pavements during the daytime. If most of the concrete pores are saturated by the time the temperature falls below the freezing mark at night, the expanding volume of freezing water builds up pressure in the rigid concrete and ultimately fractures the surface of the pavement. This phenomenon, known as the freeze-thaw cycle, occurs repeatedly throughout the winter season and continually deteriorates the less air-entrained concrete pavements. This process keeps the maintenance crews busy during the winters as they have to continuously patch up the distressed road surfaces. In the case of the two US-60 bridges examined in this report, the longitudinal centerline cracking of the overlays were also caused by the movement of the slabs, since centerline joints were never cut into the overlays (Gibson, 2004).

In order to lessen the inconvenience of long lane closures to the traveling public, the Cabinet has traditionally preferred to patch the cracks with fast-placing and fast-setting products such as cold mix asphalt or high-early strength repair mortars. While the asphalt does not last long and require the repair crews go back to same spot three to five times per winter, the traditional rapid-strength repair mortar requires a longer lane closure and may only last through one season.

Fortunately, some new fast-setting products have allowed various state transportation agencies around the country to repair pavement surfaces faster and less frequently.

The product the Cabinet has tried in Paducah, Donnacrete, has performed well over the past two years without showing any sign of surface cracking due to material failure. It is a cost-effective option when the damaged pavement can not be replaced but rather has to last another five years. However, it is only designed for non-structural repair patches and cannot be used to pave large areas. When comparing to the current methods used by the Cabinet, Donnacrete does not save much time during the preparation of the damaged area and the application of the mix. However, it allows a roadway to reopen to traffic in half an hour after the patch is applied, compared to the minimum three hour wait required from any other products. Therefore, Donnacrete is ideal for any roadway repair project with a high average daily traffic and where the majority of the surface is in good shape but there are few extensive damages that do not justify doing a complete overlay yet, particularly on old bridges that are going to be replaced soon (Gibson, 2004).

Donnacrete is also attractive because it can repair deteriorating pavements in a short period of time while only closing one lane of traffic. By not shutting down the entire roadway, the Cabinet has the flexibility to work on small parts of a project during consecutive nights, when there is a lower traffic volume, and reopen the entire roadway during the daytime, when the demand is the greatest. Even though this product has proven to be more successful than the previous products used by the Cabinet, it may not be the only solution. In fact, other states have used similar products from Degussa (formally Chemrex) and the United States Gypsum Company for many years and with great success. For example, such products as Mono-Patch Cold Set All-Surface Repair, SET 45, Duracal HP Brand Cement, and ThoRoc 10-60 have all been approved for use by the Indiana Department of Transportation. Mono-Patch Cold Set All-Surface Repair and SET 45 have been used for flat grades since they have a higher slump and are more workable, while Duracal HP Brand Cement and ThoRoc 10-60 have been used for low-slump patching on steep grades (DOTS, 2004).

These other fast-setting, high early strength, repair mortars may be worthwhile for the Cabinet to examine. All of them reach their final setting time in less than forty five minutes while also reaching 2000 psi of compressive strength within the first hour of their cure (Table 4.5-1). This means that, similar to Donnacrete, these four products would allow the roadway to

reopen in less than an hour after their application. The Missouri Department of Transportation used Duracal on their bridges for many years but they made the transition to the new Duracal HP three years ago. They like the fact that it does not require a proprietary mixer, it is easy to place, and it consistently reaches compressive strengths of 2500 psi within the first three hours and without significant shrinkage cracking. Best of all, they have yet to see a Duracal HP patch fail or exhibit any signs of distress or cracking. While Donnacrete has proven to work in normal weather conditions, some of these products were designed to sustain cold or hot weather applications. The Cabinet can consider examining the cost-benefit potential of these products (Martens, 2004).

Table 4.5-1: Typical Compressive Strengths (in psi) of Innovative Products

	Final Set (min.)	Curing Time Needed to Reach Strength				
		1 hour	2 hours	3 hours	6 hours	1 day
Set 45	10-20	2000	-	5000	5000	6000
ThoRoc 10-60	28	2000	3000	-	-	6500
Mono-Patch Cold Set	40	-	-	3000	-	4500
Duracal HP Brand	45	-	2000	2500	-	-

5.0 CONCEPTUAL USER COST MODEL

5.1 Road User Costs

Road user costs (RUC) are a monetary measure that can be utilized by engineers to aid in identifying the rapid construction methods available to a particular project. The ideal time to select these methods is during the initial planning stages when many project parameters may be unknown, making it difficult to perform a detailed estimation of RUC. Current RUC models such as QuickZone, MicroBENCOST, QUEWZ and KyUCP, can calculate many different aspects regarding work zone delays, solve complicated work zone user cost problems, and generate accurate road user costs. However these models require many input variables, such as annual average daily traffic (AADT), work zone in place schedule, traffic classification, data on alternative routes, percentage of grade and degree curvature of the existing or proposed route, which can be difficult to identify during the preliminary or conceptual design phases of a project's development process. Thus, the research team has created a conceptual RUC model, which can provide a preliminary estimate of RUC values based on the information available during the early design stages.

Currently, most roadway projects involve rehabilitation and capacity expansion in order to preserve an aging U.S. highway system and to meet increasing traffic demands. As already discussed in this report, the application of rapid construction methods is needed for roadway projects in order to minimize their impact to the surrounding communities. Road user cost is an important criteria that can be used by engineers to identify proper rapid construction methods, such as A+B contracting, incentive/disincentive contracting and precast/modular components.

Road user costs are the increased vehicle operating cost (VOC), delay cost, and crash costs to highway users resulting from construction, maintenance, or rehabilitation work zones. The cost primarily refers to lost time and increased vehicle operating cost due to the following:

- Detours and rerouting that add to travel time and vehicle operating cost;
- Reduced roadway capacity that slows travel speed and increases travel time and vehicle operating cost;
- Delay in the opening of a new or improved facility that prevents users from gaining travel

- time benefits; and
- Accident/crash costs.

Currently, most State Transportation Agencies (STA) use a constant Value of Time (VOT) in the process of determining RUC, which often neglects variances of actual VOT between metropolitan areas and rural areas in a given state. In this research, social economic conditions (i.e. per capita income and average wage) of each county in Kentucky are examined in a VOT model to reflect different VOT for passenger cars in metropolitan and rural regions of Kentucky.

Based on the proposed RUC method and VOT, a set of RUC tables are established to address different types of highway projects (four-lane, six-lane), various topographical conditions (level, rolling and mountain) traffic classification (10% truck, 15% truck) and construction schedule (daytime, night and overtime). Determining RUC by this method simplifies the method of calculating RUC by using fewer variables that are typically available during the preliminary and conceptual design stages. Meanwhile limitations and inaccuracies of these RUC tables are identified. This report introduces a concept of using conceptual road user costs to support a decision making process to identify the need and type of rapid construction methods for a particular project. Also, a specific decision making process is proposed, which uses the ratios of the Calculated Road User Cost (CRUC) to the Maximum Allowable Road User Cost (MARC) followed by a set of additional criteria based on project scope to recommend a selection of rapid construction method for a given highway project.

5.2 Basic Concept of Road User Cost

Road user cost is a function of the timing, duration, frequency, scope, and characteristics of the work zone; the volume and operating characteristics of the traffic affected; and the dollar cost rates assigned to vehicle operating, delay, and crashes. In order to calculate RUC, we need to understand each of components that consist of RUC and some fundamental variables required to determine RUC.

5.2.1 Cost Components of Road User Cost

Based on comparing the values of hourly work zone traffic capacity and hourly traffic demand, the work zone traffic conditions could be categorized into two groups, i.e. Free Flow condition and Forced Flow condition.

Free Flow The condition that road traffic demands are less than the work zone traffic capacity and vehicles can pass through the work zone at work zone speed without stopping or waiting.

Forced Flow The situation that road traffic demands exceeds the work zone traffic capacity and a queue develops in front of work zone. Vehicles have to stop and idle through the queue then enter the work zone.

There are different cost components of RUC pertinent to free flow and forced flow respectively.

(1) Free Flow Cost Components

Three user cost components are associated with this condition.

Speed Change Delay	The additional time necessary to decelerate from the normal roadway approach speed to the work zone speed and then to accelerate back to the initial normal speed after leaving the work zone.
Speed Change Vehicle Operating Cost (VOC)	The additional vehicle operating cost associated with decelerating from the normal roadway speed to the work zone speed and then accelerating back to the normal speed after leaving the work zone. The operating costs include fuel, engine oil, maintenance, and depreciation.
Reduced Speed Delay	The additional time necessary to traverse the work zone at the lower work zone speed

(2) Forced Flow Cost Components

Four user cost components are associated with this condition.

Stopping Delay	The additional time necessary to come to a complete stop from the normal roadway speed (instead of just slowing to the work zone speed as Free Flow condition) and the additional time to accelerate back to the normal speed after leaving the work zone.
Stopping VOC	The additional vehicle operating cost associated with stopping from the normal roadway speed and accelerating back up to the normal speed after leaving work zone.
Queue Reduce Speed Delay	The additional time necessary to go through the queue under forced-flow conditions at the queue speed, which is lower than normal speed.
Queue Idling VOC	The additional vehicle operating cost associated with stop-and-go driving in the queue. The operating costs include fuel, engine oil, maintenance, and depreciation.

5.2.2 Work Zone Characteristics

The *Highway Capacity Manual (HCM)* defines work zone as an area of a highway where maintenance and construction operations are imposed on the number of lanes available to traffic or affect the operational characteristics of traffic flowing through the area.

Work zone characteristics include work zone length, number and capacity of lanes open, duration of lane closures, timing (hours of the day, days of the week, season of the year, etc.) of lane closures, posted speed, and the availability and physical and traffic characteristics of alternative routes. Specific details of work zone characteristics for determination of RUC should include:

- Project when work zones occur;
- Number of days the work zone will be in place (construction period);
- Specific hours of each day when the work zone will be in place; and
- Work zone length, traffic capacity and posted speed.

5.2.3 Traffic Characteristics

User costs are closely related to the volume and operating characteristics of the traffic on the road. The construction, maintenance, and rehabilitation activities generally involve some temporary impacts on vehicles on the road. The major traffic characteristics for a work zone include:

- The overall projected Average Annual Daily Traffic (AADT) volumes;
- The associated 24-hour directional hourly demand distributions; and
- The vehicle classification distribution of the projected traffic streams.

On high-volume routes, distinctions between weekday and weekend traffic demand and hourly distributions become important. Further, seasonal AADT traffic distribution also becomes important when work zones are proposed on recreational routes during seasonal peak periods.

5.2.3.1 AADT

Current AADT volumes are normally readily available for the base year and projected compound traffic growth rates can be obtained from the state highway agency traffic monitoring section. From these two pieces of information, it is possible to calculate future year work zone AADT by applying Equation 5.2-1.

Equation 5.2-1

$$\text{Future Year AADT} = \text{Base Year AADT} \times \text{Vehicle class \%} \times (1 + \text{growth rate})^{(\text{Future Year} - \text{Base Year})}$$

5.2.3.2 Vehicle Classification

Highway user costs consist of the costs of all affected highway users, who are not a homogeneous group. They include commercial and noncommercial vehicles ranging from passenger vehicles through the heaviest trucks. These different vehicle types have different operating characteristics and associated operating costs. Further, the value of time for user delays differs between vehicle classes. As a result, road user costs need to be analyzed for each major vehicle class in the traffic stream.

There are many truck-vehicle classifications representing various size and weight configurations. A popular approach proposed in Federal Highway Administration Report *Life-Cycle Cost Analysis in Pavement Design*, is to use three broad vehicle classes:

1. Cars: passenger cars and other 2-axle, 4-tired passenger vehicles;
2. Single-unit trucks: 2-axle, 4-tired or more commercial trucks without trailers;
3. Combination-unit trucks: 4-axle trucks with trailers.

5.3 Application of Road User Cost

The calculation of road user costs (RUC) provides information that enables the designer to make better decisions in regards to design works, construction methods and construction plans. An excessive road user costs caused by queues often indicates a bad construction plan and should be avoided. Usually, queues can be avoided by simply modifying the work zone in place schedule and trying to close lanes only during non-peak hours. If the proposed construction plan reveals substantial road user costs, which can not be cut down by shifting work zone in place hours, an alternative construction method should be considered. The applications of road user costs in projects will be discussed in the following sections.

5.3.1 Road User Cost Charges

Road user costs are added vehicle operating costs (VOC) and delay costs to the travelers caused by the establishment of construction, maintenance, or rehabilitation work zones. Usually before the project completion date, a state transportation agency (STA) does not require the contractor to pay the road user costs borne by the traveling public. For each day of overrun after the project completion date, the contractor will pay a road user charge, which can be considered part of liquidated damages.

5.3.2 Lane Occupancy Charge

The contract documents provide allowable lane closure time limits for the contractor's use and occupancy of a lane or lanes to perform work. During the allowable lane closure time limits, a STA typically does not require the contractor to pay lane occupancy charges. In the event that the contractor can not reopen a lane or lanes for highway users in term of allowable lane closure time limits, the contractor may pay a lane occupancy charge (per direction) for the period of time a lane is unavailable to the traveling public beyond the allowable lane closure time limits. The rate of lane occupancy charge is based on the road user costs during the period when a contactor fails to open a lane or lanes.

5.3.3 Alternative Construction Methods

A contract that establishes proper completion dates for a construction project is more important today than ever before. Most construction projects involve the reconstruction of existing highways, which means that traffic is often maintained with lane and shoulder restrictions while the reconstruction takes place. A standard contract completion date should be based on the shortest practical duration of construction to minimize road user costs while allowing the contractor a reasonable amount of time to complete the work. When accelerated construction periods are desired to reduce high road user costs, productivity and alternative project delivery methods should be considered. The designer should consider road user costs and any other pertinent factors to determine the most appropriate project delivery method.

5.3.3.1 General Criteria

A general criterion to choose the best construction plan is based on results of cost analysis. The best construction plan is the one with minimum total cost, which consists of construction cost, road user cost and administration cost (Equation 5.3-1).

Equation 5.3-1

$$\text{Min } \{RUC_i + \text{Con}C_i + \text{Ad}C_i\}$$

Where:

RUC_i: Road User Cost under construction plan (i);

ConC_i: Construction Cost under construction plan (i);

AdC_i: Administration Cost under construction plan (i).

5.3.3.2 Method used by New Jersey Department of Transportation

The New Jersey Department of Transportation developed guidelines for the recommended Project Delivery Method for a particular project or stage of construction based on a comparison between the Estimated Road User Cost (ERUC) and the Maximum Allowable Road User Charge (MARC). The ERUC is calculated based on the procedure in New Jersey Department of Transportation (NJDOT) “Road User Cost Manual”. The MAUC is determined by the NJDOT for a roadway construction project, which is the upper limit established for a roadway construction project which the NJDOT is willing to impose additional cost on road users.

Table 5.3-1: Construction Method Based on Production Rate and Road User Cost

Comparison Condition	Production Rate	Recommended Project Delivery Method	Road User Charge Value
$CRUC \leq MARC$	1.00	Standard	ERUC
$2 \times MARC \geq CRUC > MARC$	1.00	Standard	MARC
$3 \times MARC \geq CRUC > 2 \times MARC$	1.20	Increased Production Rate	MARC
$4 \times MARC \geq CRUC > 3 \times MARC$	1.25	A + B Bidding	MARC
$CRUC > 4 \times MARC$	1.33	Incentive/Disincentive Contracting	I/D Value = 0.25 ERUC ^(*)

* I/D value is the incentive/disincentive amount included in the contract. Calculated I/D value should be rounded to the nearest hundred dollars, up to a maximum I/D value of 0.1% of the estimated contract amount. i.e. I/D value = min {0.1% × Estimated Contract

Amount, $0.25 \times \text{ERUC}$). The total accumulated I/D payment is generally limited to 5% of the estimated contract amount (NJDOT, 2004).

(1) Increased Production Rate

An Increased Production Rate project delivery method expedites the construction process by utilizing multiple crews, longer workdays, night work, and/or an around-the-clock work schedule. A production rate of 1.20 times the standard production rate would be utilized to establish the contract completion date.

(2) A+B Bidding

An A+B bidding is a Cost plus Time bidding procedure that incorporates the lowest estimated cost of construction and the cost of time to complete the project. In other words, the contract is awarded to the bidder with the lowest overall monetary combined bid of the work itself (A) and how soon they believe they can complete the project or a critical portion of the project (B) (Equation 5.3-2).

Equation 5.3-2

$$\text{Bid Amount for Evaluation} = A + (B \times \text{MARC})$$

Where:

A: Bidder's Estimate of Contract Bid Items (\$)

B: Bidder's Estimate of Construction Time (Days)

MARC: Maximum Allowable Road User Charge (\$/day)

For example, a project's CRUC value is \$20,000/day and MARC value is \$5,500/day. Since $\text{ERUC/MARC} = 3.6 \text{ MARC}$, An A+B Bidding project delivery method is recommended with a pre-bid completion date based on a production rate of 1.25 times the standard production rate (Table 5.3-2).

Table 5.3-2: A+B Bidding Price Analysis

BIDDER	A COMPANY	B COMPANY	C COMPANY
“A” Value	\$3,400,000	\$3,200,000	\$3,100,000
MARC VALUE	\$5,500/day	\$5,500/day	\$5,500/day
“B” Value	105 Days	110 Days	130 Days
Time Value	\$577,500	\$605,000	\$715,000
Combined Cost	\$3,977,500	\$3,805,000	\$3,815,000

Therefore, the B Company would be awarded the contract based on it being the lowest combined bid. The contract amount for payment purpose is the (A) value (\$3,200,000). The project completion date will be based on the (B) value (110 days).

(3) Incentive and Disincentive (I/D)

The purpose of an Incentive/Disincentive project delivery method is to motivate the contractor to complete the project, or a particular construction stage, on or ahead of an accelerated schedule. I/D projects compensate the contractor a daily amount for completing the work ahead of the I/D completion date or charge a daily amount for finishing later than the I/D completion date.

For example, an \$8 million project's CRUC value is \$30,000/day and MARC value is \$6,000/day. Since $ERUC = 5 > 4 \times MARC$, as per Table 5.3-1, an Incentive/Disincentive project delivery method is recommended with an I/D value of \$7,500/day, i.e. $\text{Min}\{\text{roundup}[0.25 \times ERUC \text{ value}], 0.1\% \times \text{the project cost}\}$. The I/D production rate is 1.33 times the standard production rate. The project would be awarded to the low bidder. The contractor would receive a \$7,500/day incentive bonus for each day he finishes prior to the contract completion date up to a maximum of 5% of the project cost (\$400,000). On the other hand, the contractor would be charged \$7,500/day for each day of overrun in the contract completion date.

(4) Lane Rental

Lane Rental is a method of innovative contracting where contractors are required to pay daily or hourly fees for occupying lanes or shoulders to perform work. The lane rental fee is determined on the basis of road user costs and the daily costs incurred by the DOT. Lane rental is

applicable to projects where the contractor can adjust the traffic control plans to reduce lane closure duration, or to take lanes out of service during periods when traffic demands are minimal.

5.4 Review of Current Road User Cost Models and Programs

In order to establish whether an innovative rapid method of construction is warranted for a project and obtain road user cost when it is still in the preliminary and concept stages, a literature review on current RUC calculation methods was conducted. The following current RUC models and programs were reviewed:

- QuickZone;
- Queue and User Cost Evaluation of Work Zones (QUEWZ);
- Arizona RUC Model;
- MicroBENCOST;
- Texas Transportation Institute (TTI) RUC Tables; and
- Kentucky User Cost Program (KyUCP).

For each of RUC models and programs, the input & output variables and pros & cons are analyzed. Finally based on the literature review, a potential method proposed in the report is to combine the TTI RUC Table approach and KyUCP algorithms together to meet the requirement of rapidly determining RUC during the preliminary and conceptual design stages of a project development process in order to determine if a rapid method of construction is warranted for a given project.

5.4.1 QuickZone

5.4.1.1 Introduction

QuickZone is a traffic impact analysis spreadsheet tool that can be used for work zone delay estimation. QuickZone was developed by the Operations and Intelligent Transportation Systems Research Team of FHWA's Turner-Fairbank Highway Research Center, in cooperation with Mitretek Systems.

5.4.1.2 Quickzone Input Variables

QuickZone requires a user to enter a great deal of information concerning a particular project. To use the QuickZone program, the user must first create a network of traffic facilities, which is made up of nodes and links. Nodes generally represent a roadway intersection and determine the beginning and end of a road or link. Links in QuickZone are categorized into four categories:

- Detour;
- Mainline;
- Work zone; and
- Ramp.

Links include most of the attribute that are used within the QuickZone algorithm such as:

- Number of lanes;
- Free-flow speed;
- Capacity;
- Jam density;
- Length;
- Direction; and
- Type and position.

Once a network has been established and necessary traffic attributes have been put into the program, QuickZone can calculate the user cost, queue length by comparing the expected travel demand against proposed capacity in facility on hour-by-hour basis for the life of the project. Unfortunately, some of this data may not be available during the preliminary and conceptual design phases.

5.4.1.3 Pros and Cons

Advantages:

The QuickZone program ideally lends itself to urban work zone planning. It has the capability to complete the following tasks:

- Quantify corridor delay resulting from capacity decreases in work zones;

- Identify delay impacts of alternative construction phasing plans;
- Support Trade-Off Analyses between construction costs and delay costs;
- Consider Alternate Phasing Schedules:
 - Location along mainline
 - Time-of-day (peak vs. off-peak)
 - Season (summer vs. winter); and
- Assess Impacts of Delay Mitigation Strategies:
 - Variable message sign deployments
 - Signal retiming on detour routes.

Disadvantages:

Although QuickZone can calculate many different attributes about work zone delays and solve some complicate work zone use cost problems. There are several drawbacks in this program:

- QuickZone itself does not calculate a reduced work zone capacity values. This important value has to be determined by users;
- QuickZone dose not distinguish the differences between passenger cars and trucks in user delay costs;
- QuickZone requires more input traffic data than other models, which may be difficult to obtain during preliminary and conceptual design phase; and
- QuickZone require a user to establish a traffic network, which may be difficult during the preliminary and conceptual design phases as well.

5.4.2 Queue and User Cost Evaluation of Work Zones (QUEWZ)

5.4.2.1 Introduction

QUEWZ is a microcomputer analysis tool for planning and scheduling use in freeway work zone lane closures. It analyzes traffic conditions on a freeway segment with and without a lane closure in place and provides estimates for additional road user costs and the queuing resulting from a work zone or lane closure. The road user costs calculated include travel time, vehicle operating costs, and excess emissions. QUEWZ was developed by Texas Transportation Institute and has been used in other states.

5.4.2.2 QUEWZ Input Variables

The input data requirements for QUEWZ include lane closure configuration, work activity, traffic volumes and alternative values for defaults. A brief description of each of these follows.

The Lane Closure Information

This includes the total number of lanes in each direction, the number of open lanes in each direction, the length of lane closures and normal operation capacity values and capacity of work zone.

Schedule of Work Activity

The times that the lane closure begins and ends and hours the work activity begins and ends. The hours of activity must be fully within the hours of lane closure.

Traffic Volume

The AADT of the roadway, hourly directional traffic counts and percentage of trucks in the traffic stream are required variables.

Default Values

There are some defaults values in the program, which users could choose to use:

- Cost update factor to allow for the effects of inflation on the CPI;
- Percentage of trucks in traffic stream;
- Speed-volume relationship with default values from HCM (1985); and
- The work zone capacity.

5.4.2.3 QUEWZ Program Output

There are two output options in QUEWZ: the Lane Closure Schedules and the Road User Costs. The Lane Closure Schedule output summarizes the hours of the day during which a given number of lanes can be closed without causing excessive queuing. The Road User Costs output gives the additional RUC due to the proposed lane closures. QUEWZ also estimates the amount of traffic that will divert away from the work site in order to avoid excessive queuing.

5.4.2.4 QUEWZ Pros and Cons

Advantages:

- QUEWZ has the ability to calculate work zone capacity based on user input;

- QUEWZ has developed the diversion algorithm, which is an optional feature that allows the user to adjust traffic demand for vehicles that may use an alternate route;
- QUEWZ can optimize the lane closure schedule, which will not cause substantial queue delay in front of the work zone; and
- QUEWZ has the ability to estimate idling emission rates of exhausted fume for each vehicle type.

Disadvantages:

- QUEWZ requires a user to input many traffic data, some of which are difficult to obtain during preliminary and conceptual design phase;
- The diversion algorithm is based on observations of work zone lane closures on roads in Texas, so it is restricted when applied in other states;
- The process of estimating queue length is based on a vehicle equivalent length, the method endorsed in Highway Capacity manual (1994). This method underestimates actual queue length in work zone; and
- QUEWZ calculate RUC on daily basis, which can not carry delay traffic into the 12:00-1:00 a.m. regardless of the length of queue experienced in the previous 11:00-12:00 p.m.

5.4.3 Arizona Road User Cost Model

5.4.3.1 Introduction

The Arizona Department of Transportation developed their own method of calculation of Road User Cost based on concepts in the Highway Capacity Manual. Among current Road User Cost algorithms, it provides a simply method to predict RUC values during the preliminary and conceptual design stages.

5.4.3.2 Arizona RUC Methodology

The Daily Value of RUC can be calculated utilizing the following equation (Equation 5.4-1).

Equation 5.4-1

$$\text{Daily Value of RUC} = (\text{AADT}) \times (\Delta t) \times (w) \times (f) \times (d)$$

where:

AADT: Average Annual Daily Traffic (AADT);

Δt : the additional time required by the drivers to travel through the work zone, as compared to when the project is completed;

w: the average hourly wage of the driver;

f: a factor that takes into account impacts to local businesses and safety;

d: the weighted duration

(1) Average Annual Daily Traffic (AADT)

Periodically, the Arizona DOT performs counts at numerous locations on state routes, U.S. highways and interstates throughout the state. These counts are converted to the AADT. The Average Annual Daily Traffic (AADT) can also be obtained from the state highway agencies.

(2) Additional Time (Δt)

Additional time to travel through the work zone can be calculated by the following model. Figure 5.4-1 illustrates the model to calculate the travel time from 'A' to 'B' in ADOT's method. This graph shows that it takes time 't' to travel from point 'A' to point 'B' when the AADT per lane is 7,000 or less. (Level of Service of A/B). In this model, time increases linearly as the AADT per lane increases over 7,000. The linear increase is based on the assumption that at a Level of Service of D/E, or approximately 20,000 AADT per lane, it would take twice the amount of time '2t' to travel from point 'A' to point 'B' (as compared to an ADT per lane of 7,000).

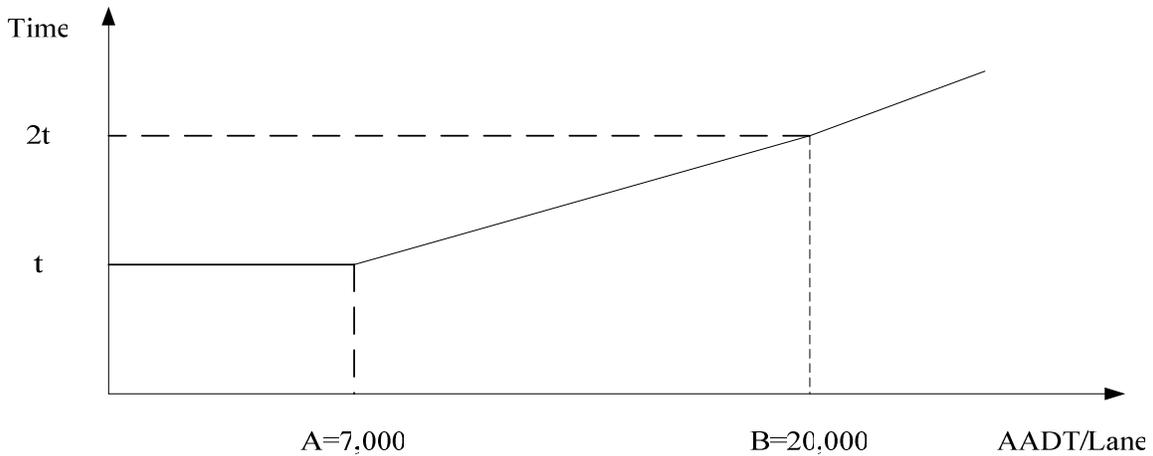


Fig. 5.4-1: Relationship Between AADT and Travel Time

This linear depiction is then applied to compute the time to travel through the work zone during construction (t_c) and the time to travel through the project after construction is finished (t_f). The additional time (Δt) required to travel through the project is the difference between the two: $\Delta t = t_c - t_f$ (Equation 5.4-2).

Equation 5.4-2

(a) Calculating Δt when the ADT/lane is less than or equal to 7,000

$$\Delta t = t_c - t_f$$

$$t_c = l_c \div s_c$$

$$t_f = l_f \div s_f$$

$$\Delta t = (l_c \div s_c) - (l_f \div s_f)$$

where:

- t_c time to travel from point A to B during construction
- l_c distance from point A to B during construction
- s_c average posted speed between point A and B during construction
- t_f time to travel from point A to B when the project is finished
- l_f distance from point A to B after the project is finished
- s_f average posted speed between point A and B when the project is finished

Equation 5.4-3

(b) Calculating Δt when ADT/lane > 7,000

$$\Delta t = t_c - t_f$$

where:

$$t_c = lc \div sc \times [1 + (A_c - 7000) / 13,000]$$

$$t_f = lf \div sf \times [1 + (A_f - 7000) / 13,000]$$

A_c Average Daily Traffic per lane under construction i.e. $ADT \div b_c$

b_c Number of lanes open under construction

A_f Average Daily Traffic per lane when completed i.e. $ADT \div b_f$

b_f Number of lanes open when finished

(3) Average Hourly Wage (w)

Currently ADOT uses \$10.50/hour for non-commercial vehicles and \$18.50/hour for commercial vehicles as average hourly wage (Walls, 1998). To determine the average hourly wage, the percent of commercial vehicles using this portion of the highway should be determined (Equation 5.4-4). ADOT has compiled these percentages for Arizona's major roads and they are available at their web site.

Equation 5.4-4

$$w = \text{average hourly wage} = C \times \$18.50 + (1 - C) \times \$10.50$$

where:

c : the percentage of commercial vehicles

(4) Impact Factor (f)

Detours, closures, and lane reductions may not only impact the road user, but also cause other disturbances, such loss of revenue to local businesses, limit the exposure to pedestrians, increasing accidents on the roadway.

The factor **f** equals 1.0 unless the designers consider impacts from construction other than the road user. ADOT currently uses a factor of 1.2 when the construction will significantly impact local businesses. This 20% increase is an estimate and there is no data to back up this factor. To determine **f**, total all relevant factors below and add to 1.0.

Table 5.4-1: Impact Factor

Area Characteristics	f
Concentration of business use	1.2
History of a high number of traffic accident	1.2
Heavy pedestrian usage or school in vicinity	1.2
Others (only considering impacts on road users)	1.0

(5) Weighted Duration (d)

This is the duration of a specific traffic control condition divided by the estimated duration of the project. The duration of these conditions is measured in calendar days.

5.4.3.3 Pros and Cons of Arizona RUC

After reviewing the Arizona RUC, the following pros and cons are proposed.

Advantages:

- The model is very simple and easily understood;
- The input variables required in this method, such as AADT, the percentage of truck, vehicle speed in normal condition and work zone and the construction duration, are typically available during the preliminary and conceptual design phase;
- The calculation could be completed by a spreadsheet program quickly.

Disadvantages:

- This model calculates RUC based only on daily AADT and does not consider the hourly change of traffic volume, which limits the accuracy of its values of RUC.
- It does not analyze the queue condition in work zone, which constitutes a majority in RUC ;

- It only considers the delay cost caused by speed reduction but neglect the change speed operation cost in work zones, so the RUC reached by this model is less than other models.

5.4.4 MicroBENCOST

5.4.4.1 Introduction

MicroBENCOST is a DOS based computer program for analyzing benefits and costs of highway improvement projects. Texas Transportation Institute (TTI) researchers developed it during the National Cooperative Highway Research Program (NCHRP) in the early 1990's. The program is designed to analyze different types of highway improvement projects in a corridor. It compares the road user costs in an existing situation to the road user costs after an improvement is completed. MicroBENCOST can select the most beneficial projects and improvement plans from a pool of alternatives, and provide prompt information about the rankings of these plans based on their potential benefit.

MicroBENCOST can estimate vehicle delays and operating costs for nine passenger vehicle types and nine truck types. Meanwhile MicroBENCOST can evaluate seven types of highway projects:

- Capacity enhancement;
- Bypass construction;
- Intersection or interchange improvement;
- Pavement rehabilitation;
- Bridge improvement;
- Highway safety improvement; and
- Railroad grade crossing improvement.

5.4.4.2 Input and Output for MicroBENCOST

MicroBENCOST requires the user to input detailed existing route data and proposed route data, which include:

- Current year;
- area type;
- project type;
- alternate route switch;
- year improvement completed;
- functional class;
- growth rate;
- access control;
- segment length;
- type of intersection;
- lane width;
- percent of grade;
- degree curvature;
- free flow speed.
- speed limit;
- capacity/lane/hour;
- number of work zone;
- percent trucks;
- number of segments;
- type of distribution;
- HOV lane present;
- base year;
- AADT base year;
- number of intersections;
- number of lanes inbound;
- number of lanes outbound; and
- median width.

5.4.4.3 Pros and Cons of MicroBENCOST

Advantage:

- MicroBENCOST is a powerful program to analyze a broad spectrum of projects, including new location projects, bypass projects, pavement rehabilitation projects and bridge rehabilitation and replacement projects.

Disadvantages:

- MicroBENCOST requires many input variables, some of which are difficult to obtain during preliminary and conceptual design phases; and
- Using MicroBENCOST to calculate RUC is relatively complicated and does not meet the project's requirement of quick determinations of RUC in order to choose rapid construction methods during the preliminary and conceptual design phases.

5.4.5 Texas Transportation Institute Road User Cost Value Tables

5.4.5.1 Introduction

In the TTI research report *Techniques for Manually Estimating Road User Costs Associated With Construction Projects*, the researchers established a set of RUC look-up tables to address RUC for highway projects. These look-up tables provide RUC values based on project types and a minimal number of project attributes such as AADT and percent of truck traffic. The RUC Tables divide the highway construction projects into added-capacity projects and rehabilitation projects. The tables for these two types of projects are constructed in a somewhat different way and require different procedures to use the values.

5.4.5.2 Methodology

RUC tables are developed by the MicroBENCOST Program. Users can easily pick up values from the tables based on very simple input variables:

- Project type;

- AADT; and
- Percentage of trucks.

(1) Added-Capacity Projects

The RUC Tables use a “before versus after” comparison to determine RUC. “Before” refers to the RUC before beginning the add-capacity projects. “After” refers to the RUC after completing the add-capacity projects. The RUC for add-capacity project is equal to the total road user costs in the “before” condition minus total road user costs in the “after” conditions. In order to cover the greatest possible range of added-capacity project types, separate tables were developed for ten different types of projects listed as follows:

- Two-Lane Rural Highway;
- Four-Lane Rural Undivided Highway;
- Four Lane Rural Divided Highway;
- Four-Lane Rural Interstate Highway;
- Six-Lane Rural Interstate Highway;
- Two-Lane Suburban Arterial;
- Four-Lane Suburban Arterial;
- Six-Lane Suburban Divided Arterial;
- Four-Lane Urban Freeway; and
- Six-Lane Urban Freeway.

5.4.5.3 Pros and Cons of ITT Lookup Tables

Advantages:

- TTI RUC Tables provide quick determination of road user costs with minimum inputs. These tables can generate a preliminary estimate of RUC during the preliminary and conceptual design phases when many inputs required in other RUC calculation models are not always available.

Disadvantages:

- RUC Tables only consider the work zone user delay costs, which are only part of the total user costs. Thus, the RUC calculated by this method is less than the RUC generated by other models, which consider work zone queue delay.
- Because TTI RUC Tables are developed by Texas, they uses Texas value of time (VOT) to calculate RUC.

- VOT used in TTI RUC Tables are based on 1998 values. These values can be updated using the Consumer Price Index (CPI).

5.4.6 Kentucky User Cost Program (KyUCP)

5.4.6.1 Introduction

The Kentucky Transportation Center developed a Microsoft Excel based program to calculate RUC. The algorithm of KyUCP is based on research results of FHWA's Demonstration Project 115 (Walls, 1998). However, modifications have been made to improve the original program. First, KyUCP applies a new short-term work zone capacity equation, which was developed by the Texas Transportation Institute and confirmed by the national Research Council in the 2000 Highway Capacity Manual. Second, KyUCP defines road user costs and queue lengths on an hourly basis. Third, KyUCP allows the user to input traffic data that can be used to calculate normal capacity. The fourth improvement of KyUCP is that the program is linked with the website for CPI in order to accurately account for inflation.

5.4.6.2 Required Input Variables

KyUCP requires the following input variables:

Traffic Data:

- AADT;
- Vehicle classification;
- Vehicle normal speed;
- Number of lane; and
- Type of terrain: (Level, Rolling, and Mountain).

Work Zone Data:

- Vehicle work zone speed;
- Work zone length;
- Number of lane when work zone in place; and
- Work zone in place schedule.

5.4.6.3 Flow Diagram of KyUCP

Figure 5.4-2 shows the flow diagram used by KyUCP to determine RUC values for a project. Users have to complete the following steps to calculate RUC:

Calculating Normal Service Flow Rate (Steps 1-7)

Users have to input roadway speed, peak hour factor (PHF), number of lanes in one direction (N), percentage of trucks and buses in stream (P_T), type of terrain (level, rolling and mountain) and driver population factor (f_p). The normal service flow rate (V) is determined by an equation located in the Highway Capacity Manual 2000. For detail information, refer to Section 9.3.1.2 A.

Calculating Work Zone Capacity (Steps 8-10)

Users have to identify the reduction of lane width due to construction, construction intensity and ramp adjustment factors. The Work Zone Capacity is calculated using an equation found in the Highway Capacity Manual 2000. For detailed information refer to Section 9.3.1.2 B.

Calculating RUC in One Direction (Steps 11-23)

Users have to identify the percentage of single unit trucks and combination trucks in stream, work zone speed, work zone length, project duration and the work zone in place time. Based on the Normal Service Flow Rate and Work Zone Capacity, KyUCP is able to generate the RUC of the roadway project. Users are allowed to input the most recent Consumer Price Index (CPI) to adjust the value of time to the current value.

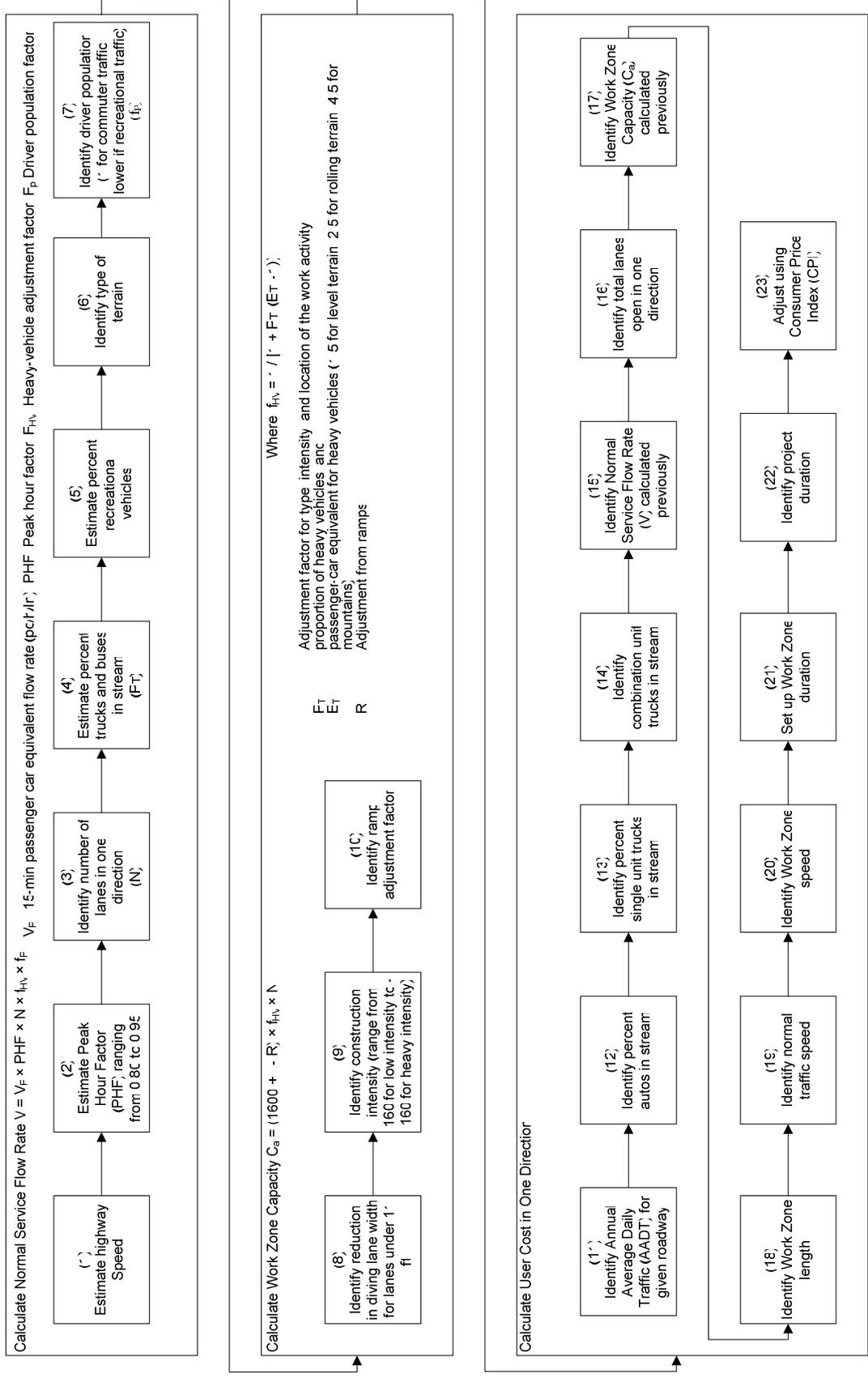


Fig. 5.4-2: Flow Diagram of KyUCP

5.4.6.4 Pros and Cons

Advantages:

- KyUCP is programmed in Microsoft Excel, which provides a user friendly interface and allows for quicker transfer of the program from one computer to another.
- The cost updating factors used for determining RUC in present day dollars can easily be adjusted by the US Bureau of Labor Statistics data.
- KyUCP can evaluate a work zone with traffic volume entered in either an AADT or hourly directional volume format.
- KyUCP can generate accurate work zone traffic capacity due to the application of a new short-term work zone capacity to calculate work zone traffic capacity. The national Research Council in the 2000 Highway Capacity Manual endorsed this approach.
- For determining queue length, KyUCP is based on roadway density rather than vehicle equivalent length. This algorithm will generate more precise calculations.

Disadvantage:

- KyUCP asks users to input many project variables, some of which may not be available during the preliminary and conceptual design stages.

5.4.7 Conclusion

After review of current RUC programs, the main characteristics of each RUC model are listed below.

Table 5.4-2: Review Results of Different RUC Models

	QuickZone	MiroBENCOST	QUEWZ	KyUCP	RUC Table	Arizona Model
Calculation Precision	High +	High +	High	High	Moderate	Low
Required Input Variables	Many +	Many +	Many	Many	Fewer	Few
Application	Urban & Interstate	Urban & Interstate	Interstate	Interstate	Interstate	Interstate
Optimize Working Schedule	No.	No.	Yes	No.	No.	No.
Economic Analysis	Yes	Yes	No	Yes	No	Yes

QuickZone, MicroBENCOST, QUEWZ and KyUCP can calculate many different attributes about work zone delays, solve complicated work zone user cost problems, and generate relatively accurate road user costs. However, they generally require many input variables such as work zone in place schedule, traffic classification, data on alternative routes, percentage of grade and degree curvature; some of which can be difficult to identify during the preliminary and conceptual design phases of a project.

On the other hand, the Arizona RUC model and TTI Road User Cost Tables were developed specifically to provide preliminary RUC estimates. The Arizona RUC Model was developed by the Arizona Department of Transportation for A+B contracting. The input variables required for this method, such as AADT, the percentage of truck traffic and vehicle speed in normal and work

zone condition, are typically available during the early design stage. The TTI Road User Cost Tables provide RUC values based on project types, such as added-capacity projects or rehabilitation projects, AADT and percent of truck traffic (Daniels, 1999). These two models provide a preliminary estimate for road user cost values, however their accuracy is suitable to allow STA's to begin making the conceptual decisions required during early design stages.

Based on the literature review of current RUC models and programs, a potential method is proposed here to combine the TTI RUC Table approach and KyUCP algorithms. This method meets the research's need for rapidly determining the RUC during preliminary and conceptual design stages in order to begin the decision making process to identify the need and type of rapid construction method for any given roadway construction project.

The research developed RUC tables reflecting different types of highway projects (four-lane, six-lane), various topographical conditions (level, rolling and mountain), different AADT, and construction schedule (daytime, night and overtime). Determining RUC by this method simplifies the current methods employed to calculate RUC.

5.5 Value of Time for Different Kentucky Counties

Value of time is the cost rate assigned to user delay. Currently, most STA use a constant value of time (VOT) in the process of determining RUC, which neglects variance in actual VOT between metropolitan areas and rural areas in a given state. A significant point of departure on how this research estimates RUC versus other existing RUC models is that it identifies RUC based on varying socioeconomic conditions. A common dilemma for many STA's is to determine when the added investment of using a rapid method of construction is warranted versus using conventional methods of contracting strategies. Typically, it is evident that projects in urban areas do warrant the added effort and expense of accelerating construction, this decision is less clear on rural projects. The research addresses this issue by adjusting VOT based on local wages and income estimates used to determine RUC.

5.5.1 Literature Review on Determination of the Value of Time

Three main research areas have been reviewed in order to establish a model to determine the value of time in Kentucky:

1. National Cooperative Highway Research Program (NCHRP) Report 133 (1972), *Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effect*;
2. Federal Highway Administration, Highway Economic Requirements Systems (HERS) Model (Walls, 1998); and
3. Office of the Secretary of Transportation (OST), *The Value of Time: Departmental Guidance for Conducting Economic Evaluations* (Walls, 1998).

5.5.1.1 National Cooperative Highway Research Program (NCHRP) Report 133 (1972), Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effect.

A base case value can be obtained from the NCHRP 133 report, which used 1970 dollar values of \$3 per hour for passenger vehicles and \$5 per hour for all trucks. These values must be escalated to reflect current year values. In this case, the escalation factor for the dollar value of time is determined by using changes to the *All Items Component* of the Consumer Price Index (CPI) for the base year (1970) and the current year (2005). The *All Items Component* of the CPI was 38.8 in 1970 and 188 in April 2005. The value of time escalation factor to escalate 1970 prices to April 2005 price is:

$$\text{Escalation Factor} = \frac{194.6 (\text{CPI April 2005})}{38.8 (\text{CPI 1970})} = 5.015$$

Table 5.5-1 shows the updated value of time.

Table 5.5-1: Update NCHRP 133 Values of Time (\$/Veh-Hr)

Value of Time	Passenger Cars	Trucks	
		Single-Unit	Combination
Value 1970	\$3.00	\$5.00	\$5.00
Value 2005	\$15.05	\$25.08	\$25.08

In NCHRP Project 7-12 (William, 1993), *Microcomputer Evaluation of Highway User Benefit*, the researchers developed a computer program, *MicroBENCOST*, to analyze life cycle costs of highway projects. It uses 1990 base year default values and establishes the value of time for passenger cars, single-unit trucks and combination trucks. The research applies another escalation factor to convert the 1990 base year costs to the 2005 base year costs. Once again, the escalation factor for the values of time is calculated by dividing the 2005 overall CPI by the overall CPI for 1990.

$$\text{Escalation Factor} = \frac{194.6 (\text{CPI April 2005})}{130.7 (\text{CPI 1990})} = 1.489$$

Table 5.5-2: Updated MicroBENCOST Default Values of Time (\$/Veh-Hr)

Value of Time	Passenger Cars	Single-Unit Trucks		Combination Trucks	
		2AX 12 Kips	3AX 35 Kips	2S2 40 Kips	3S2 63 Kips
Value 1990	\$9.75	\$13.64	\$16.28	\$20.30	\$22.53
		\$14.96		\$21.42	
Value 2005	14.52	\$22.27		\$31.89	

Although values of time developed by NCHRP projects are widely used in other states to calculate RUC, these values were obtained through a statewide research based on average conditions throughout the US. However, they are not based on the demographic data of a region and cannot reflect the differing value of time between metropolitan and rural areas.

5.5.1.2 Federal Highway Administration, Highway Economic Requirements Systems (HERS) Model (Walls, 1998)

The FHWA applied the HERS Model on a nation wide basis in order to analyze highway performance, needs, and economic evaluation of proposed highway improvements. Part of the economic analysis included determining the value of travel time delay. Table 5.5-3 shows the default dollar (1995) values of travel time used in the HERS model.

Table 5.5-3: Values of One Vehicle Hour of Travel Time

Travel Category	Autos		Trucks				
	Small	Medium	Single-Unit			Combinations	
			4 Tire	6 Tire	3-4 Axle	4 Axle	5 Axle
Business	\$27.99	\$28.29	\$20.20	\$24.96	\$27.02	\$31.02	\$31.58
Personal	\$12.78	\$12.78	\$12.78	NA	NA	NA	NA
% AADT Personal Use	90%	90%	69%	0%	0%	0%	0%
Weighted Average	\$14.30	\$14.33	\$15.08	\$24.96	\$27.02	\$31.02	\$31.58

The research uses an escalation factor to change the above values into 2005 dollars and lists these values in Table 5.5-4.

$$\text{Escalation Factor} = \frac{194.6 (\text{CPI April 2005})}{152.4 (\text{CPI 1995})} = 1.277$$

Table 5.5-4: Updated Values of One Vehicle Hour and Travel Time

Travel Category	Autos		Trucks				
	Small	Medium	Single-Unit			Combinations	
			4 Tire	6 Tire	3-4 Axle	4 Axle	5 Axle
Business	\$35.74	\$36.12	\$25.79	\$31.87	\$34.50	\$39.61	\$40.32
Personal	\$16.32	\$16.32	\$16.32	NA	NA	NA	NA
% AADT Personal Use	90%	90%	69%	0%	0%	0%	0%
Weighted Average	\$18.26	\$18.30	\$17.27	\$3.19	\$3.45	\$3.96	\$4.03

The values of travel time shown on lines 1 and 2 of table 5.5-4 are per vehicle hour based on typical vehicle occupancy rates. The values in *% AADT Personal Use* on line 3 represent the percent of travel that is Personal. The *Weighted Average* values shown on line 4 are for mixed flow of business and personal travel at the percentages shown in line 3 and are used when traffic flow distribution by travel category is not known.

5.5.1.3 Office of the Secretary of Transportation (OST), The Value of Time: Departmental Guidance for Conducting Economic Evaluations (Walls, 1998)

The OST provided a guidance to determine the value of time. OST recommended using a percentage of the national wage rate for the value of time. OST also recommended procedures applied different percentages of the national wage rate as a function of vehicle classification and trip type and purpose. Table 5.5-5 provides U.S. DOT ranges of the percentage of the national wage rate that should be applied to various combinations of trip type and purpose. The rates shown are per person hour. The following table shows that business and truck travel are valued more highly than personal travel, and intercity personal travel is valued more highly than local personal travel.

Table 5.5-5: Value of Travel Time Ranges as a Percent of National Wage Rate (\$/Person-Hr)

Travel Category	Travel Type	
	Local	Intercity
Personal	35 to 60%	60 to 90%
Business	80 to 120%	80 to 120%
Truck Drivers	100%	100%

Table 5.5-6 provides information on national hourly wage rates used by OST in 1995 dollars.

Table 5.5-6: OST Recommended Hourly Wage Rates

Travel Category	Travel Type	
	Local	Intercity
Personal	\$17.00	\$17.00
Business	\$18.80	\$18.80
Truck Drivers	\$16.50	\$16.50

Once again the research converts the above wage rates into 2005 dollars by an escalation factor.

$$\text{Escalation Factor} = \frac{194.6 (\text{CPI April 2005})}{152.4 (\text{CPI 1995})} = 1.277$$

Table 5.5-7: Updated Recommended Hourly Wage Rates

Travel Category	Travel Type	
	Local	Intercity
Personal	\$21.71	\$21.71
Business	\$24.01	\$24.01
Truck Drivers	\$21.07	\$21.07

Based on the information of appropriate percentages provided in Table 5.5-5 and the recommended national hourly wage rates provided in Table 5.5-7, the recommended ranges for the value of travel time can be developed as shown in Table 5.5-8. The values associated with “Mixed” are the ranges to be used when the distribution between auto business and personal trips are not known. In that circumstance, the ratio of personal travel to business travel is assumed as 19:1 in OST research. Hourly values shown for trucks are \$21.07 for both local and intercity trip types.

Table 5.5-8: OST Recommended Hourly Wage Rates

Travel Category	Local		Intercity	
	Low	High	Low	High
Personal	\$7.60	\$13.02	\$13.02	\$19.54
Business	\$24.01	\$28.81	\$24.01	\$28.81
Mixed	\$8.42	\$13.81	\$13.57	\$20.00
Truck Drivers	\$21.07	\$21.07	\$21.07	\$21.07

5.5.2 Surveys of Selected States Regarding the Value of Time

A survey regarding the value of time was conducted in the research *Techniques for Manually Estimating Road User Costs Associated with Construction Projects*, Texas Transportation Institute (Daniels et al. 1999). Nine states were chosen in this research, including Ohio, Georgia, North Carolina, Pennsylvania, Washington, Florida, Virginia, New York and California.

5.5.2.1 Value of time used in selected states

A summary of the values are shown in Table 5.5-9. It should be noted that there is a substantial difference between each state's truck VOT compared to its automobile VOT.

Table 5.5-9: Summary of Comparable Values for Selected States

(1998 Dollars)

State	Value of time Autos	Value of Time Trucks
North Carolina	\$8.70	-
New York	\$9.00	21.14
Florida	\$11.12	22.36
Georgia	\$11.65	-
Texas	\$11.97	21.87
Virginia	\$11.97	21.87
California	\$12.10	30.00
Pennsylvania	\$12.21	24.18
Washington	\$12.51	50.00
Ohio	\$12.60	26.40
Median	\$11.97	\$23.61
Mean	\$11.38	\$27.23

5.5.5.2 How to obtain the value of time

It was discovered by the research team that most states use an established state-average VOT, but some states use a varying VOT for projects which meet certain criteria or are located in certain areas (Daniels, 1999). For example, Florida employs rural versus urban value of time. The urban VOT is approximately \$12 per hour, while the rural VOT is \$10. North Carolina uses the average annual hourly wage rate in the county where the analysis of road user cost is being determined. The VOT is employed as a component to analyze the impact of the project on user benefits, costs, and the improvements on economic development. Georgia uses a process similar to North Carolina to determine the VOT, which is simply the average hourly wage in the county where the analysis has been conducted. In California, VOT is developed for each particular project on an individual basis. This means, each project has a unique, but uniform, value of time even if the project traverses different parts of the state. According to the team's research, VOT will vary when a roadway project crosses different portions of Kentucky.

5.5.3 Review the Current Method in Kentucky

Currently, the values of time for Kentucky highway users are obtained by combining the research of NCHRP 133 (Walls, 1998) and MicroBENCOST (William, 1993). NCHRP 133 was carried out in 1972 to develop procedures for estimating highway user costs, air pollution, and noise effect. MicroBENCOST is a comprehensive program utilizing the most practical procedures for highway economic analysis. It was developed to replace the 1977 AASHTO "Red Book -A manual on User Benefit Analysis of Highway and Bus-Transit Improvements."

In NCHRP 133 and MicroBENCOST, values of time for different vehicle classifications (i.e. passenger cars, single-unit trucks and combination trucks) were developed. Table 5.5-10 shows that KyUCP uses the average values obtained from NCHRP 133 and MicroBENCOST as the value of time in Kentucky. However the values in Table 5.5-10 do not reflect the different values of time that actually exist in Kentucky due to the varying wage and income earnings throughout the different geographic locations.

Table 5.5-10: Value of Time Used by Kentucky User Cost Program

	Passenger Cars	Single-Unit Trucks	Combination Trucks
NCHRP 133 (\$1970)	\$3	\$5	\$5
NCHRP 133 (\$1996)	\$11.78	\$19.64	\$19.64
MicroBENCOST (1990 Dollars)	\$9.75	\$14.96	\$21.42
MicroBENCOST (1996 Dollars)	\$11.37	\$17.44	\$24.98
Average (\$1996)	\$11.58	\$18.54	\$22.31

5.5.4 Develop Value of Time for each county in Kentucky

U.S. Department of Transportation Office of the Secretary of Transportation (U.S. DOT OST), determined values of time on the basis of the hourly wages (Walls, 1998). As shown in Tables 5.5-5, the U.S. DOT OST recommends that ranges of the percentage of the national wage rate should be used to estimate value of time. Based on the assumption that the value of time is a percentage of the average income/wage, the research obtained the value of time for each Kentucky County by the following steps.

- Obtained the per capita income of each county in Kentucky from the Kentucky Cabinet for Economic Development;
- Obtained the average wage of each county in Kentucky from US Bureau of Labor Statistics (BLS), Department of Labor; and
- Apply the percentages of average wages as shown in Table 5.5-5 to estimate values of time for different travel types.

5.5.4.1 Value of Time for Personal Travel

From the Kentucky Cabinet for Economic Development, the research identified the annual per capita income of each county in Kentucky in 2002. After applying the assumption of the U.S. BLS, which states that the annual working hour is 2080 hours, the research team obtained hourly per capita incomes for each county in Kentucky. After considering inflation, the average hourly incomes of each county in Kentucky was calculated.

Table 5.5-11: Average Per Capita Income of Counties in Kentucky

County	Hourly per capita Income
Clay, Elliott, Jackson, McCreary	\$7
Edmonson, Lawrence, Lee, Lewis, Menifee, Morgan, Rockcastle, Wolfe	\$8
Bell, Breathitt, Butler, Carter, Casey, Cumberland, Estill, Fleming, Green, Harlan, Hart, Knott, Knox, Leslie, Lincoln, Magoffin, Martin, Metcalfe, Owen, Owsley, Powell, Robertson, Trimble, Wayne	\$9
Adair, Bath, Bracken, Breckinridge, Clinton, Crittenden, Floyd, Gallatin, Garrard, Grayson, Hancock, Johnson, Laurel, Letcher, Lyon, Madison, Monroe, Muhlenberg, Ohio, Pendleton, Rowan, Russell, Taylor, Todd, Washington, Whitley	\$10
Allen, Barren, Caldwell, Carlisle, Fulton, Grant, Graves, Greenup, Harrison, Livingston, Logan, Marion, Meade, Montgomery, Nicholas, Perry, Pike, Pulaski, Spencer,	\$11
Anderson, Bullitt, Calloway, Carroll, Christian, Henry, Hopkins, Larue, Marshall, Mason, Mercer, Simpson, Union	\$12
Ballard, Boyd, Boyle, Daviess, Hardin, Henderson, Jessamine, McLean, Nelson, Trigg, Warren, Webster,	\$13
Bourbon, Campbell, Clark, Franklin, Scott, Shelby	\$14
Boone, Kenton, McCracken,	\$15
Hickman, Oldham	\$16
Fayette, Jefferson, Woodford	\$17
Average	\$13

5.5.4.2 Value of Time for Business Travel

According to the U.S. BLS, the average hourly wage of all occupations in Kentucky is \$15.15 (2003 Dollar). Using CPI for April 2005 to adjust inflation, the average hourly wage of Kentucky is adjusted to \$15.48. The average hourly wage of each Kentucky county is adjusted according to the ratio of each county’s hourly per capita income to the average per capita income of Kentucky. Next, the average hourly wage of each county was adjusted according to the ratio of each county’s hourly per capita income to the average per capita income of Kentucky (Equation 5.5-1).

Equation 5.5-1

$$\text{Average hourly wage of " A" county} = \text{Average hourly wage of Kentucky} \times \frac{\text{Average per capita income of " A" county}}{\text{Average per capita income of Kentucky}}$$

For example, the average hourly wage of Clay, Elliott, Jackson and McCreary Counties are obtained by the following steps:

$$\text{Average hourly wage} = \$15.48 (\text{Average hourly wage of Kentucky}) \times \frac{\$7 (\text{Average per capita income of "A" county})}{\$13 (\text{Average per capita income of Kentucky})}$$

Thus the research obtains the average hourly wages of each county in Kentucky, which are shown in Table 5.5-12.

Table 5.5-12: Average Wages of Counties in Kentucky (2005 Dollars)

County	Hourly Wage
Clay, Elliott, Jackson, McCreary	\$8.34
Edmonson, Lawrence, Lee, Lewis, Menifee, Morgan, Rockcastle, Wolfe	\$9.53
Bell, Breathitt, Butler, Carter, Casey, Cumberland, Estill, Fleming, Green, Harlan, Hart, Knott, Knox, Leslie, Lincoln, Magoffin, Martin, Metcalfe, Owen, Owsley, Powell, Robertson, Trimble, Wayne	\$10.72
Adair, Bath, Bracken, Breckinridge, Clinton, Crittenden, Floyd, Gallatin, Garrard, Grayson, Hancock, Johnson, Laurel, Letcher, Lyon, Madison, Monroe, Muhlenberg, Ohio, Pendleton, Rowan, Russell, Taylor, Todd, Washington, Whitley	\$11.91
Allen, Barren, Caldwell, Carlisle, Fulton, Grant, Graves, Greenup, Harrison, Livingston, Logan, Marion, Meade, Montgomery, Nicholas, Perry, Pike, Pulaski, Spencer,	\$13.10
Anderson, Bullitt, Calloway, Carroll, Christian, Henry, Hopkins, Larue, Marshall, Mason, Mercer, Simpson, Union	\$14.29
Ballard, Boyd, Boyle, Daviess, Hardin, Henderson, Jessamine, McLean, Nelson, Trigg, Warren, Webster,	\$15.48
Bourbon, Campbell, Clark, Franklin, Scott, Shelby	\$16.67
Boone, Kenton, McCracken,	\$17.86
Hickman, Oldham	\$19.05
Fayette, Jefferson, Woodford	\$20.24
Average	\$15.48

5.5.4.3 Value of Time for Truck Driver and Cargo

Since one-way truck routes rarely originate and terminate in a single county, the research did not use a regional adjustment for the value of time for truck and cargo traffic. Instead, the research team used the state average value of time for truck drivers, which was already established by the Kentucky Transportation Cabinet.

5.5.4.4 Divide Kentucky into Different Regions

After obtaining the hourly per capita income and average hourly wage rate of truck drivers in each county of Kentucky, the team divided the counties into four groups based on their hourly per capita income.

Group	Hourly Per Capita Income
I	From \$7 to \$9
II	From \$10 to \$11
III	From \$12 to \$13
IV	From 14 to \$17

Equation 5.5-2 calculates the hourly per capita income and average hourly wage of each group.

Equation 5.5-2

$$\text{Average Per Capita Hourly Income/Wage in Region A} = \frac{\sum \text{Per Capita Hourly Income/Wage} \times \text{Number of Counties}}{\text{Total Number of Counties in the Region}}$$

Using County Group I as an example,

Table 5.5-13: Average Hourly Per Capita Income of County Group IV

County Group I	Number of Counties	Average Hourly per Capita Income
Clay, Elliott, Jackson, McCreary	4	7
Edmonson, Lawrence, Lee, Lewis, Menifee, Morgan, Rockcastle, Wolfe	8	8
Bell, Breathitt, Butler, Carter, Casey, Cumberland, Estill, Fleming, Green, Harlan, Hart, Knott, Knox, Leslie, Lincoln, Magoffin, Martin, Metcalfe, Owen, Owsley, Powell, Robertson, Trimble, Wayne	24	9

According to Equation 5.5-2,

$$\text{Average Per Capita Hourly Income of County Group A} = \frac{7 \times 4 + 8 \times 8 + 9 \times 24}{4 + 8 + 24} = 8.56$$

Table 5.5-14: Value of Time for Counties of Kentucky

(2005 Dollars)

No.	County	Hourly per capita Income	Average Hourly Wage
I	Clay, Elliott, Jackson, McCreary	\$8.56	\$10.19
	Edmonson, Lawrence, Lee, Lewis, Menifee, Morgan, Rockcastle, Wolfe		
	Bell, Breathitt, Butler, Carter, Casey, Cumberland, Estill, Fleming, Green, Harlan, Hart, Knott, Knox, Leslie, Lincoln, Magoffin, Martin, Metcalfe, Owen, Owsley, Powell, Robertson, Trimble, Wayne		
II	Adair, Bath, Bracken, Breckinridge, Clinton, Crittenden, Floyd, Gallatin, Garrard, Grayson, Hancock, Johnson, Laurel, Letcher, Lyon, Madison, Monroe, Muhlenberg, Ohio, Pendleton, Rowan, Russell, Taylor, Todd, Washington, Whitley	\$10.42	\$12.41
	Allen, Barren, Caldwell, Carlisle, Fulton, Grant, Graves, Greenup, Harrison, Livingston, Logan, Marion, Meade, Montgomery, Nicholas, Perry, Pike, Pulaski, Spencer,		
III	Anderson, Bullitt, Calloway, Carroll, Christian, Henry, Hopkins, Larue, Marshall, Mason, Mercer, Simpson, Union	\$12.48	\$14.86
	Ballard, Boyd, Boyle, Daviess, Hardin, Henderson, Jessamine, McLean, Nelson, Trigg, Warren, Webster,		
IV	Bourbon, Campbell, Clark, Franklin, Scott, Shelby	\$15.14	\$18.03
	Boone, Kenton, McCracken,		
	Hickman, Oldham		
	Fayette, Jefferson, Woodford		

5.5.4.5 Percentage of Hourly Wage Counted for the Value of Time

As mentioned, the OST recommends that the VOT be set as a percentage of the average hourly per capita income or average hourly wage, which has been determined in the previous sections. Following the recommended ranges developed by the OST (Table 5.5-16); the research used 80% of average hourly income and 100% of average hourly wage to determine the values of time for

personal and business travel accordingly. Table 5.5-15 shows how VOT's for personal and business travel were determined for the counties in Group IV.

Table 5.5-15: Value of Time for Different Travel Types of Group IV (2005\$/Person-Hr)

Vehicle Classification	Travel Category	Hourly Income /Wage	Value of Time
Passenger Car	Personal	\$15.14	$15.14 \times 80\% = \$12.11$
	Business	\$18.03	$18.03 \times 100\% = \$18.03$

5.5.4.6 Determine Value of Time for Each County in Kentucky

Based on value of time for personal and business travel, the research determined the aggregate value of time of passenger cars for each of the four county groups in Kentucky by considering the estimated percentages of personal and business AADT in the traffic flow. Table 5.5-16 shows the aggregate VOT calculated for Group IV counties.

Table 5.5-16: Value of Time of Group IV (2005\$/Person-Hr)

Vehicle Classification	Travel Category	Value of Time	%AADT ⁽¹⁾	VOT
Passenger Car	Personal	\$12.11	90%	$12.11 \times 90\% + 18.03 \times 10\% =$ \$12.70
	Business	\$18.03	10%	

⁽¹⁾ The ratio of personal to business travel of AADT is obtained from *Highway Economic Requirements Systems (HERS) Model*, Federal Highway Administration (Walls, 1998)

5.5.4.7 Determine the Value of Time for Interstate Travel in Kentucky

Since travelers on interstate highways rarely originate and terminate in a single county, the research did not use a regional adjustment for the value of time for interstate travel. Also, the statewide average value of time for truck drivers was used to calculate RUC. The state-wide average hourly per capita income and wage rate are listed in Table 5.5-17.

Table 5.5-17: Average Per Capita Income and Wage of Kentucky (2005 Dollars)

Items	Value (\$/hr)
Average Hourly per Capita Income	12.81
Average Hourly Wage	15.48

The research used 80% of the average hourly income and 100% of the average hourly wage when determining the values of time for personal and business travel.

Table 5.5-18: Value of Time for Different Travel Types (2005 Dollars)

Vehicle Classification	Travel Category	Hourly Income /Wage	Value of Time
Passenger Car	Personal	\$12.81	$12.81 \times 80\% = \$10.25$
	Business	\$15.48	$15.48 \times 100\% = \$15.48$

Finally, the research determined the aggregate value of time of passenger cars for interstate travel in Kentucky by considering the estimated percentage of personal and business AADT in the traffic flow. The following Table 5.5-19 shows the calculation procedure.

Table 5.5-19: Value of Time for Passenger Car (2005 Dollars)

Vehicle Classification	Travel Category	Value of Time	%AADT	Value of Time
Passenger Car	Personal	\$10.25	90%	$10.25 \times 90\% + 15.48 \times 10\% =$ \$10.77
	Business	\$15.48	10%	

Based on a CPI of 194.6 for April 2005, the rates for the value of time were updated to 2005 dollars, which are shown in the Table 5.5-20.

Table 5.5-20: Value of Time for Counties in Kentucky

(2005\$/Person-Hr)

No.	County	VOT for Passenger Car	VOT for Single-Unit Truck	VOT for Combination Truck
I	Clay, Elliott, Jackson, McCreary			
	Edmonson, Lawrence, Lee, Lewis, Menifee, Morgan, Rockcastle, Wolfe	\$7.43	\$23.67	\$28.49
	Bell, Breathitt, Butler, Carter, Casey, Cumberland, Estill, Fleming, Green, Harlan, Hart, Knott, Knox, Leslie, Lincoln, Magoffin, Martin, Metcalfe, Owen, Owsley, Powell, Robertson, Trimble, Wayne			
	Adair, Bath, Bracken, Breckinridge, Clinton, Crittenden, Floyd, Gallatin, Garrard, Grayson, Hancock, Johnson, Laurel, Letcher, Lyon, Madison, Monroe, Muhlenberg, Ohio, Pendleton, Rowan, Russell, Taylor, Todd, Washington, Whitley	\$9.04	\$23.67	\$28.49
	Allen, Barren, Caldwell, Carlisle, Fulton, Grant, Graves, Greenup, Harrison, Livingston, Logan, Marion, Meade, Montgomery, Nicholas, Perry, Pike, Pulaski, Spencer,			
III	Anderson, Bullitt, Calloway, Carroll, Christian, Henry, Hopkins, Larue, Marshall, Mason, Mercer, Simpson, Union	\$10.84	\$23.67	\$28.49
	Ballard, Boyd, Boyle, Daviess, Hardin, Henderson, Jessamine, McLean, Nelson, Trigg, Warren, Webster,			
	Bourbon, Campbell, Clark, Franklin, Scott, Shelby			
	Boone, Kenton, McCracken, Hickman, Oldham	\$13.15	\$23.67	\$28.49
	Fayette, Jefferson, Woodford			
	Interstate Highway Travel	\$11.15	\$23.67	\$28.49

5.6 RUC Tables for Different Regions of Kentucky

5.6.1 Overview

By employing the concept of creating look-up tables to reflect RUC obtained from TTI research *Techniques for Manually Estimating Road User Costs Associated With Construction Projects*, the researcher team established a set of RUC look-up tables to address RUC for highway projects. TTI RUC Tables divide highway construction projects into added-capacity projects and rehabilitation projects and reflect different RUC under different AADT. TTI research provides a quick method to determine RUC, but the accuracy of this method is relatively low.

In the team's research, the TTI concept using look-up tables to address RUC is adopted by utilizing KyUCP, whose algorithm is adapted from NCHRP DP-115. The accuracy of this algorithm is endorsed and confirmed throughout the state. The research team made the tables reflect more roadway project characteristics than the RUC tables established in TTI research, so the accuracy of RUC tables was increased. The RUC tables reflect the following differences regarding roadway projects:

- Value of time in each of county group in Kentucky;
- Topographical conditions (Level, Rolling, Mountain);
- Type of roadway (Four Lane, Six Lane)Type of roadway (Four Lane, Six Lane);
- Different AADT (from 5,000 to 100,000);
- Length of Work Zone (from 1 mile to 5 miles);
- Traffic classification (10% Truck, 15%Truck); and
- Work schedule (Day, Night, Overtime Construction).

The RUC tables are available under separate cover with this project's report.

As previously stated, the research does not use regional adjustments for the VOT associated with interstate travel. Instead, the state-wide average value of time for truck drivers is used to calculate and develop the RUC tables for interstate travel. The research does however use a varying VOT with regional adjustments when dealing with parkway travel. This is due to the fact that travelers on parkways often do originate and terminate in a single county, which allows for the regional adjustment.

5.6.2 Applications

Using the RUC tables, a designer can quickly identify the RUC according to the most basic information, which will assist the selection of rapid construction methods during the preliminary and conceptual design phases. **The RUC tables developed in this research are not intended to replace or be a substitute for KyUCP. When detailed information pertinent to an individual project is available, KyUCP should calculate more accurate RUC during detailed design and construction phases.**

The Table 5.6-1 shows a RUC table for County Group I. The table is used to determine RUC for a four-lane freeway project with level terrain and a 10% truck ADT, with a work zone in place from 8 am to 4 pm. A complete set of RUC tables are attached in Appendix A of this report.

Table 5.6-1: Example of RUC Table (County Group I)

County Group I					
Speed (mile/hour)	Normal	65	Truck Percentage (%)	Single Truck	6
	Work Zone	40		Combination	4
Highway	Three Lane in One Direction				
Terrain	Rolling				
Work Zone in Place	8 am to 4 pm				
One Lane Closed in One Direction					
ADT	Daily Road User Cost (2005 Dollars)				
	Work Zone Length (mile)				
	1	2	3	4	5
18,000	958	1,330	1,701	2,072	2,444
19,000	1,012	1,404	1,796	2,188	2,580
20,000	1,065	1,478	1,890	2,303	2,715
21,000	1,118	1,551	1,985	2,418	2,851
22,000	1,171	1,625	2,079	2,533	2,987
23,000	1,225	1,699	2,174	2,648	3,123
24,000	1,278	1,773	2,268	2,763	3,258
25,000	1,331	1,847	2,363	2,878	3,394
26,000	1,384	1,921	2,457	2,994	3,530
27,000	1,438	1,995	2,552	3,109	3,666
28,000	1,491	2,069	2,646	3,224	3,802
29,000	1,544	2,142	2,741	3,339	3,937
30,000	1,597	2,216	2,835	3,454	4,073

5.6.3 Limitations

These RUC tables are limited due the fact that the research team established them based on default work zone schedules. The research only considered Day Construction (8 am to 4 pm), Night Construction (10 pm to 6 am), Day / Night Overtime Construction (6 am to 6 pm or 6 pm to 6 am). Therefore, if the default work zone schedules do not match a specific project, the accuracy will be affected. When work zone schedules are available during detail design or construction phases, other RUC programs such as QuickZone and QUEWZ can be applied to determine a more accurate RUC.

5.7 RUC Tables for Interstate Travel in Kentucky

Once again, since travelers on interstate rarely originate and terminate in a single county, **the research did not use a regional adjustment for the value of time for the interstate travel.** Instead, the state-wide average value of time. The research used the values of time determined in Section 5.5.4.7 shown below in Table 5.7-1.

Table 5.7-1: Value of Time for Interstate Travel

Items	Value (\$/hr)
Value of Time for Passenger Car	11.15
Value of Time for Single Unit Truck	23.67
Value of Time for Combination Truck	28.49

After determining the value of time for interstate travel, the research team used the Kentucky User Cost Program (KyUCP) to develop a set of RUC tables for interstate travel, which is attached in Appendix B. Due to the fact that interstate travelers rarely originate and terminate within the same county, the statewide average VOT for truck drivers was used to calculate RUC. However, **if RUC of parkway travel is to be determined, it is recommended to use a varying value of time based on regional adjustments**, since most of the parkway travel it limited to local traffic.

5.8 Example Problem

The following example illustrates the different RUC tables for the same project characteristics, but for different regions, including interstate travel. For a four-lane freeway with an ADT of 54,000 and 10% truck volume, a rehabilitation project is proposed to close one lane in one direction and use day time construction. Terrain is Level and work zone length is 1 miles. Based on the RUC tables shown in Figures 5.8-1 to 5.8-3, the different RUC's are listed in Table 5.8-1.

County Group I					
Speed (mile/hour)	Normal	65	Truck Percentage	Single Truck	6
	Work Zone	40		Combination	4
Highway	Two- Lane in One Direction				
Terrain	Level				
Work Zone in Place	8 am to 4 pm				
One Lane Closed in One Direction					
ADT	Daily Road User Cost (2005\$)				
	Work Zone Length (mile)				
	1	2	3	4	5
50,000	11,215	12,197	13,180	14,162	15,144
51,000	13,551	14,544	15,538	16,532	17,526
52,000	16,075	17,080	18,086	19,091	20,096
53,000	18,818	19,835	20,852	21,868	22,885
54,000	22,642	23,669	24,696	25,723	26,750
55,000	28,211	29,246	30,280	31,315	32,350
56,000	34,564	35,605	36,646	37,687	38,728
57,000	42,539	43,585	44,631	45,678	46,724
58,000	51,599	52,650	53,700	54,751	55,801
59,000	61,164	62,218	63,273	64,327	65,382
60,000	71,207	72,266	73,324	74,383	75,442

Fig. 5.8-1: RUC Tables Group I

Project in County Group I, daily
Road User Cost: **\$22,642**

County Group IV					
Speed (mile/hour)	Normal	65	Truck Percentage	Single Truck	6
	Work Zone	40		Combination	4
Highway	Two- Lane in One Direction				
Terrain	Level				
Work Zone in Place	8 am to 4 pm				
One Lane Closed in One Direction					
ADT	Daily Road User Cost (2005\$)				
	Work Zone Length (mile)				
	1	2	3	4	5
50,000	15,905	17,434	18,964	20,493	22,022
51,000	19,378	20,925	22,472	24,019	25,566
52,000	23,130	24,695	26,260	27,826	29,391
53,000	27,208	28,791	30,374	31,957	33,540
54,000	32,854	34,453	36,052	37,650	39,249
55,000	41,134	42,745	44,355	45,966	47,577
56,000	50,666	52,286	53,907	55,528	57,149
57,000	62,567	64,196	65,824	67,453	69,082
58,000	76,175	77,810	79,445	81,080	82,715
59,000	90,540	92,181	93,823	95,464	97,106
60,000	105,637	107,285	108,933	110,581	112,229

Fig. 5.8-2: RUC Tables Group IV

Project in County Group IV, daily
Road User Cost: **\$32,854**

Interstate Travel					
Speed (mile/hour)	Normal	65	Truck	Single Truck	6
	Work Zone	40	Percentage	Combination	4
Highway	Two- Lane in One Direction				
Terrain	Level				
Work Zone in Place	8 am to 4 pm				
One Lane Closed in One Direction					
ADT	Daily Road User Cost (2005\$)				
	Work Zone Length (mile)				
	1	2	3	4	5
50,000	14,261	15,599	16,937	18,274	19,612
51,000	17,336	18,689	20,042	21,395	22,749
52,000	20,658	22,027	23,396	24,765	26,134
53,000	24,267	25,652	27,037	28,421	29,806
54,000	29,275	30,673	32,072	33,470	34,869
55,000	36,605	38,014	39,423	40,832	42,240
56,000	45,023	46,440	47,858	49,276	50,693
57,000	55,548	56,973	58,397	59,822	61,247
58,000	67,562	68,993	70,423	71,853	73,283
59,000	80,245	81,681	83,117	84,553	85,988
60,000	93,572	95,013	96,454	97,896	99,337

Fig. 5.8-3: RUC Tables Interstate Travel

Project is an interstate highway
daily Road User Cost: **\$29,275**

Table 5.8-1: Road User Cost Output

Project Location	Daily Road User Cost (2005 Dollars)
County Group I	\$22,642
County Group IV	\$32,854
Interstate	\$29,275

Table 5.8-1 shows the daily RUC for county group I is much lower than the RUC for county group IV. This is due to the fact that the value of time is less for projects in county group I than county group IV. The table also shows that the daily RUC for interstate travel is less than the daily RUC for county group IV. This is due to the fact that projects involving interstate travel utilize the state-wide average VOT to calculate road user costs, resulting in a lower monetary amount.

6.0 DECISION SYSTEM FOR SELECTION OF INNOVATIVE RAPID CONSTRUCTION METHOD BASED OF ROAD USER COSTS

6.1 Overview

There are many advantages to using innovative rapid construction methods to expedite roadway projects, such as reducing construction time, minimizing delays, mitigating congestion, saving money for the transportation agencies and the road users, and improving the safety of the motorists and the workers without losing the quality. However, due to the limited budget, state transportation agencies cannot expedite every highway project. In urban areas, due to the high traffic volume, rapid construction methods are always warranted to mitigate the negative impact caused by construction activities. However, the need for expediting roadway construction is not always evident, especially on roadway projects in rural areas. Identifying where and what type of rapid construction methods to implement is crucial for a highway construction project. In this research, Road User Cost (RUC) was used as the primary criterion to exam the applicability of a rapid construction method. Based on established RUC tables, the research developed a decision making model, which is based on RUC in order to assist the selection of rapid construction methods. Next, through identifying the basic features of a highway project, potential rapid construction methods can be recommended for a specific project.

The decision making model, which is programmed in Microsoft Access, stores the rapid construction methods identified through literature review and case studies. It first asks users to input the information such as the ratios of the Calculated Road User Cost (CRUC) to the Maximum Allowable Road User Cost (MARC), the type of pavement, major construction activities, special construction activities, and special concerns/constrains of the project. Based on this information, the system can recommend potential applicable rapid construction methods for a given highway project.

The method of comparing ERUC to MAUC has been used by other state department of transportation to identify the need for different contracting methods (New Jersey DOT 2001). The New Jersey DOT uses a comparison between the Calculated Road User Cost (CRUC) and the Maximum Allowable Road User Charge (MARC) to provide guidelines for the recommended project delivery method for a particular project or stage of construction. The designer should

consider road user costs and any other pertinent factors to determine the most appropriate project delivery method.

6.2 System Description

The decision making system has three primary sections which are detailed in the following paragraphs. These sections are as follows:

- The user must input the ratio of ERUC/MAUC through a series of yes or no questions.
- The user must input basic project features through a series of yes or no questions.
- The system will then output all viable rapid construction methods for that particular project.

6.2.1 Classification of the Project Based on the Ratio of Estimated Road User Cost (ERUC) Versus Maximum Allowable Road User Cost (MAUC).

In this step, the users of the decision making system identify a project's Estimated Road User Cost from the RUC tables based on fundamental information available during the planning and conceptual design phases and compare the value to a project's Maximum Allowable Road User Cost, which is determined by a state transportation agency for a roadway construction project. It is the upper limit established for a roadway construction project which a state transportation agency is willing to impose additional cost on road users.

When the ratio is greater than 1, rapid construction methods could be employed in order to mitigate the negative impact caused by construction. Generally a higher ERUC vs. MAUC ratio indicates more severe traffic conditions caused by construction work zone justifying the added use of rapid construction methods to alleviate the burden on the community. As the ERUC versus MAUC ratio increases, the decision making system recommends different rapid construction methods.

6.2.2 Identifying Basic Features of a Project Through Decision Nodes

It is quite obvious that the ratio of ERUC versus MAUC is not enough to recommend appropriate rapid construction methods for a highway project. Many rapid construction methods are applicable to only a specific project type, therefore identifying the different features of a project is important to identify the potential methods from a list of rapid construction methods. The decision making system established by the research team expands beyond consideration of ERUC/MAUC by identifying elements of the project's scope. Figure 6.2-1 shows a set of systematical decision nodes that were established to determine the basic features of a project. Based on this information the system locates potential rapid construction methods in the database and displays them for the designers and contractors.

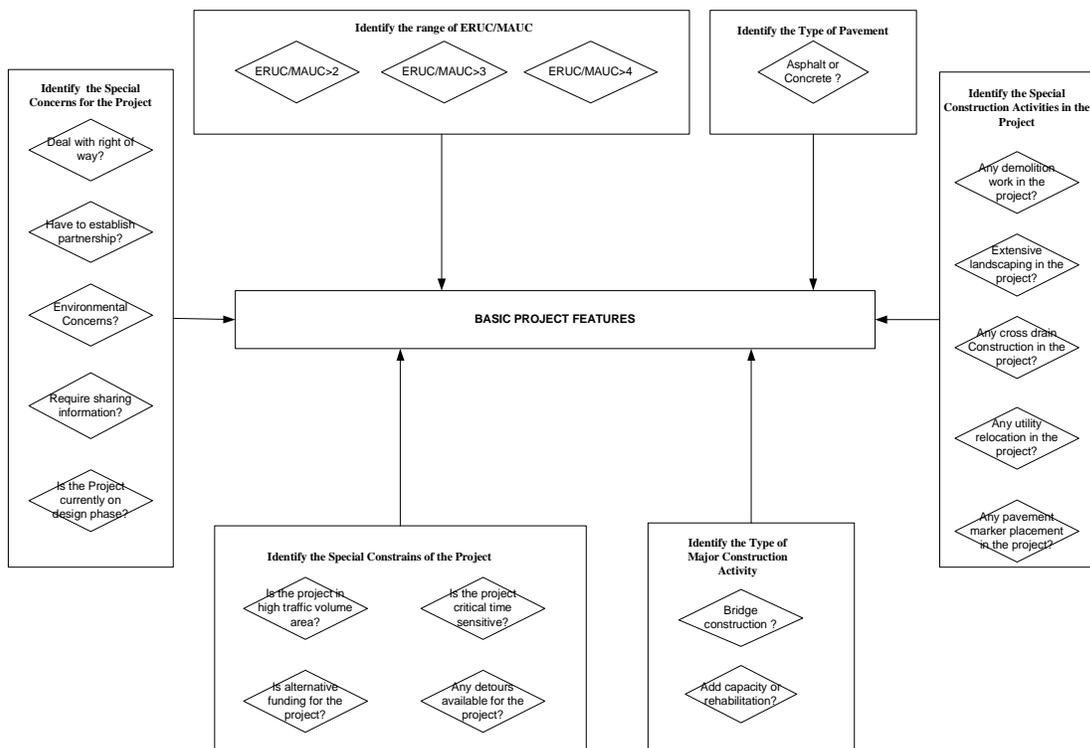


Figure 6.2-1: Decision Nodes in the System

6.2.3 Recommend Applicable Rapid Construction Method

According to the characteristic information of the project obtained in step two, the decision making system will identify applicable rapid construction methods from a database for a given roadway construction project.

The research effort identified nearly ninety rapid construction methods for roadway projects through literature review and case studies. These methods are classified based on their applicable use on a project with varying ERUC/MAUC ratios and elements of the project scope. As the ERUC/MAUC ratios increase, methods requiring greater investment on behalf of a state DOT are included in a list of alternatives for consideration. Meanwhile, methods are sorted and identified as candidates based on project characteristics. Ultimately, a list of alternatives is generated from which certain methods can be considered for implementation in order to accelerate the project.

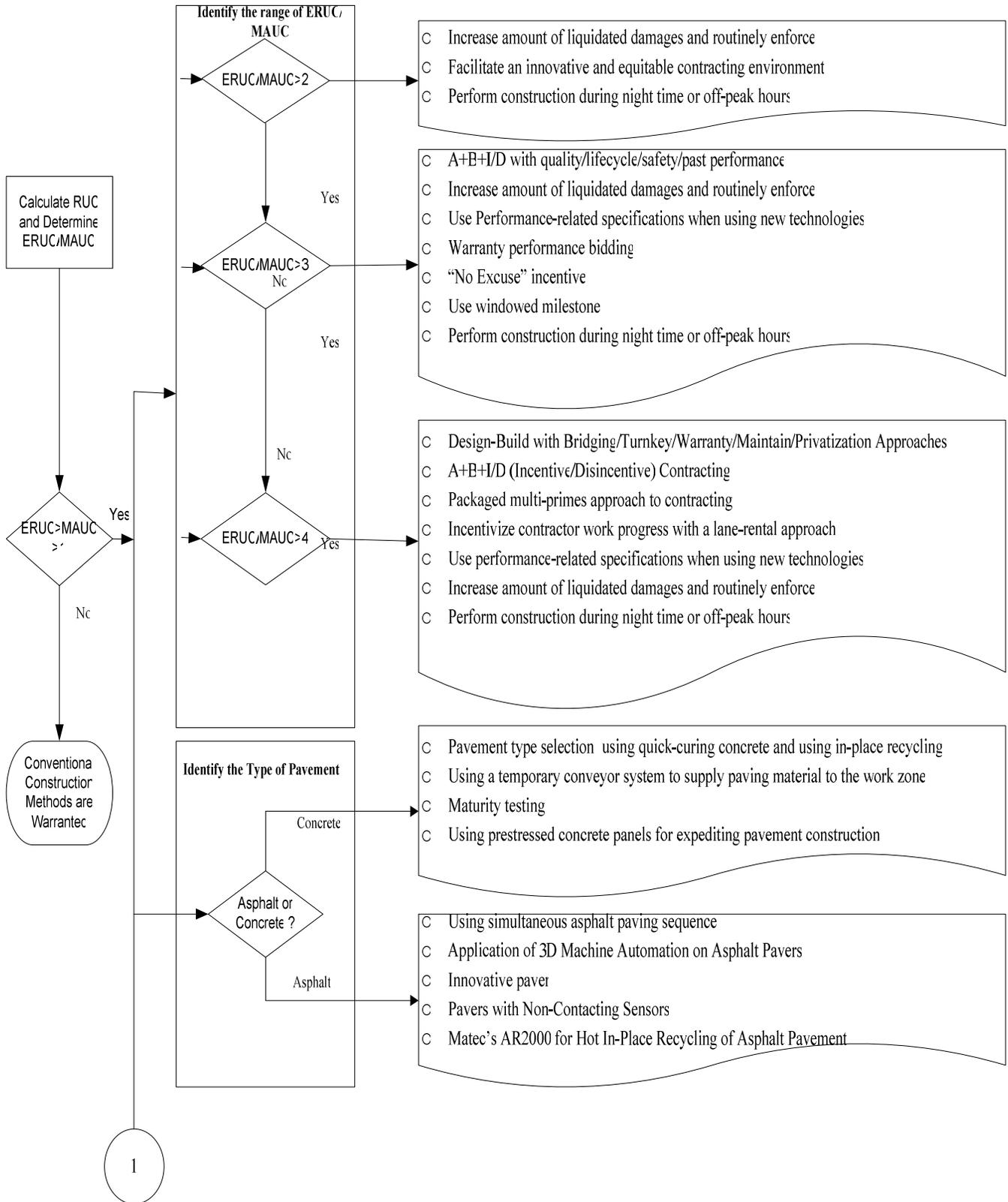


Figure 6.2-2: Flow Diagram #1

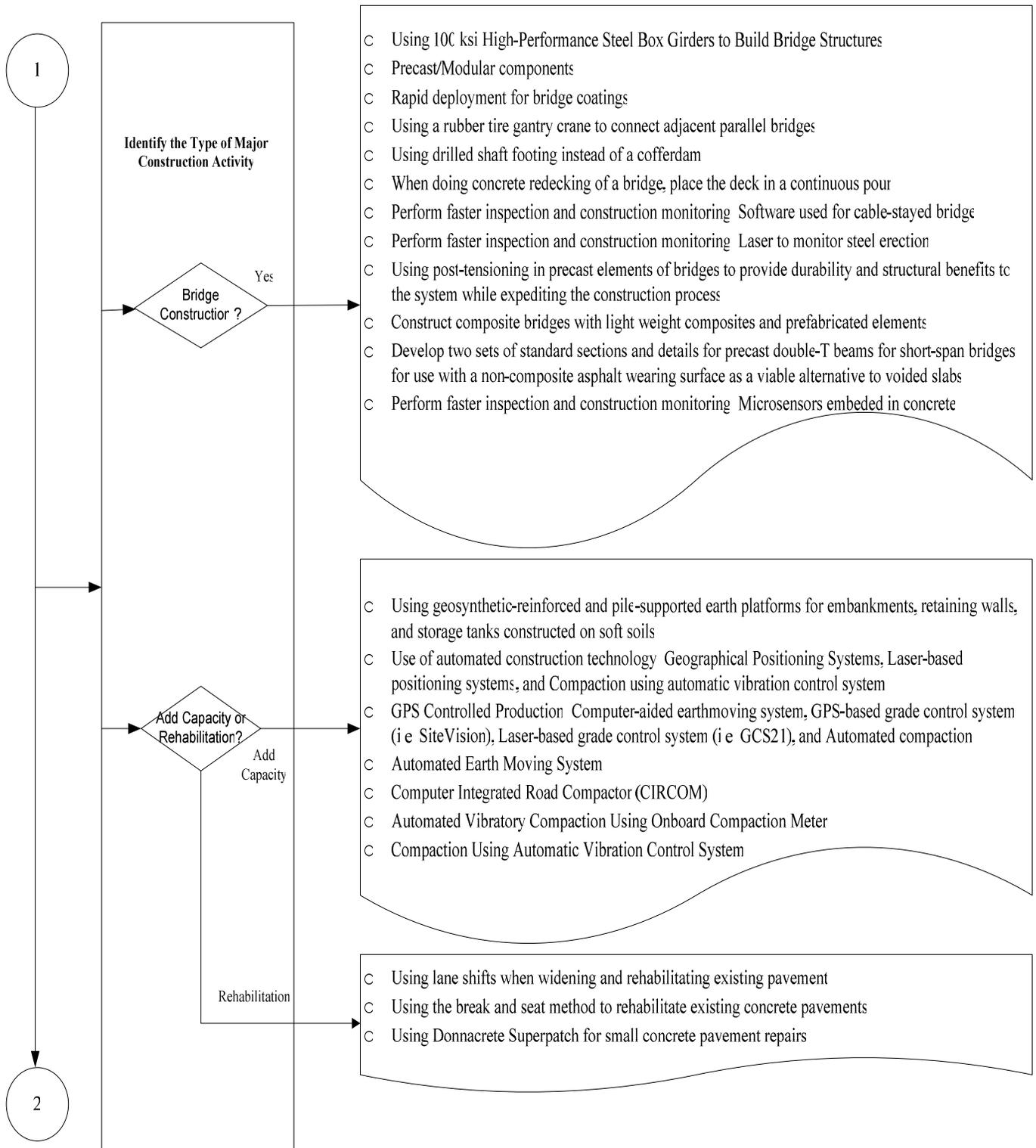


Figure 6.2-3: Flow Diagram #2

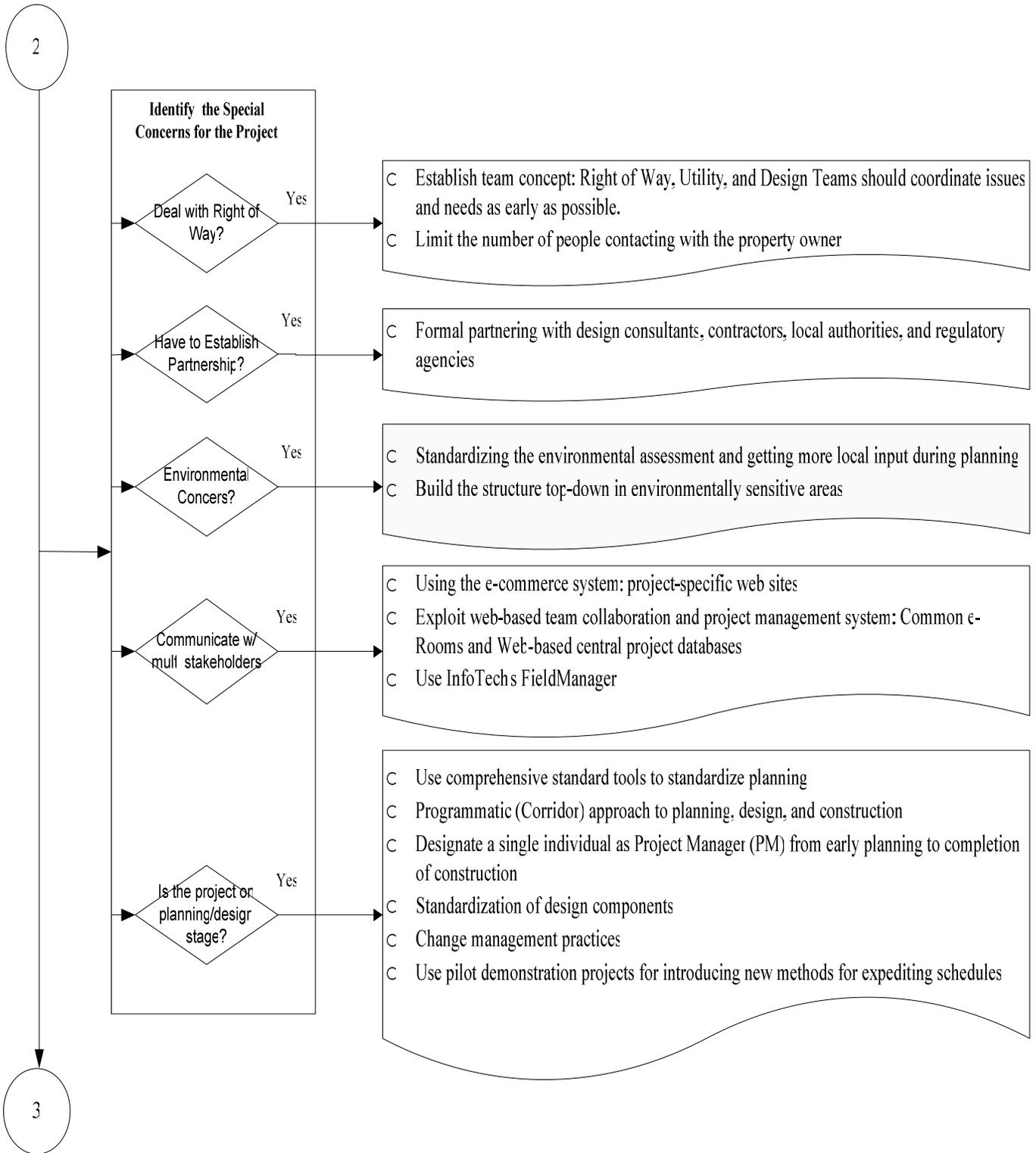


Figure 6.2-4: Flow Diagram #3

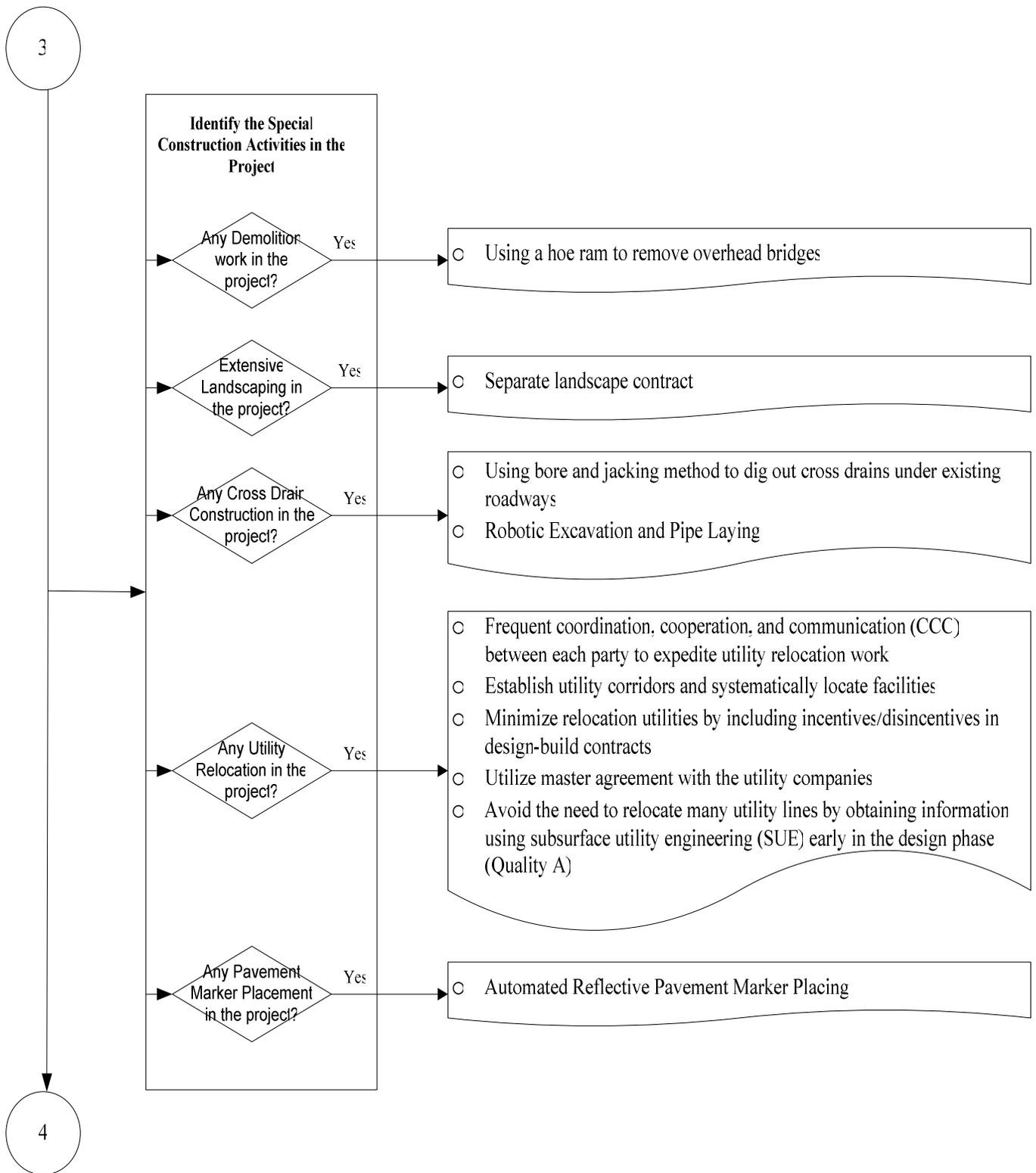


Figure 6.2-5: Flow Diagram #4

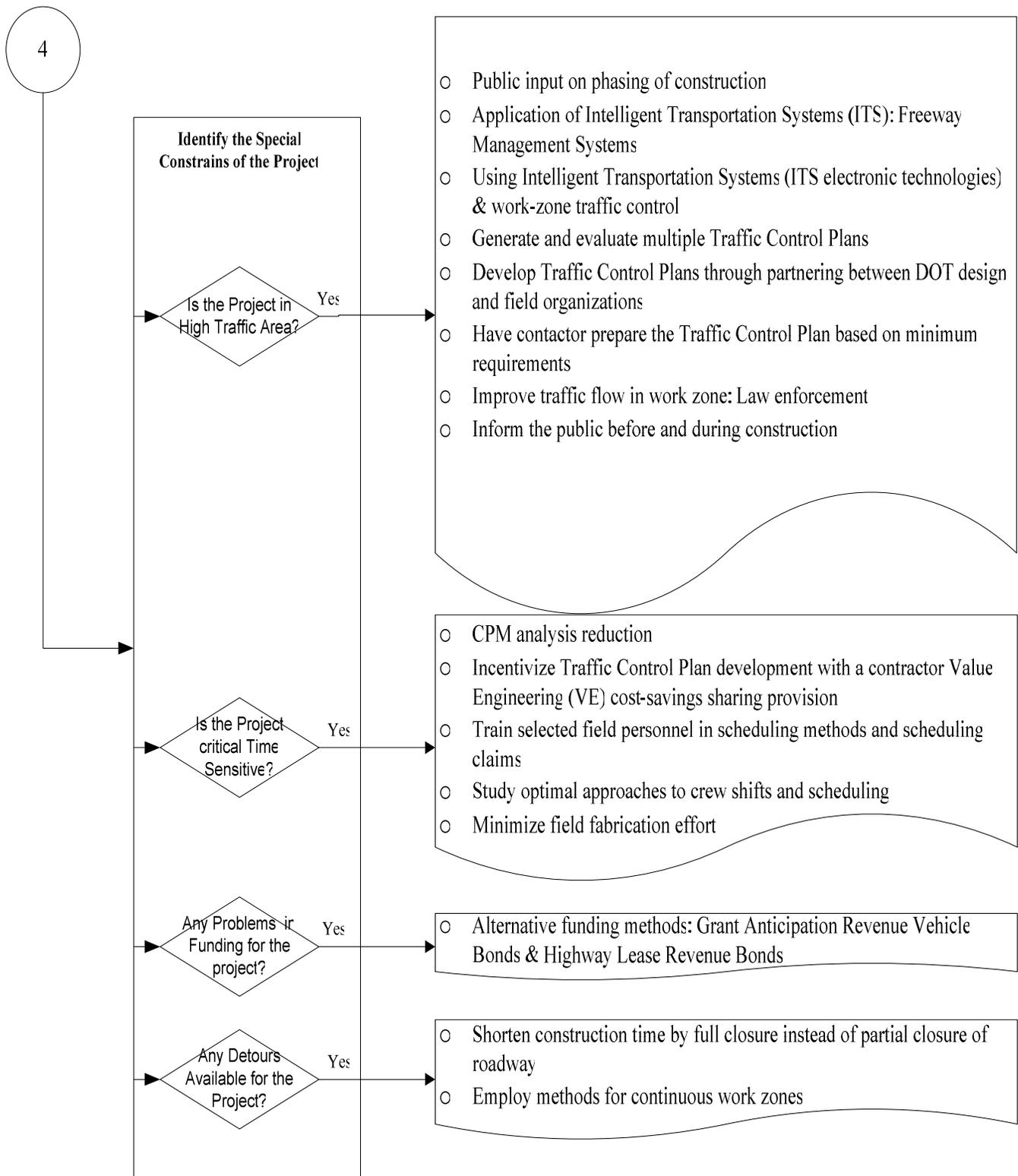


Figure 6.2-6: Flow Diagram #5

6.3 Software Architecture

The rapid construction decision making system was programmed in Microsoft Access, which allows the users to transfer the program easily from one computer to another. Meanwhile, users can update the rapid construction methods database conveniently when new rapid methods become available. Figure 6.3-1 briefly illustrates some of the screen shots and steps involved with using the decision making model.

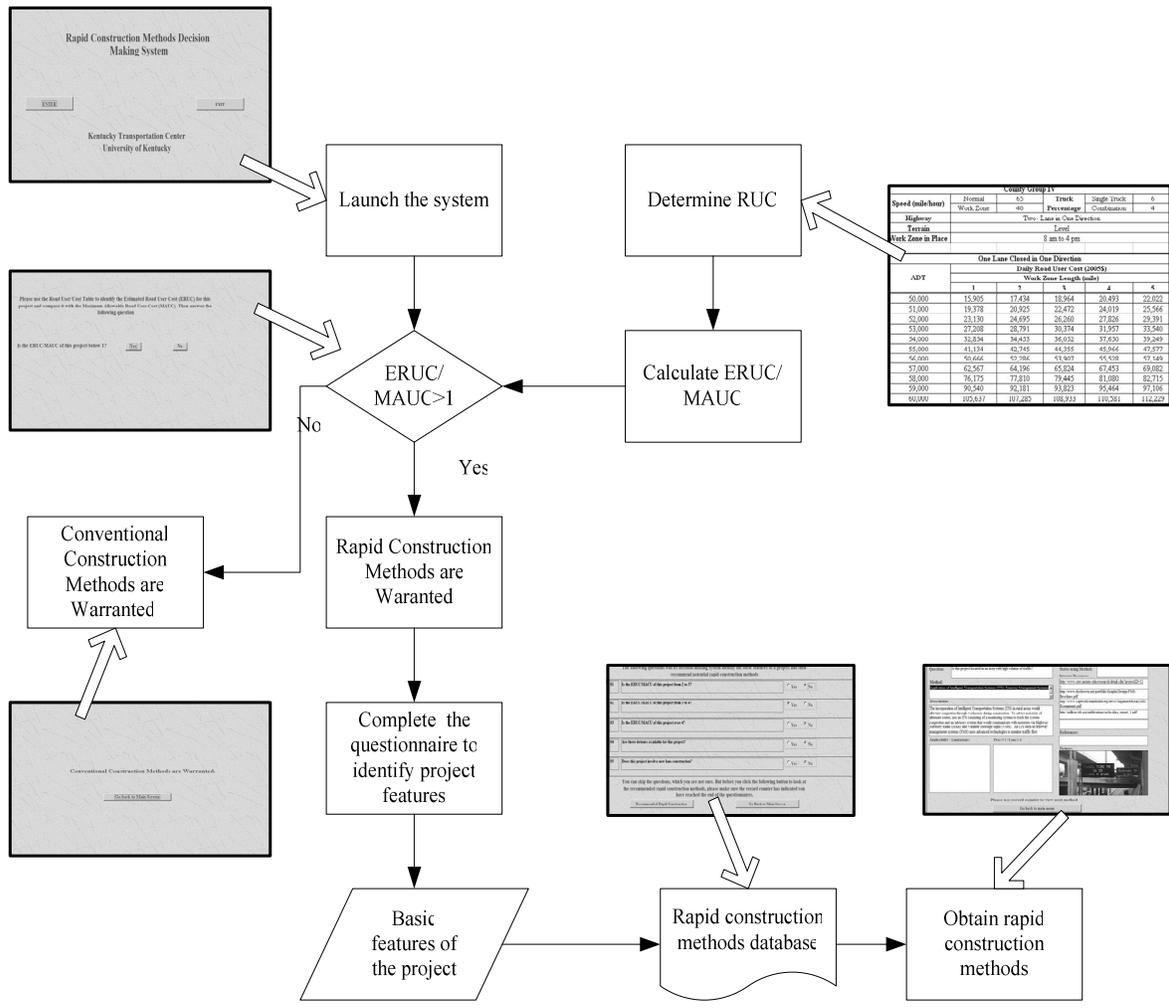


Figure 6.3-1: Flow Chart of Using Decision Making System

I. Determine ERUC and MAUC

Before using the rapid construction method decision making system, users have to determine the estimate road user cost, which can be obtained by using the RUC tables along with basic project information.

II. Calculate the Ratio of ERUC versus MAUC

MAUC should be determined by an STA for a specific roadway construction project. This cost is the upper limit established for a roadway construction project which a STA is willing to impose road users.

III. Launch the System

Run the program on a computer and the user-friendly windows will pop up. Next, users can follow the instructions to complete the rapid construction method decision making process.

IV. Determine the Economical Feasibility of the Rapid Construction Methods

Based on the results of Step II, answer the questions regarding the value of the ratio of ERUC versus MAUC.

V. Fill in the Questionnaire

There are twenty-two questions embedded in the system in order to identify the basic features of a project. However, users can skip the questions which cannot be answered due to lack of information stem from early design.

VI. Identify the Recommended Rapid Construction Methods

When users enter the last question in the questionnaire and click on “Recommended Rapid Construction Method”, the system will display the recommended methods for that particular project.

6.4 Decision Making Model Validation

In order to validate that the decision making system does offer accurate suggestions for accelerating a construction project, the research team tested the project against the Leestown Pike Rehabilitation Project. The research team assessed the system's results generated by the team's decision making model by inputting project specific characteristics and comparing the suggested methods with the methods actually used to accelerate construction on the project. Skees Engineering designed the Leestown Pike Rehabilitation Project. Faulkner Construction performed the construction portion of the project, which began on April 4, 2005 and was opened to traffic on July 1, 2005. The project involved several factors such as detours, bridge demolition, new bridge construction, pavement rehabilitation, utility relocation, and both concrete and asphalt pavements. The half-mile work zone was located in a high traffic area that was allotted a maximum allowable user cost of \$25,000 per day with a RUC of approximately \$95,000 per day.



Fig. 6.4-1: New Leestown Pike Bridge

Once all the necessary project parameters were input, the decision-making model provided 59 proposed methods applicable to this project. Upon meeting with the Cabinet's Project Manager for this venture, the research team discovered that the KyTC employed 21 of the 59 proposed approaches to completing this project. These results show that 36% of the program's feedback was employed for this project, leaving 38 potential methods unused. These unused methods could be viewed as areas for improvement when planning future projects. Below is the list of methods utilized by the Cabinet that were output by the model.

1. Public input on phasing of construction;
2. Using Intelligent Transportation Systems (ITS electronic technologies) & work-zone traffic control;
3. Generate and evaluate multiple Traffic Control Plans;
4. Develop Traffic Control Plans through partnering between DOT design and field organizations;
5. Inform the public before and during construction;
6. Establish team concept: Right of Way, Utility, and Design Teams should coordinate issues and needs as early as possible;
7. Using drilled shaft footing instead of a cofferdam;
8. Frequent coordination, cooperation, and communication (CCC) between each party to expedite utility relocation work;
9. Establish utility corridors and systematically locate facilities;
10. Avoid the need to relocate many utility lines by obtaining information using subsurface utility engineering (SUE) early in the design phase;
11. CPM analysis reduction;
12. Train selected field personnel in scheduling methods and scheduling claims;
13. Study optimal approaches to crew shifts and scheduling;
14. Minimize field fabrication effort;
15. Using the e-commerce system: project-specific web sites;
16. A+B+C Bidding with Quality/Lifecycle/Safety/Past Performance;
17. "No Excuse" incentives;
18. Use of windowed milestone;
19. Shorten construction time by full closure instead of partial closure of roadway;
20. Using a hoe ram to remove overhead bridges; and
21. Formal partnering with design consultants, contractors, local authorities, and regulatory agencies.

The following list contains the methods that were not employed on this project, but were recommended by the decision-making model.

1. Application of Intelligent Transportation Systems (ITS): Freeway Management Systems;
2. Have contractor prepare the traffic control plan based on minimum requirements;
3. Choosing the best Traffic Control Plan implementing multiple work shift and/or night work;
4. Improve traffic flow in work zone: Law enforcement;
5. Limit the number of people contacting with the property owner;
6. Using 100 ksi High-Performance Steel Box Girders to Build Bridge Structures;
7. Precast/Modular components;
8. Rapid deployment for bridge coatings;
9. Using a rubber tire gantry crane to connect adjacent parallel bridges;
10. When doing concrete redecking of a bridge, place the deck in a continuous pour;
11. Perform faster inspection and construction monitoring: Software used for cable-stayed bridge;
12. Perform faster inspection and construction monitoring: Laser to monitor steel erection;
13. Using post-tensioning in precast elements of bridges to provide durability and structural benefits to the system while expediting the construction process;
14. Construct composite bridges with light weight composites and prefabricated elements;
15. Develop two sets of standard sections and details for precast double-T beams for short-span bridges for use with a non-composite asphalt wearing surface as a viable alternative to voided slabs;
16. Perform faster inspection and construction monitoring: Microsensors embedded in concrete;
17. Minimize relocation utilities by including incentives/disincentives in design-build contracts;
18. Utilize master agreement with the utility companies;
19. Incentivize Traffic Control Plan development with a contractor Value Engineering (VE) cost-savings sharing provision;
20. Exploit web-based team collaboration and project management system: Common e-

- Rooms and Web-based central project databases;
21. Use InfoTech's FieldManager;
 22. Warranty performance bidding;
 23. Employ methods for continuous work zones;
 24. Automated Reflective Pavement Marker Placing;
 25. Using bore and jacking method to dig out cross drains under existing roadways;
 26. Robotic Excavation and Pipe Laying;
 27. Using lane shifts when widening and rehabilitating existing pavement;
 28. Using the break and seat method to rehabilitate existing concrete pavements;
 29. Using Donnacrete Superpatch for small concrete pavement repairs;
 30. Pavement type selection: using quick-curing concrete and using in-place recycling;
 31. Using a temporary conveyor system to supply paving material to the work zone;
 32. Maturity testing;
 33. Using prestressed concrete panels for expediting pavement construction;
 34. Using simultaneous asphalt paving sequence;
 35. Application of 3D Machine Automation on Asphalt Pavers;
 36. Innovative paver;
 37. Pavers with Non-Contacting Sensors; and
 38. Matec's AR2000 for Hot In-Place Recycling of Asphalt Pavement.

The results of the validation indicate that the decision making model can offer accurate suggestions for accelerating construction projects. The Cabinet had already employed 21 of the 59 methods output by the research team's decision making model on the Leestown Pike Rehabilitation Project. Based on this pilot's assessment, the model does yield accurate suggestions, which can be valuable to future projects.

7.0 CONCLUSION

It is essential for the Cabinet to continue looking at the different ways to expedite the completion of highway construction projects, especially when rehabilitating existing roadways. Traditionally, the lingering traffic controls through work zones create lengthy periods of inconvenient traffic delays for the motorists. The Cabinet's recent efforts to *get in, get out, and stay out* have been welcomed by the public. As proven by the I-64 Project, the public would rather be inconvenienced by major construction over a short period of time, even if the roadway is totally shutdown for an entire weekend, as long they are notified in advanced and they are provided an effective detour route. Such innovative traffic control approaches provide the perfect conditions for contractors to work with a bigger work force and to produce higher quality work.

Also, the research team developed a set of road user cost tables to determine road user costs during planning and conceptual design stage in order to facilitate selection of rapid construction methods for highway construction projects. The road user costs calculated by these efforts are based on varying values of travel time to reflect the different social economic conditions between metropolitan and rural areas. The RUC tables developed in this research are particularly useful in preliminary and conceptual design stages, but are not intended to replace any other RUC programs or models, such as QuickZone, QWUZE and KyUCP, which are applicable during detailed design or construction. The direct application of the RUC tables is to establish a decision system for selection of rapid construction methods. This decision-making system recommends potential applicable rapid construction methods for specific roadway construction projects based on ERUC/MAUC ratio and other features of the project. This system should help designers and other project participants identify the need for and the types of rapid construction methods during the early stages of a project's development process. This will allow time to develop the design and contract agreements to accommodate and facilitate these types of construction methods.

8.0 RECOMMENDATIONS AND IMPLEMENTATION

Based on observations from the case studies, major field innovations are initiated by the contractor on projects that contain unique design restrictions, such as time constraints and traffic control obligations, and monetary provisions. The Cabinet can encourage the contractor to develop innovative rapid construction methods by rewarding them for early completion and penalizing them for late completion. On projects offering monetary rewards, even if they do not develop innovative construction methods, the contractors are influenced to hire additional crews to simultaneously run multiple operations instead of working sequentially.

The contract is the Cabinet's most powerful tool to influence the contractor to use innovative rapid construction methods, especially when accurate project durations are established. The Cabinet's effort of establishing contract duration was especially effective on the Shawnee project. The Cabinet has the ability to influence the contractor to perform as many simultaneous operations as it is physically possible under the work site conditions and tasks at hand by providing monetary incentives in the contract. Incentives do influence a contractor to acquire a large work force of specialists, pieces of equipment with high productivity rates, and fast-installation materials in order to expedite traditional construction methods.

The Cabinet has been successful in using the A + B competitive bidding method with incentive and disincentive provisions and with maximum caps on their large projects. This method works effectively on projects with many bidders because it allows the contractors to lower the contract duration at their own will in order for them to attempt bidding the lowest price to win the project. Establishing the maximum duration limit and the provision amounts so that they still can attract a large number of bidders is critical.

Employing engineers with experience in both highway design and highway construction during the planning stages of large urban construction projects is beneficial. This allows for CPM analysis reductions when estimating contract durations, which has proven successful in the past. Designers with the ability to think like contractors are best suited for accelerated critical path analyses to estimate how long it would take a contractor to complete the multiple jobs required on a project in the most efficient manner. They have the ability to analyze the project constraints, regional resources available, workdays available, and operations available for parallel

work. It is important to use provisions with the A + B bidding method. In cases where they may be concerned about quality as well as speed, the Cabinet could also use the A+B-C bidding method. This method gives the contractor the opportunity to lower the total combined bid with a credit amount representing the lifecycle cost of the pavement.

Another expediting factor that was evident from the analysis of the case studies was the fact that the contractor was much more productive when working in a protected environment, away from the traveling public. In order to provide the most effective working environment for the contractor, the Cabinet should evaluate the possibilities of using lane shifting with protective barriers or applying full weekend closures before specifying the traffic control plans. The impact on local communities is greatly reduced by keeping the public well informed of such plans. Furthermore, as shown by the Shawnee Expressway Project, the use of police enforcement to impose reduced speed limits can drastically reduce the number of accidents in work zones, leading to fewer interruptions to the production of workers.

The Cabinet should continue to experiment with innovative field methods and materials through experimental projects to evaluate their potential ability to expedite future construction projects. When testing new methods, the Cabinet may want to consider using a working-day contract instead of a completion-date contract. By dictating an allowable number of working days instead of a completion date, the Cabinet is effectively accepting the burden of the learning curve for both parties. A working-day contract does not expedite the experimental project since the contract completion date may vary, but it allows both parties to become familiar with the innovative method/material to be used and gives them time to develop an efficient approach. The use performance-based specifications instead of prescriptive specifications will also facilitate the use of innovative rapid methods and may also attract smaller contractors to become involved in the innovation process as well. In order to expedite each working day, the Cabinet could specify the use of incentives/disincentives or lane rental fees for lane closures. However, they would not specify which method to use during that timeframe. To be effective, the Cabinet could provide non-penalized practice areas where the contractor could adjust to using new equipment/material and they could work on improving their production rate. In that aspect, the Cabinet could require the contractor to reach a minimum production rate before allowing them to move into the areas with lane closures with provisions. This requirement would encourage the contractor to train their workers in the non-penalized areas before attempting to

work on the areas with the lane closures and to acquire additional resources until they have the work force and equipment needed to reach the specified production rate.

When replacing full-depth slabs of concrete on interstates where one lane needs to remain open to traffic, the Cabinet could allow less than a twelve-hour window at nighttime and they could set lane rental fees if the contractor maintains the lane closure past the allotted time frame. The Cabinet could also provide specifications on using the concrete maturity testing method, where they could specify the use of the Arrhenius equation over the Nurse-Saul equation when dealing with high-early strength concrete mixes.

During the pre-construction meetings, it is also important for the Cabinet to utilize the contractors' experience and listen to their ideas of possible methods that could expedite the projects. This strategy will influence the contractor to assemble as many resources as need to perform simultaneous operations and/or to develop innovative methods, materials, and equipment to expedite the construction process.

The conceptual user cost tables could be utilized to identify a project's need to accelerate construction. The tables are based on variable value of time that exist within the different economic regions of Kentucky. There are tables designed for interstate travel and should be used regardless of which county a project is located; the interstate tables were developed based on the overall state's average value of time. Projects involving the state's parkways should consider using the project's county group value of time, since it is considered that most travel on the state's parkways involve local travel. Projects that overlap two economic regions, should use the county with the higher value of time. The conceptual user cost tables could also be used internally regarding methods to be used for maintenance. However, the researchers strongly suggest that the conceptual user cost tables not be used to establish incentives/disincentives or liquidated damages. Instead the states existing method of determining detailed RUC should be used.

The Innovative Rapid Construction Method Decision Making System can be used to help the Cabinet identify a menu of rapid methods of construction for consideration during the project's early planning stages. The Innovative Rapid Construction Method decision-making model can be utilized by the Kentucky Transportation Cabinet to guide Engineers in Training (EIT) who are uncertain which methods to employ while working on a new project in

development. Where more experienced engineers are typically familiar with many options available to a particular project, a young engineer may not recognize or be aware of the numerous contract options or methods that are available, such as A+B bidding, traffic phasing, nighttime work, incentives/disincentives, and certain innovative materials. This information and understanding of how justifications can be made to accelerate construction will assist EIT's during their early careers.

9.0 APPENDIX A

9.1 Innovative Rapid Construction Methods

Method 1

Approaches

Meet with property owners and public early for their involvement in design process for Right of Way Innovative Contracting

Description

Let the property owners, community members, and local authorities be involved before the completion of the final right of way plans. Also, make use of an extensive property review process to discuss the impact of the project with the property owners and get an understanding of how property owners use their property. Encourage owner participation in design issues at early stages of project development to assess the impact of the proposed design and to determine if a design revision is warranted. Appropriate use of this practice will result in more timely purchases and reduce damages to properties.

References

http://international.fhwa.dot.gov/Pdfs/scan_summaries/rowscans.pdf

Method 2

Approaches

Establish team concept: Right of Way, Utility, and Design Teams should coordinate issues and needs as early as possible. Innovative Contracting

Description

The utility and right of way teams can coordinate and design their work on abstracts, descriptions, appraisals, and acquisitions before the final design is complete. This could speed up right of way clearance by as much as a year. Close coordination with utilities could determine if right of way team can assist in acquiring necessary utility easements. If the DOT or contractor can make the contract for both right of way and utility needs, it means dealing with the property owner once only and saving time.

References

http://international.fhwa.dot.gov/Pdfs/scan_summaries/rowscans.pdf

Method 3

Approaches

Limit the number of people contacting with the property owner Innovative Contracting

Description

Allow one person to serve as appraiser and negotiator for acquisition and relocation services. By limiting the need for appraisal reviews and through the passage of special enabling legislation to streamline the acquisition process, the time needed to provide offers to property owners could be reduced.

References

http://international.fhwa.dot.gov/Pdfs/scan_summaries/rowscans.pdf

Method 4

Frequent coordination, cooperation, and communication (CCC) between each party to expedite utility relocation work

Approaches

Relocation of Utilities
Innovative Contracting

Description

Frequent coordination, cooperation, and communication (CCC) between the DOT and utilities personnel result in more timely and efficient relocation activities. This is a method to expedite relocation of utilities, such as telephone, electric power, water and gas. The unresolved/undetected utility issues are possibly the major cause of delay in highway construction. Their impact can be minimized if the highway agencies address fundamental relationships and explore innovative agreement arrangements.

Pros (+) / Cons (-)

- + Incentives encourage PMs to develop more economical means and methods
- + Less formal documentation and communication improvement would shorten the project execution
- + Reduction of executive personnel
- + More continuity during project
- Selection of PM is highly critical
- Independent engineers may be needed to check PM's work
- Must overcome "specialist mindset" of organization

Applicability / Limitations

- In highway construction the need for the relocation of utilities often arises
- Relocation is handled primarily by utility companies
- Little current recourse against utilities for delays
- Utilities have to pay for relocations

References

- http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
- <http://www.fhwa.dot.gov/construction/fs02048.htm>
- <http://www.tfhrc.gov/focus/aug02/03.htm>
- <http://www.fhwa.dot.gov/construction/washto02/utility.htm>

Method 5

Establish utility corridors and systematically locate facilities

Approaches

Relocation of Utilities
Innovative Planning and Design Phase

Description

Consider a utility tunnel/corridor along the side of the road which is the most cost effective strategy for handling future utility work. Locating all utilities in one corridor facilitates future access for maintenance operations while at the same time minimizing traffic disruption.

References

- Transportation Research Board Task Force A5T60

Method 6

Minimize relocation utilities by including incentives/disincentives in design-build contracts

Approaches

Relocation of Utilities
Innovative Contracting

Description

Try to include utilities as essential components of design-build contracts to force the design team to locate all utilities and design accordingly in order to minimize the relocation of utilities. This should improve the coordination between the design-build contractor and the affected utility companies.

References

- Transportation Research Board Task Force A5T60

Method 7

Utilize master agreement with the utility companies

Approaches

Relocation of Utilities
Innovative Contracting

Description

Jurisdiction-wide master agreements with each utility company are used to avoid having to deal with utility

agreements on every project.

References

Transportation Research Board Task Force A5T60

Method 8

Avoid the need to relocate many utility lines by obtaining information using subsurface utility engineering (SUE) early in the design phase

Approaches

Automation Equipment / Construction Technology
Relocation of Utilities

Description

During the design phase, obtain better information on utility location using subsurface utility engineering (SUE). By detecting the location of the utilities early, the designer can plan around the utility lines and avoid the need to relocate them. SUE uses surface geophysical techniques to identify the presence and approximate position of underground utilities. Studies have shown that SUE costs less than 0.5 percent of the total project construction cost, saves more than \$4 for every \$1 spent, and reduces project delivery time by as much as 20 percent.

References

<http://www.fhwa.dot.gov/construction/fs02048.htm>

Transportation Research Board Task Force A5T60

Method 9

Public input on phasing of construction

Approaches

Public Involvement / Increased Awareness

Description

Forming public-private partnerships and encouraging the community to participate in construction can lead to faster completion. If the local concerns and commuters can choose construction options, it could allow a jurisdiction to close complete highways.

Pros (+) / Cons (-)

+ More expeditious construction methods can be employed

- Requires more public relations effort earlier

Applicability / Limitations

· This method is applicable on construction projects where there is significant impact on the public

· Perhaps having the public vote on sequencing and methods of construction

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 10

Use comprehensive standard tools to standardize planning

Approaches

Innovative Planning and Design Phase

Description

Organizations with a standardized front-end planning approach have better capital effectiveness. This approach focuses on the gateways and required steps to ensure that the proper planning issues have been addressed. Organizations adopt a process that firmly establishes the project's scope (pre-project planning) before the planning and design is finalized, which leads to improved performance on industrial projects in the areas of cost, schedule, and operational characteristics. To assist in performing this critical stage of the project, non-proprietary tools such as the Construction Industry Institute's Project Definition Rating Index (PDRI) are being used by some of the larger owner companies of industrial capital facilities.

Pros (+) / Cons (-)

+ Better decision making process

+ More consistent approach

+ More predictable project outcomes

+ Cost and schedule savings

- Less flexibility

Applicability / Limitations

· Large owner organizations such as DOT benefit from a standard planning process

· Requires top management support

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

<http://www.nap.edu/books/0309082803/html/22.html>

http://www.construction-institute.org/services/catalog/more/ir113_2_more.cfm

<http://www.cii-pdri.org>

Method 11

Programmatic (Corridor) approach to planning, design, and construction

Approaches

Innovative Planning and Design Phase
Innovative Field Methods

Description

Consider an entire road as a whole, rather than breaking the corridor into separated segments tied to yearly funding limitations. The procurement is simplified, and the speed to delivery is increased, since the project can be completed using larger multi-year contracts. Funding restrictions and political considerations often prevent construction activity to be applied on a corridor basis. However, the Mobility Funds may be used on some corridors. The Mobility Funds are administered as revolving funds to provide a method of financing the construction, reconstruction, acquisition, and expansion of state highways.

Pros (+) / Cons (-)

- +Faster delivery of project
- Financing

Applicability / Limitations

- Multi-year funding and common contractor
- usage is standard procedure in the private sector
- This would require long-term planning
- Legislative limitations restrict this method

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 12

Alternative funding method: Grant Anticipation Revenue Vehicle bonds

Approaches

New Financing

Description

This is an alternative funding to build roads. It is a debt financing instrument authorized to receive Federal reimbursement of debt service and related financing costs incurred in connection with an eligible debt financing instrument, such as a bond, note, certificate, mortgage, or lease. A debt financing Instrument is a type of financing through the selling of a debt instrument. In other words, it is a written promise to repay a debt. Debt financing is used for the transportation projects that are so large that their costs exceed available current grant funding and tax receipts. The state and local agency often look to financing the projects through borrowing then retires its obligation by making principal and interest payments to the investors over time.

Pros (+) / Cons (-)

- + Faster project completion due to adequate financing
- + Advancing completion dates saves money
- + Allows for “programmatic (corridor) planning”
- Can over commit a state resulting in future funding restrictions

Applicability / Limitations

- funding methods
- GARVEE bonds or other methods are applicable to major highway projects where financing is not immediately available
- Legislative limitations restrict this method

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

<http://www.tfsrc.gov////////focus/aug02/03.htm>

Transportation Research Board Task Force A5T60

Method 13

Alternative funding method: Texas Mobility Fund

Approaches

New Financing

Description

The Texas Mobility Fund is created in the state treasury and shall be administered by the commission as a revolving fund to provide a method of financing the construction, reconstruction, acquisition, and expansion of state highways, including costs of any necessary design and costs of acquisition of rights-of-way, as determined by the commission in accordance with standards and procedures established by law. This Mobility Fund is an alternative funding to build roads and it is key to Corridor Approach.

References

<http://www.capitol.state.tx.us/txconst/sections/cn000300-49-k00.html>

Method 14

Approaches

Alternative funding method: Highway Lease Revenue Bonds New Financing

Description

Lease revenue bonds are an alternative funding to build roads. They are a form of long-term borrowing in which the debt obligation is secured by a revenue stream produced by the project. These bonds are issued by municipalities when their general obligation bond limit is not large enough to allow a project to be financed in that manner. If a municipality is reserving its general obligation limit for other future projects it may elect to issue lease revenue bonds to finance current projects. Some states do not allow the issuance of general obligation bonds without a referendum. In those states, lease revenue bonds have become the method of financing infrastructure projects that will be paid for from property taxes. A lease revenue bond is not an unconditional obligation of the municipality. Rather, the revenue necessary to repay bond owners must be appropriated from tax revenue by the municipality each year.

References

<http://www.gardnymichaelcapital.com/Q2.html>

<http://sam.dgs.ca.gov/TOC/6000/6872.htm>

Method 15

Approaches

Designate a single individual as Project Manager (PM) from early planning to completion of construction Innovative Management

Description

Select a project manager to handle the execution of the whole project. Empower and equip PM with needed tools and data to select appropriate expediting methods. The PM should possess leadership qualities and the ability to effectively handle intricate interpersonal relationships within the organization, while maintaining continuity throughout the project from initiation to end of construction. Motivation of the PM can be granted with the use of incentives such as salary bonuses and future assignments.

Pros (+) / Cons (-)

- + Incentives encourage PMs to develop more economical means and methods
- + Less formal documentation and communication improvement would shorten the project execution
- + Reduction of executive personnel
- + More continuity during project
- Selection of PM is highly critical
- Independent engineers may be needed to check PM's work
- Must overcome "specialist mindset" of organization

Applicability / Limitations

- This method is probably most applicable for large and complex projects
- Legislation controls may preclude payment for bonuses

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 16

Design-Build (D-B): Bridging approach

Description

Contrary to Design-Bid-Build, Design-Build contracting means that a single company completes the design and construction duties for the project. The bridging approach requires the owner to develop preliminary project design to the 30-50 percent level.

Pros (+) / Cons (-)

- + Time Savings
- + Reduced cost due to accelerated schedules
- + Reduced administration and inspection costs
- + Eliminates conflicts between designer and contractor
- + Reduced number of in-house design personnel needed in DOT
- + Reduced change orders and claims
- + Increased final product quality by allowing innovations and new approaches
- Singular responsibility
- Reduces competitiveness of small companies

References

- http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
- <http://www.tfrc.gov/focus/aug02/03.htm>

Approaches

Innovative Contracting

Applicability / Limitations

- Although it is being used by almost half the states, D-B is not allowed legally in Texas
- Primarily, D-B is used when there are opportunities for the owner or agency to save time by having construction begin before the final design has been completed
- Not applicable to all projects; should be used on projects that have time constraints or have complex/innovative project needs
- Legislative limitations restrict this method

Method 17

Design-Build (D-B): Turnkey approach

Description

Contrarily to Design-Bid-Build, Design-Build contracting means that a single company completes the design and construction duties for the project. The turnkey approach is when the owner requires outside expertise and then allows the entity to turn over the keys at project completion. Design-Build is one of the variations of turnkey project delivery. There are many variations of turnkey project delivery. Some of the most common methods include the following: Design/Build, Design-Build-Operate-Maintain, and Design-Build-Transfer-Operate.

References

- http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
- <http://www.fta.dot.gov/research/equip/civil/turnkey/turnkey.htm>

Approaches

Innovative Contracting

Method 18

Design-Build-Warranty (D-B-W) approach

Description

Contrarily to Design-Bid-Build, Design-Build contracting means that a single company completes the design and construction duties for the project. The Design-Build-Warranty approach combines a warranty provision with Design-Build.

References

- http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Approaches

Innovative Contracting

Method 19

Design-Build-Maintain (D-B-M) approach

Description

Contrarily to Design-Bid-Build, Design-Build contracting means that a single company completes the design and construction duties for the project. The Design-Build-Maintain approach combines maintenance provisions with Design-Build.

References

- http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Approaches

Innovative Contracting

Method 20

Design-Build (D-B): Privatization approach

Approaches

Innovative Contracting

Description

Contrarily to Design-Bid-Build, Design-Build contracting means that a single company completes the design and construction duties for the project. The privatization approach is when a private entity designs, builds, and maintains a section of roadway in return for a toll or fee.

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 21

Formal partnering with design consultants, contractors, local authorities, and regulatory agencies

Approaches

Innovative Contracting

Innovative Planning and Design Phase

Innovative Management

Description

This is a formal management process in which all parties voluntarily agree at the beginning of the project to act as a team and cooperate during project development and problem resolution. Many meetings can be used to promote partnering concepts, including project concept conferences, design concept conferences, and postconstruction meetings.

Pros (+) / Cons (-)

- +Faster and cheaper construction process due to reduction of conflicts, litigation, and claims (win-win situation)
- + Continuous improvement in the quality of services and products
- + More effective utilization of resources
- + Can easily be implemented because already being used on an informal basis
- + Improves communication
- Negative perception of partnering by some participants
- Limits competitive market strategy
- Creates strong dependency on the partners

Applicability / Limitations

- Already used extensively in DOT
- Has not been applied very much to designers or other agencies
- Little training has been done and much skepticism is in place

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

Method 22

Standardizing the environmental assessment and getting more local input during planning

Approaches

Innovative Planning and Design Phase

Description

When adequate environmental assessment meeting NEPA requirements is done in a timely manner, it helps improve delivery speed. This process can be improved by standardizing the environmental assessment and getting more local input. The environmental streamlining section of the TEA-21 establishes a coordinated environmental review process by which the USDOT would work with other federal agencies to emphasize using concurrent, rather than sequential, reviews to save time. The DOT should try to incorporate environmental streamlining into its project approval process.

Pros (+) / Cons (-)

- + Fewer “surprises”
- + More consistent estimates for schedule delays
- + Better understanding of submission/accountability problems
- Reluctance to move fast

Applicability / Limitations

- Environmental issues often cause delay
- An interface with many local and federal agencies can cause confusion over responsibility
- Getting contractor input prior to award can be difficult

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 23

Application of Intelligent Transportation Systems (ITS): Freeway Management Systems

Approaches

- Information Technology
- Public Involvement / Increased Awareness
- Workzone Traffic Control

Description

The incorporation of Intelligent Transportation Systems (ITS) in rural areas would alleviate congestion through workzones during construction. To advise motorists of alternate routes, use an ITS consisting of a monitoring system to track the system congestion and an advisory system that would communicate with motorists via Highway Advisory Radio (HAR) and Variable Message Signs (VMS). An ITS such as freeway management systems (FMS) uses advanced technologies to monitor traffic flow electronically, detect slowdowns, alert emergency response crews, and relay information to motorists by freeway message signs.

References

- <http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>
- <http://www.docbrown.net/portfolio/GraphicDesign/FMS-Brochure.pdf>
- <http://www.capecodcommission.org/news/SagamoreRotaryDEIRcomments.pdf>
- http://gulliver.trb.org/publications/sp/its-idea_report_1.pdf

Method 24

Using Intelligent Transportation Systems (ITS) electronic technologies) & work-zone traffic control

Approaches

- Information Technology
- Workzone Traffic Control
- Public Involvement / Increased Awareness

Description

Minimizing the impact of work zone delays through technology has a positive impact on mobility, safety, access and productivity. The use of ITS technology in work zones, such as ramp metering systems, intrusion alarms, and queue detection information, is aimed at increasing safety for both workers and road users and ensuring a more efficient traffic flow. These technologies provide the means to better monitor and manage traffic flow through and around work zones and they also offer new solutions to improving transportation conditions. For example, ITS can be used in congestion management, incident management, real-time traffic data acquisition, variable speed limit, dynamic lane merge, automated enforcement, and moveable barrier technology.

Pros (+) / Cons (-)

- + Increases safety
- + Reduces congestion
- + Enhances mobility
- + Minimizes environmental impact
- + Increases energy efficiency
- + Promotes economic productivity for healthier economy
- Additional training of employees
- Cost to implement

Applicability / Limitations

- Applicable areas include but not limited to: Traffic Control, Route Guidance, Automated Highway Systems, Collision Avoidance, En-route Driver Information, Transportation Demand Management, etc...

References

- http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
- http://www.aashtotig.org/focus_technologies/its_technologies/
- http://gulliver.trb.org/publications/sp/its-idea_report_1.pdf

Method 25

Pavement type selection: using quick-curing concrete

Approaches

Innovative Materials
Innovative Field Methods

Description

Typically Portland cement concrete pavement has been the rigid pavement type used in roadway construction. Road workers have long had quick-curing cement materials and other speedy road repair products at their disposal. But recently, new cold-weather, all-surface road repair products, such as quick-curing concrete, have hit the market. It offers quick, one-step solutions for repairing highways, bridge decks, parking lots and other asphalt, concrete and masonry surfaces during cold temperatures and numerous freeze/thaw cycles.

Pros (+) / Cons (-)

+ Enhances optimal decision of pavement type for minimizing lifecycle costs
+ May impact speed of construction
- Extra data requirements

Applicability / Limitations

· Any pavement-related new construction or rehabilitation projects

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
<http://www.tfhr.gov////////focus/aug02/03.htm>
<http://www.tfhr.gov/focus/aug02/02.htm>
http://www.gypsumsolutions.com/newscenter/news/roadrepair/cs_dot.asp

Method 26

Pavement type selection: using in-place recycling

Approaches

Innovative Materials
Innovative Field Methods

Description

Typically, Reclaimed Asphalt Pavement, aged asphalt milled off the top of the road and recovered, has been the only waste material recycled for pavements. At this stage, more in-place recycling is available as an additional option to explore during the design phase. Today, such products as demolition PCC, coal fly ash, silica fume from the manufacture of glass, ground granulated blast furnace slag, crumb rubber from old tires, waste shingles, waste foundry sand, broken glass and crushed toilets can be recycled into roadways and pavements.

References

ARTBA Transportation Builder, Sept 2003 Smart Construction edition

Method 27

Precast/Modular components

Approaches

Innovative Field Methods
Innovative Materials

Description

Using prefabricated modular components, such as bridge sections and road slabs, can maximize concurrent work activity. According to the a Construction Industry Institute (CII) report, a decision support system could be developed to help the DOT decide when Precast/Modular components are a good option.

Pros (+) / Cons (-)

+ Enables concurrent activity
+ Offsite prefabrication can start early
- Limited dimensional flexibility

Applicability / Limitations

· Common approach for girders, bridge decks, retaining walls, piping, culverts

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
<http://www.tfhr.gov/focus/sep01/nextgeneration.htm>
<http://www.tfhr.gov////////focus/aug02/03.htm>
<http://domenici.senate.gov/newscenter/record.cfm?id=184489>
http://www.construction-institute.org/services/catalog/more/ir171_2_more.cfm

Method 28

Standardization of design components

Description

Repeatedly-used components should not have to be redesigned everytime. Increased levels of standardization can eliminate the "reinvention of the wheel" by designers. Even though all project are unique, standard designs can be used and tailored to each project's needs.

Pros (+) / Cons (-)

- + Design time & effort could be reduced
- + Materials management efforts could be made easier
- Catalogs of standard components will have to be maintained
- Competitive supplier agreements will be needed

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Approaches

Innovative Planning and Design Phase

Applicability / Limitations

- A standard handbook may be needed in order to increase levels of design component standardization
- Design software would need to be developed

Method 29

Generate and evaluate multiple Traffic Control Plans (TCP's)

Description

Traffic Control Plans drive both the project schedule and the impact of construction in traffic operations. Multiple TCP approaches should be analysed during design, as opposed to the current habit of starting construction on the first workable TCP. There should be vigorous analysis in order to carefully arrange signs, barricades, delineators, flashing arrow boards, cones and traffic control persons to clearly direct and control the flow of traffic with little interruption to the normal flow while decreasing the traffic hazards to workers.

Pros (+) / Cons (-)

- + Optimal TCPs can lead to reductions in both construction cost and user costs
- More thorough TCP analysis may require larger consultant fees for their development

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Approaches

Workzone Traffic Control

Applicability / Limitations

- TCP solutions for small simple jobs are often apparent, but otherwise they should be thoroughly investigated earlier in the process

Method 30

Develop a descriptive catalog of construction technologies that facilitate expedited schedules

Description

Identify new time-saving construction technologies and assess them for their potential impact and use. Developing a catalog would be a good way to keep a database of these innovative technologies.

Pros (+) / Cons (-)

- + An on-line catalog could easily be accessed and supported by FHWA and other states
- Maintenance & upkeep of the catalog will entail effort

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Approaches

Innovative Software / Database
Information Technology
Innovative Management

Applicability / Limitations

- Applicability of new technologies could be widespread, but DOT specs may be affected

Method 31

Develop Traffic Control Plans (TCPs) through partnering between DOT design and field organizations

Description

The DOT and contractor should partner to develop TCPs in order to lead to a more schedule-efficient approach and to more efficient design and construction.

Pros (+) / Cons (-)

- + Win-win TCPs may result from this approach
- Timing of construction involvement in this may be problematic

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Approaches

Innovative Planning and Design Phase
Innovative Contracting
Workzone Traffic Control

Applicability / Limitations

- TCPs are often an integral part of a project design. Waiting until a construction firm is signed on to develop a partnered-TCP may be too late

Method 32

Have contractor prepare the Traffic Control Plan (TCP) based on minimum requirements

Description

Reduce constraints on the contractors by allowing- or requiring- them to develop an acceptable TCP before the start of field construction.

Pros (+) / Cons (-)

- + Reduction in efforts
- + Will provide incentive for construction innovation
- Possible increase in costs
- Possible exclusion of impact on local businesses
- Contractor compliance with safety standards may be challenging (for DOT)

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Approaches

Innovative Planning and Design Phase
Innovative Contracting
Workzone Traffic Control

Applicability / Limitations

- This approach will encourage contractor innovation, but may be possible only on smaller, simpler projects

Method 33

Pre-qualify bidders on basis of past schedule performance

Description

Eliminate the bidders with a poor record of schedule performance. The DOT should consider a contractor's past schedule performance and quality of work when awarding the contract.

Pros (+) / Cons (-)

- + Shorter and easier selection process
- + Possibly better contractors
- Reduces the competition
- Schedule performance data will need to be well kept
- DOT & other non contractual schedule impacts will have to be recognized and equitably settled

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Approaches

Innovative Contracting

Applicability / Limitations

- Key items for the selection are:
- specific project type experience
 - individual experience
 - past performance
 - capacity of firm
 - primary firm location

Method 34

Incentivize TCP development with a contractor Value Engineering (VE) cost-savings sharing provision

Description

Utilize the VE change proposal contractual clause with special emphasis on time-saving or duration-reducing innovations on TCPs.

Pros (+) / Cons (-)

- + Leads to innovative ideas for successful TCPs
- Savings are difficult to estimate

Approaches

Innovative Contracting
Workzone Traffic Control

Applicability / Limitations

- Seek involvement of local municipalities in funding the incentive (e.g. 5% of estimated user cost savings)
- Requires close scrutiny to determine actual time savings

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 35

Increase amount of liquidated damages and routinely enforce

Description

Liquidated damages are the certain amount of money taken away from a contractor's payment for each delayed time unit. This punishment due to the contractor's delayed performance can be used in conjunction with incentives to improve project speed.

Pros (+) / Cons (-)

- + Motivate better contractor performance
- Requires rigorous documentation and quick Request for Information (RFI) response to enforce

Approaches

Innovative Contracting

Applicability / Limitations

- Just as important as the damages happening in the contract are the claims made for damages. The time and effort involved in pursuing these claims is however, a limitation. This should be weighed against potential benefits
- Possibly provide incentives to finish projects ahead of time

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 36

A+B Bidding/Contracting

Description

A+B bidding is a Cost + Time bidding procedure that incorporates the lowest estimated cost of construction and the cost of time to complete the project. In other words, the contract is awarded to the bidder with the lowest overall combined bid of the work itself (A) and how soon they believe they can complete the work (B).

Pros (+) / Cons (-)

- + Consideration of the time component of a construction contract
- + Favorable treatment of contractors with the most available resources to complete the project
- + Incentives for contractors to compress the construction schedule
- + Greater potential for early project completion
- Incentives & disincentives need to be carefully managed
- Costs are concrete whereas benefits are distributed to the public

Approaches

Innovative Contracting
Innovative Planning and Design Phase

Applicability / Limitations

- A+B bidding can be used to motivate the contractor to minimize the delivery time for high priority and highly trafficked roadways
- There must be a balance between the benefits of early completion and any increased cost of construction
- Approach requires incentives & disincentives to be effective

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
<http://www.tfsrc.gov////////focus/aug02/02.htm>
http://ops.fhwa.dot.gov/wz/workshops/originals/Stuart_Thompson.ppt

Method 37

A+B+Quality Bidding/Contracting

Approaches

Innovative Contracting
Innovative Planning and Design Phase

Description

A+B+Quality bidding is a Cost + Time + Quality bidding procedure that incorporates the estimated cost of construction, the cost of time to complete the project, and the quality to be achieved. In other words, the contract is awarded to the bidder with the lowest overall combined bid of the work itself (A), how soon they believe they can complete the work (B), and the level of quality they guarantee to perform (C). Quality does not affect the bid price, but if the contractor fails to achieve the set level of quality promised, he will receive a disincentive such as a reduction in his payment.

References

<http://gulliver.trb.org/publications/millennium/00023.pdf>

Method 38

A+B+Lifecycle Cost Contracting

Approaches

Innovative Contracting
Innovative Planning and Design Phase

Description

A+B+Lifecycle bidding is an Initial Cost + Time + Lifecycle Cost bidding procedure that incorporates the estimated cost of construction, the cost of time to complete the project, and the life cycle cost adjustment. In other words, the contract is awarded to the bidder with the lowest overall combined bid of the work itself (A), how soon they believe they can complete the work (B), and the lifetime maintenance and user delays cost (C).

References

http://louisiana.construction.com/features/archive/0307_cover_Future.asp

Method 39

A+B+Safety Contracting

Approaches

Innovative Contracting
Innovative Planning and Design Phase

Description

Besides Cost and Time, safety of workers is considered as a factor when appraisal of the bid proposal.

References

<http://gulliver.trb.org/publications/millennium/00023.pdf>

Method 40

A+B+Past Performance Contracting

Approaches

Innovative Contracting
Innovative Planning and Design Phase

Description

Besides Cost and Time, past performance of the contractor is considered as a factor when appraisal of the bid proposal.

References

<http://gulliver.trb.org/publications/millennium/00023.pdf>

Method 41

A+B+I/D (Incentive/Disincentive) Contracting

Approaches

Innovative Contracting
Innovative Planning and Design Phase

Description

The contractor is financially rewarded for on time delivery of specific work tasks (plus the additional requirement in the contract, such as quality, warranty). Otherwise, the contractor will receive a financial punishment accordingly.

References

<http://gulliver.trb.org/publications/millennium/00023.pdf>

Method 42

Packaged multi-primes approach to contracting

Approaches

Innovative Contracting
Innovative Management

Description

The owner acts as the "general contractor" by having several separate prime contracts. Each contract is for the performance of a particular portion of the total project work. This method could lead to reduction of indirect costs, but imposes more responsibility and requirements on the state.

Pros (+) / Cons (-)

- + Increased competition among construction bidders
- + Reduced pyramiding of costs, particularly overhead and profit
- + Reduced project time through overlap of design and construction or from multiple work forces
- + More direct control by the project owner
- Interface management challenges for DOT
- Physical interferences between contractors

Applicability / Limitations

- Can be used when a specific highway project is composed of several major segments or is very large

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 43

Incentivize contractor work progress with a lane-rental approach

Approaches

Innovative Contracting

Description

In order to minimize the time that roadway restrictions impact traffic flow, lane rental provisions are assessed. The contractor is subject to daily/hourly rental fees for each lane and shoulder taken out of service during a project. The lane-rental approach can be incorporated into cost plus time (A+B) contract clauses.

Pros (+) / Cons (-)

- + Leads to innovative ideas for successful TCPs
- + Minimizes contractor impact on traffic
- Not easy to administer

Applicability / Limitations

- Must be explicitly described in the bid package
- Rental rates have to be significant and should address high impact lanes

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

http://ops.fhwa.dot.gov/wz/workshops/originals/Stuart_Thompson.ppt

Method 44

Tool & best practices for implementing multiple work shift and/or night work

Approaches

Innovative Field Methods
Workzone Traffic Control

Description

This method pays attention to safety and implements night TCPs in order to improve project speed. Contrary to typical daytime work zones, the traffic control used for night work uses multiple work shifts. The NCHRP Report 475 provides a comprehensive, quantitative basis for selecting the most cost-effective plan for ensuring the safety of the public and workers, maintaining capacity, minimizing the impact on the community, and getting the work completed on schedule.

Pros (+) / Cons (-)

- + Increased safety for road users and workers
- + Reduced user costs
- + Faster completion time
- Research and design costs

Applicability / Limitations

- New technologies (such as intrusion alarms), modified traffic control plans, and new methods to monitor traffic can potentially provide improvements in night work zone safety
- These improvements will lead to higher nighttime productivity

References

- http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
- <http://www.dot.wisconsin.gov/library/research/docs/tsrs/tsrnighttimeconstruction.pdf>
- http://gulliver.trb.org/publications/nchrp/nchrp_rpt_475.pdf

Method 45

Warranty performance bidding

Description

A warranty is an assurance that a product will serve its useful life and that if it does not, the contractor will replace the product or pay to return it to its proper condition. The constructor assumes more post construction risk than in traditional methods. He/she is responsible for the quality and performance of the work for a specific “warranty period.” The length of warranty can be incorporated into cost plus time (A+B) contract clauses.

Pros (+) / Cons (-)

- + Usually results in a better quality product and therefore longer time between renovations
- + Encourages innovation by the contractor
- + Reduces the needs for agency resources
- Contractors bid higher to offset increased risk

Approaches

Innovative Contracting

Applicability / Limitations

- Performance specifications must be well developed
- If contractor goes out of business, who pays?

References

- http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
- [http://ops.fhwa.dot.gov/wz/workshops/originals/Stuart Thompson.ppt](http://ops.fhwa.dot.gov/wz/workshops/originals/Stuart%20Thompson.ppt)

Method 46

Using the e-commerce system: project-specific web sites

Description

E-commerce systems, such as project-specific web sites, can be used for procurement and employment to improve document management, communication, and project speed.

Pros (+) / Cons (-)

- + Faster processes
- + Improved document management and tracking
- New technology raises new concerns about security, reliability, and data integrity
- Requires organizational changes and learning

Approaches

Information Technology
Innovative Software / Database

Applicability / Limitations

- Hidden behind the technology's promise of greater efficiency, accountability, and speed are traditional issues of contract formation and enforcement, project relationships, and assessment of liability

References

- http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 47

Exploit web-based team collaboration and project management system: Common e-Rooms

Description

Common e-Rooms are web-based project management systems that speed the construction process by improving communication. They are basically web-based file managers that enable the users to share files, vote on issues, and chat with each other. They also enable teams to share ideas and information, make and document decisions, capture and archive knowledge, tap and manage resources, create repeated templates for future projects, track changes, keep everything organized in one place, and learn what they need to work faster and smarter. e-Rooms enable business teams to produce better results, speed projects to completion on time and on budget, and empower companies to realize the benefits of increased speed, profits and competitiveness.

Pros (+) / Cons (-)

- + Enhances project communication
- + Eases collaboration with project managers, designers, contractors, vendors, and the public
- + Everyone is kept in the loop
- + Track project on-line – this minimizes time and enhances performance

Approaches

Innovative Management
Information Technology
Innovative Software / Database

Applicability / Limitations

- To be efficient, access to information is needed quickly and without hassle. Web based system can be used to
 - track project deliverables – track project tasks on-line; receive email alerts as items become due
 - share documents – reduce administrative

- + High installation and learning costs
- + Unstable interfaces
- Lack of standards

document production and delivery costs by uploading documents. This is handy for CAD drawings or anything else that needs to be shared with the project team

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
http://www.gmtonline.com.my/solutions/eroom/support/about_eroom.htm

Method 48

Exploit web-based team collaboration and project management system: Web-based central project databases

Approaches

Innovative Management
 Information Technology
 Innovative Software / Database

Description

Web-based central project databases are web-based project management systems that speed the construction process by improving communication. They are technologically advanced web-based software systems that promote project management and communications management for complex public projects. Web-based project systems support critical tasks within project management, notably project scheduling, project controls and general communication among all the project participants. Some examples are Buzzsaw.com, Constructware.com, and e-Builder.com, but go to constructionrisk.com's project management directory for more.

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
http://www.lsgallegos.com/web_based_services.htm
<http://www.constructionrisk.com/projectmanagement.htm>

Method 49

“No Excuse” incentives

Approaches

Innovative Contracting
 Innovative Planning and Design Phase

Description

The constructor is given a "firm delivery date" with no excuses for missing this date. There are incentives for early completion but there are no disincentives other than normal liquidated damages.

Pros (+) / Cons (-)

- + This method can result in considerable improvements in schedule performance
- Transfers risk to contractor and therefore may increase costs on the average over time

Applicability / Limitations

- Precludes delay claims by contractors
- Gives contractor incentives to finish early
- Requires a realistic schedule

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
http://nisee.berkeley.edu/northridge/highway_bridges_part3.html

Method 50

Change management practices

Approaches

Innovative Management
 Innovative Software / Database

Description

This method identifies how changes will be handled, who should be informed, and alternatives to changes. Also, it records the effect of the change on the overall project, including the schedule. New software is being developed to expedite the manager's duties.

Pros (+) / Cons (-)

- + More efficient handling of changes in the construction environment and therefore faster delivery
- Training and implementation costs

Applicability / Limitations

- There are many tools available to help project teams to be adept at handling change management
- Planning and managing change is one of the most challenging elements of any project
- Understanding the key areas of change management and the associated traps and pitfalls is critical to project success

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

Method 51

Shorten construction time by full closure instead of partial closure of roadway

Description

Closing the roadway completely instead of partial closure can increase efficiency and decrease project duration significantly. It frees up space and reduces interferences.

Pros (+) / Cons (-)

- + Shortens construction time
- Possible traffic congestion on alternative routes

Approaches

Workzone Traffic Control
Innovative Field Methods

Applicability / Limitations

- Full closure could be used in areas where there is at least one alternative route for drivers and where volume is limited

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
<http://www.fhwa.dot.gov/construction/fs01023.htm>
http://www.wsdot.wa.gov/Regions/Northwest/paffairs/NewsReleases/MC03_HOVLanesOpenJan15.htm
<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

Method 52

When doing concrete redecking of a bridge, place the deck in a continuous pour

Description

To save time and produce a uniform deck and smooth ride, place the deck in a continuous pour for the concrete redecking of a bridge. This originally required several separate placements.

References

<http://199.79.179.82/sundev/detail.cfm?ANNUMBER=00750549>

Approaches

Innovative Field Methods

Method 53

Maturity testing

Description

By considering the speed to reach strength and lost opportunity costs, maturity testing helps with the concrete placement options and with the concrete placement cost. Knowing more rapidly when the specified strength is attained allows the project to proceed more quickly.

Pros (+) / Cons (-)

- + Cost and schedule savings
- + Improves reliability of mixes chosen
- Reluctance of contractors to implement

Approaches

Automation Equipment / Construction Technology
Innovative Field Methods

Applicability / Limitations

- Any new concrete pavement construction or rehabilitation projects
- Special software requirements for the contractors

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf
<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

Method 54

Employ methods for continuous work zones

Description

Larger work zones can be developed in the TCP and result in lower unit costs and schedule compression since the relative impacts of mobilization and demobilization are reduced. While the corridor approach recommends designing longer roadways by one company, this approach recommends building longer workzones.

Pros (+) / Cons (-)

- + Decrease duration and unit costs
- + Safer
- May result in higher user costs and traffic congestion

Approaches

Workzone Traffic Control
Innovative Field Methods

Applicability / Limitations

- Can be used where road geometry and weekend or night scheduling permit

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 55

Use of windowed milestone

Description

Windowed milestones provide more flexibility in scheduling and lead to improved project speed. They are milestones with float within a window that do not artificially constrain a schedule.

Pros (+) / Cons (-)

- + Lowers project costs
- + Possibly lower user costs
- Reduces ability to “hold contractor’s feet to the fire”

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 56

Use pilot demonstration projects for introducing new methods for expediting schedules

Description

A pilot study testing new expediting methods should be used to aid the transition process. Lessons can be learned from the application to smaller projects, and wider acceptance of the methods will be achieved.

Pros (+) / Cons (-)

- + Eases the transition process
- + Leaves open the option implement
- + Costly experiment
- + Not proof of effectiveness
- A poor demonstration second chance

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 57

Train selected field personnel in scheduling methods and scheduling claims

Description

Trained personnel can assess schedule impacts and make good decisions to expedite schedule performance and make more effective and realistic time estimates.

Pros (+) / Cons (-)

- + Flexible and quick-to-adapt project team
- + Faster project completion
- Possibly too many people trying to manage

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Approaches

Innovative Planning and Design Phase
Innovative Management

Applicability / Limitations

- Can be used where milestone dates are not based on hard constraints. Milestones should be related to allow contractor maximum flexibility in efficiently allocating project resources

Approaches

Information Technology
Innovative Management
Innovative Planning and Design Phase

Applicability / Limitations

- The benefits/limitations of the new methods can be analyzed and a lessons learned database developed for future improvements
- A demonstration project may improve confidence and may be a good learning experience, but it seldom proves that a new method is advantageous
- A well known phenomenon in business experiments is that an observed change leads the participants to feel special and perform accordingly. The improvement may not persist

Approaches

Information Technology
Innovative Management
Innovative Planning and Design Phase

Applicability / Limitations

- Schedule flexibility may be minimal in practice, but for complex jobs a broad understanding of scheduling issues should help expedite progress

Method 58

Annual-based incentive program to measure and track project schedule performance

Description

Annual evaluations or direct incentive and compensation programs of the owner and contractor will improve project schedule performance and result in faster delivery schedules.

Pros (+) / Cons (-)

- + Works in simple lump sum contracting situations in the private sector and is a motivator
- + Difficult to implement fairly
- May encourage negligent or counterproductive behavior

Approaches

Innovative Contracting

Applicability / Limitations

- Changes would have to be made via DOT's HR department and balanced with other aspects of project performance
- Consideration would have to be given to conditions beyond employee's control

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 59

Track duration & productivity effects associated with different technologies

Description

For qualification-based bidding and best-value bid awards, a database of duration and productivity associated with different technologies is useful in deciding on the best technologies to be used on future projects.

Pros (+) / Cons (-)

- + Quicker and more dependable exploitation of new technologies

Approaches

Information Technology
Innovative Software / Database

Applicability / Limitations

- Data collected can be very useful in cost and time estimation for optimal plans
- Technology choices may be limited, however, by project conditions and logical equipment spreads

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 60

Create a "smart" database of activity productivity rates

Description

A database of productivity rates of different construction methods is useful in providing scheduling on future projects and leads to more realistic schedule targets.

Pros (+) / Cons (-)

- + More accurate estimation of duration and cost of future projects
- Complexity and cost to maintain

Approaches

Information Technology
Innovative Software / Database
Innovative Planning and Design Phase

Applicability / Limitations

- Data collected can be very useful in cost and time estimation

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 61

Study optimal approaches to crew shifts and scheduling

Description

In order to maintain productivity and the rate of progress, optimization of crew shifts and scheduling should be studied carefully, especially for overly long work weeks and/or night work.

Pros (+) / Cons (-)

- + Possible cost savings

Approaches

Innovative Management
Innovative Planning and Design Phase

Applicability / Limitations

- The schedule can be shortened through use of

- + Increase in productivity
- + Reduction in cycle time of tasks improves schedule
- + Careless planning may create negative results
- Contractor must implement

additional crews on regular shift, multiple shifting, or selective overtime

- Scheduled overtime can be used where appropriate but effects should be evaluated carefully

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 62

Create a lessons-learned database on ways to expedite schedules

Description

A database of lessons-learned on ways to expedite schedules for all phases of the project can be a key tool in deciding which methods to used on future projects.

Pros (+) / Cons (-)

- + Quick reference for implementation of expediting measures
- Must be maintained

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Approaches

Innovative Software / Database

Applicability / Limitations

- This would be broadly applicable but limited by legal and policy constraints

Method 63

Incentive-based pay for retaining key STA personnel

Description

Retention of personnel and their expertise and organizational knowledge is a key to overall project time performance. Performance of project teams is enhanced with experienced and skilled personnel.

Pros (+) / Cons (-)

- + Enhances project performances owing to a more cohesive team.
- Requires additional funding and institutional commitment

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Approaches

Innovative Contracting

Applicability / Limitations

- Measures to retain key personnel should be implemented. Experience and institutional knowledge of these people is valuable; however, some with great experience may be resistant to constructive change

Method 64

Perform faster inspection and construction monitoring: Software used for cable-stayed bridge

Description

Once the project has been built, it usually takes a while for it to be accepted by the inspectors before opening to the public. The inspection process can be accelerated with an innovative high-speed process to make sure the overall quality is obtained without delaying the project. Software is being tested on a cable-stayed bridge project.

References

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

Approaches

Innovative Field Methods

Automation Equipment / Construction Technology

Innovative Software / Database

Method 65

Perform faster inspection and construction monitoring: Laser to monitor steel erection

Description

Once the project has been built, it usually takes a while for it to be accepted by the inspectors before opening to the public. The inspection process can be accelerated with an innovative high-speed process to make sure the overall quality is obtained without delaying the project. Laser is being tested to scan monitoring of ongoing

Approaches

Innovative Field Methods

Automation Equipment / Construction Technology

Innovative Software / Database

steel erection for early defect detection.

References

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

Method 66

Approaches

Facilitate an innovative and equitable contracting environment Innovative Contracting

Description

It is expected that agencies will be transferring more responsibilities to consultants and contractors in the future. This requires new strategies and cooperation among the various interests.

References

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

Method 67

Approaches

Improve traffic flow in work zone: Law enforcement Workzone Traffic Control

Description

There is a need to move traffic quickly and safely through construction work zones. To do so, the contractor could use law enforcement to slow down the speed of vehicles. There are three different ways to use law enforcement in a construction workzone. First, using a stationary patrol car, which is a marked patrol car parked in side of road parallel to traffic with/without flashing red. It can also be a marked patrol car parked on side of road perpendicular to traffic with radar on and pointed toward traffic stream. A circulating patrol car can also be used. It is a marked patrol car continuously driven back and forth through work zone. Finally, a police traffic controller can be used. It is a uniformed officer standing on side of road next to speed sign and manually motioning traffic to slow down.

References

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

"Transportation Research Record" 1035 Page 66 to 77

Method 68

Approaches

Performance related specifications for new technologies Innovative Contracting

Description

Establish the specification to let contractor establish their own specifications according to their experience and strength.

References

Strategic Highway Research Special Report 260

Method 69

Approaches

Using prestressed concrete panels for expediting pavement construction Innovative Field Methods

Description

Using prestressed concrete panels can expedite pavement construction. The concept for a precast prestressed pavement includes three types of precast panels: joint panels, central stressing panels and base panels. Some benefits of precast concrete over conventional cast-in-place pavement construction include rapid construction and increased durability.

References

<http://199.79.179.82/sundev/detail.cfm?ANNUMBER=00941135>

Method 70

Approaches

Using geosynthetic-reinforced and pile-supported earth platforms for embankments, retaining walls, and storage tanks constructed on soft soils Innovative Field Methods
Innovative Materials

Description

Geosynthetic-reinforced and pile-supported earth platforms are an economic and effective solution for

embankments, retaining walls, and storage tanks constructed on soft soils, especially if rapid construction and/or strict deformation of structures are called for.

References

<http://199.79.179.82/sundev/detail.cfm?ANNUMBER=00823120>

Method 71

Approaches

Using post-tensioning in precast elements of bridges to provide durability and structural benefits to the system while expediting the construction process Innovative Field Methods

Description

The use of post-tensioning in bridges can provide durability and structural benefits to the system while expediting the construction process. When post-tensioning is combined with precast elements, traffic interference can be greatly reduced through rapid construction. Post-tensioned concrete substructure elements include bridge piers, hammerhead bents, and straddle bents.

References

http://www.utexas.edu/research/ctr/pdf_reports/1405_2.pdf

http://www.utexas.edu/research/ctr/pdf_reports/1405_5.pdf

Method 72

Approaches

Construct composite bridges with light weight composites and prefabricated elements Innovative Materials

Description

Bridges with high content of light weight composites and the use of prefabricated elements can make for rapid construction. For example, long cable-stayed composite bridges with carbon-fiber-reinforced polymer composites can be made of glass and carbon hybrid transverse girders, glass-fiber-reinforced polymer decks, and carbon and aramid fiber cable stays.

References

<http://199.79.179.82/sundev/detail.cfm?ANNUMBER=00759647>

Method 73

Approaches

Develop two sets of standard sections and details for precast double-T beams for short-span bridges for use with a non-composite asphalt wearing surface as a viable alternative to voided slabs Innovative Materials
Innovative Field Methods

Description

The current standard for precast short-span bridges (span lengths from 25 to 60 ft) is to use voided slabs. Details for rapid construction of double-T beam systems used with asphalt wearing surfaces include 1) standard precast prestressed beams, 2) grouted longitudinal shear keys, 3) transverse post-tensioning of the beams through their flanges, 4) precast post-tensioned diaphragms, 5) waterproofing membranes, and 6) fixed and expansion supports. It is concluded that 20 to 30% savings in materials may be possible if the proposed beams are used instead of the current voided slabs.

References

<http://199.79.179.82/sundev/detail.cfm?ANNUMBER=00753950>

Method 74

Approaches

Inform the public before and during construction Public Involvement / Increased Awareness
Information Technology
Workzone Traffic Control

Description

By informing the public about the highway construction project and suggesting detours, the traffic flow through the work zone may be alleviated. When informed ahead of time, the public can plan to use alternative routes and therefore cause less congestion through the construction site.

References

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

Method 75

**Use of automated construction technology:
Geographical Positioning Systems**

Approaches

Automation Equipment / Construction Technology
Information Technology
Innovative Field Methods

Description

Geographical Positioning Systems result in faster and higher quality construction operations.

Pros (+) / Cons (-)

- + Can result in savings
- + Opportunity for significant schedule compression
- Some training required
- Contractor required to implement

Applicability / Limitations

- Numerous research and implementation efforts are currently underway to automate conventional infrastructure construction, condition assessment, and maintenance activities such as earth moving, compaction, road construction and maintenance, and so forth
- Commercial systems are available from companies such as Trimble/Spectra-Physics

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

Method 76

Use of automated construction technology: Laser-based positioning systems

Approaches

Automation Equipment / Construction Technology
Information Technology
Innovative Field Methods

Description

Laser-based positioning systems result in faster and higher quality construction operations. Currently positioning in the construction industry is achieved using theodolites, levels, total stations, and chains or tapes. These current methods are laborious, time consuming, expensive and are susceptible to errors in collecting, transcribing and reducing data. A new real-time laser-based positioning system can be linked to CAD and other database applications so that the data can be effectively transformed into useful information to help guide project activities. The system itself is made up of two transmitters and a receiver. All that is needed for the system to self-calibrate and function is the known location of four points. Once calibrated any point may be found within the working envelope of the receivers.

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

http://www.sv.vt.edu/classes/ESM4714/Student_Proj/class94/spsi/spsi.html

Method 77

**Use of automated construction technology:
Compaction using automatic vibration control system**

Approaches

Automation Equipment / Construction Technology
Information Technology
Innovative Field Methods

Description

Automated compaction results in faster and higher quality construction operations. A compactor with automatic vibration control system automatically selects the correct amount of vertical vibration needed to concentrate compaction on multiple passes of a newly laid pavement. On the initial pass, the system automatically sets vertical vibrations for deep and fast compaction then it adjusts the horizontal-to-vertical movement ratio when the operator reverses the roller's direction. With this automatic fine-tuning feature, the roller's impact can be adjusted so that the machine's performance can be matched to constantly changing conditions of the increasingly compacted surface, thus improving work efficiency and quality.

References

http://www.utexas.edu/research/ctr/pdf_reports/4386_1.pdf

<http://gulliver.trb.org/publications/circulars/ec017.pdf>

Method 78

GPS Controlled Production: Computer-aided earthmoving system

Approaches

Automation Equipment / Construction Technology
Information Technology

Description

Caterpillar's Computer Aided Earthmoving System (CAES), a joint development between Caterpillar and Trimble Navigation, is a differential GPS-based system offering extremely precise realtime machine position monitoring. This capability enables precision control, monitoring, and recording of grades/slopes and compaction passes. Advances in computer systems, computational geometry algorithms, and location systems have made computer-aided earthmoving feasible. Compared with traditional techniques, computer control should cut the cost of earthmoving by 50-75%. The three principal components are a central computer system that maintains design data and directs operations, a location system that can determine the position of earthmoving vehicles in real time, and on-vehicle computers that assist the operator and/or directly control implements.

References

ARTBA Transportation Builder, Sept 2003 Smart Construction edition

http://www.cat.com/services/shared/technology_products/pdf/swana_landfill_symposium2001.pdf

<http://philip.greenspun.com/research/tr1408/intro.html>

http://www.cat.com/products/shared/technology_products/pdf/morenci_ion_paper.pdf

http://www.caterpillar.com/products/shared/technology_products/pdf/caes_improves_safety_at_kcgm.pdf

Method 79

GPS Controlled Production: GPS-based grade control system (i.e. SiteVision)

Approaches

Automation Equipment / Construction Technology
Information Technology

Description

Trimble's SiteVision GPS system allows construction professionals to significantly increase productivity and efficiency in a stakeless environment as well as improving the profitability of the project. It is a revolutionary earthmoving grade control system that puts design surfaces, grades, and alignments inside the cab. Using precise GPS technology, the SiteVision GPS system allows machine operators to accurately (within 0.1 ft) perform earthmoving operations for highway and road construction using either automatic or manual blade control. Finishing is faster, more efficient, and more predictable.

References

ARTBA Transportation Builder, Sept 2003 Smart Construction edition

http://www.seilerinst.com/images/pdf/gps/tn_sitevis.pdf

http://www.cif.org/Nom2002/Nom21_02.pdf

Method 80

GPS Controlled Production: Laser-based grade control system (i.e. GCS21)

Approaches

Automation Equipment / Construction Technology
Information Technology

Description

The Trimble GCS21 Grade Control System is a highly flexible, configurable system for machine guidance and machine control. This advanced "plug and play" laser-based system is easy to use and can be configured with a range of laser receivers and control options. Ideal for a range of construction earthwork applications and machines, including dozers, scrapers and motorgraders, the GCS21 reduces rework and operating costs to improve profitability. Using the AutoBench feature, operators can automatically set the ongrade position on the receiver and get to grade faster and more precisely than usual with the ability to make as small as 1-millimeter adjustments to the blade elevation. Note that Topcon is also developing high accuracy, high speed, site-plan-based grade control.

References

ARTBA Transportation Builder, Sept 2003 Smart Construction edition

<http://www.laserlineontario.com/GSC21brochure.pdf>

http://www.topconmc.com/images/PDF/3DMC_Broch.pdf

Method 81

GPS Controlled Production: Automated compaction

Approaches

Automation Equipment / Construction Technology
Information Technology

Description

An automated compaction monitoring system using differential GPS technology allows operators to monitor the actual number of passes done by the compactor. In order to get real-time positioning information, two GPS receivers are utilized, one as a static base station and the other is placed on the compactor. Once the device records positioning information of the compactor, the real-time positioning information is then transmitted to a remote computer, through an appropriate wireless technology. The software displays the areas covered by colors, based on the calculation of the direction of motion and the number of drums. From this, the operator can proceed to compact until all surface locations reach a specific color on the screen.

References

<http://gulliver.trb.org/publications/circulars/ec017.pdf>

Method 82

Using lean production management

Approaches

Innovative Management

Description

Lean Construction is a production management-based approach to project delivery - a new way to design and build capital facilities. It changes the way work is done throughout the project delivery process to maximize value and minimize waste. In Lean Construction, the facility and its delivery process are designed together to better reveal and support customer purposes. Positive iteration within the process is supported and negative iteration reduced. Efforts to manage and improve performance are aimed at improving total project performance because it is more important than reducing the cost or increasing the speed of any activity. Lean Construction challenges the belief that there must always be a trade between time, cost, and quality.

References

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

<http://www.leanconstruction.org>

Method 83

Using smart chip technology (RFID tags)

Approaches

Information Technology
Automation Equipment / Construction Technology

Description

By embedding smart computer chips into materials and equipment, a contractor is able to track their placement on a worksite and locate them rapidly. By knowing the on-site inventory at all times, one is able to make sure that all tools and equipment are available before the beginning of a task.

References

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

Method 84

Use InfoTech's FieldManager

Approaches

Innovative Software / Database
Innovative Management
Information Technology

Description

InfoTech's FieldManager is a Sybase project management application used to speed and simplify the completion of road and bridge construction projects. It allows for advanced user support through the ability to connect to various data sources. The FieldManager software also enables mobile workers to enter and access information using a laptop computer, synchronizing all changes with the organization's back-end database. Using this mobile solution, DOT technicians can automatically generate payment estimates on-site, providing more timely and accurate invoicing. This ensures that construction managers work as effectively in the field as in their office.

References

<http://www.govtech.net/news/news.phtml?docid=2003.08.20-64951>

Method 85

Using 3D laser scanning

Approaches

Information Technology

Automation Equipment / Construction Technology

Description

In order to give the most updated information to the project manager, laser scanning can be used to document project status by indicating the real-time progress.

References

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

Method 86

Application of 3D Machine Automation on Asphalt Pavers

Approaches

Automation Equipment / Construction Technology

Description

Installing 3D machine automation system on asphalt pavers could yield faster, easier, and more precise paving, automatic height control, and cross-slope regulation. Height accuracy could be controlled within 1/5 of an inch. Continuous paving is possible using a second Total Station.

References

<http://construction.leica-geosystems.com/products/3d-machine-control/>

Method 87

Innovative paver

Approaches

Automation Equipment / Construction Technology

Description

An innovative design in paver is to rolling of asphalt may be completed by one pass of single high-performance compactor, or at the rear of an asphalt paver by an attached plate. Caterpillar's new high-production asphalt roller line features a new compaction technology called "Versa Vibe", in which drum vibration is achieved by rotating an unbalanced shaft mounted in a sealed housing inside each drum. The technology permits the operator to match the machine's vibratory system to a wide range of applications, including high frequency compaction.

References

ARTBA Transportation Builder, Sept 2003 Smart Construction edition

Method 88

Robotic Paving Machine

Approaches

Automation Equipment / Construction Technology

Description

This machine uses machine-vision image processing routines to follow the curb or a chalk line to control its screed and steering. The vision sensor detects the edge of the curb by using a laser beam that hits the curb at an angle. It can follow a chalk line by detecting the difference between bright and dark values in the image. There is an audible alarm that rings if a person is between the paver and the dump truck during its material feeding mode. The screed position and paving thickness are controlled by a computer system which uses feedback from the solenoids and other sensors to maintain a uniform finish.

References

<http://gulliver.trb.org/publications/circulars/ec017.pdf>

Method 89

Pavers with Non-Contacting Sensors

Approaches

Automation Equipment / Construction Technology

Description

Automatic paving systems using non-contacting sensors are currently being used in the paving industry. For example, PAVER SYSTEM FOUR can be mounted and installed in any existing paver. It is composed of two control boxes, two Sonic Tracker™, and a slope sensor. The Sonic Tracker is used to control elevation by measuring the distance to a physical reference using sound pulses, as in sonar sensors. The slope sensor includes a precision electronic device. Once the slope sensor is tilted, an electronic signal is generated. By measuring this electronic signal, the slope sensor can precisely calculate the slope of the screed. During paving operation, the components work together to determine the screed's position relative to desired grade and generate correction signals to keep the screed on grade.

References

<http://gulliver.trb.org/publications/circulars/ec017.pdf>

Method 90

Automated Reflective Pavement Marker Placing

Description

The user of the equipment uses a remote video system to view the road surface and selects the position for marker placement by moving the cursor to the desired location. A coordinate transformation converts the cursor position into the workspace position and the marker is installed. This machine is at the prototype stage.

References

<http://gulliver.trb.org/publications/circulars/ec017.pdf>

Approaches

Automation Equipment / Construction Technology

Method 91

Robotic Excavation and Pipe Laying

Description

A real-time graphical programming model was developed for a manipulator used for excavation and pipe laying. It used a long-range, 3-D positioning system to give the operator of the equipment its exact position in a real-time CAD simulation. The laser-based positioning sensors were on the cabin of the excavator and the position of the end-effector was obtained from encoders on the joints. Thus, one can change to any viewing angle and any amount of zooming within the simulation to precisely see the progress of the excavation. A metal detector for sensing buried utility lines was installed and provided the user with a warning signal when lines were detected. The user interface with the excavator can be accomplished with remote joysticks, which allow the operator to be at a safe distance from a hazardous environment. This system is in a field prototype system.

References

<http://gulliver.trb.org/publications/circulars/ec017.pdf>

Approaches

Automation Equipment / Construction Technology

Method 92

Automated Earth Moving System

Description

In the Pentagon's Technology Reinvestment Project's first round of awards, a team including Magnavox Electronic Systems Co., Spectra-Physics Laserplane Inc., and the Army Corps of Engineers was awarded \$17,700,000 to develop (GPS) and laser technology to control earth-moving equipment blades. The team promised earth moving "to accuracy of half an inch" without site and topographic surveys. A graphical interface is used in the control scheme that has been developed.

References

<http://gulliver.trb.org/publications/circulars/ec017.pdf>

Approaches

Automation Equipment / Construction Technology

Method 93

Computer Integrated Road Compactor (CIRCUM)

Description

The CIRCUM is based on the system architecture comprised of three subsystems. The role of the ground subsystem is to provide the compactor with geometric data about the worksite, coming from CAD data, as well as guidelines for operation, and to compute compacting results and some statistics about the work achieved. The role of the positioning subsystem is to locate precisely and in real-time the compactor by using GPS, in real-time kinematic (RTK) mode as well as dead reckoning sensors (Doppler radar, encoder and fiber-optical gyrometer). The role of the onboard subsystem embedded on the compactor is to memorize and complete instruction data, position data, work done, and to manage a man-machine interface (MMI) which assists the driver in compacting. Other multi-compactors' functionalities are currently under development.

References

<http://gulliver.trb.org/publications/circulars/ec017.pdf>

Approaches

Automation Equipment / Construction Technology

Method 94

Approaches

Automated Vibratory Compaction Using Onboard Compaction Meter Automation Equipment / Construction Technology

Description

With an onboard compaction meter, the system operator can monitor the density of the soil on a continuous basis. A sensor is mounted on the vibrating drum to measure the reaction forces between the surface and the drum. An onboard computer then converts the reaction forces into a relative value, and displays this value on the console so that the system operator can easily monitor the density of the base material being compacted, and stop the compacting operation when a desired density level is achieved. As an upgraded version of this, Hamm Compactors Inc., provides a more expensive and sophisticated onboard compaction meter that allows the system operator to document compaction results for all passes being compacted, including more display information in the cab of the equipment.

References

<http://gulliver.trb.org/publications/circulars/ec017.pdf>

Method 95

Approaches

Compaction Using Automatic Vibration Control System Automation Equipment / Construction Technology

Description

A compactor with automatic vibration control system has been developed by Compaction America Inc. The system automatically selects the correct amount of vertical vibration needed to concentrate compaction on multiple passes of a newly laid pavement. On the initial pass, the system automatically sets vertical vibrations for deep and fast compaction. Then it adjusts the horizontal-to-vertical movement ratio when the operator reverses the roller's direction. With this automatic fine-tuning feature, the roller's impact could be adjusted so that the machine's performance can be matched to constantly changing conditions of the increasingly compacted surface, thus improving work efficiency and quality.

References

<http://gulliver.trb.org/publications/circulars/ec017.pdf>

Method 96

Approaches

Martec's AR2000 for Hot In-Place Recycling of Asphalt Pavement Innovative Field Methods

Description

Hot in-place recycling (HIR) is a rapid asphalt pavement construction process for rehabilitating deteriorated asphalt pavements. HIR recycling enables repaving to be 25-30% cheaper than traditional asphalt resurfacing systems and minimizes the disruption of traffic. Martec's AR2000 Super Recycler is a self-propelled equipment train, which could potentially save up to 30% in cost and 50% in time compared to conventional resurfacing methods.

References

<http://www.new-technologies.org/ECT/Civil/ar2000.htm>

Method 97

Approaches

Build the structure top-down in environmentally sensitive areas Innovative Field Methods
Innovative Planning and Design Phase

Description

When building in an environmentally sensitive area, build the precast bridge superstructure top-down from the deck to the water level, instead of the conventional ground-up approach, to minimize disturbance to the sensitive ecosystem.

References

<http://www.louisberger.com/berger/world/1999q2/abam.html>

Method 98

Minimize field fabrication effort

Approaches

Innovative Field Methods

Innovative Planning and Design Phase

Description

Minimizing the amount of construction and fabrication at the construction site will speed up the on-site construction that impacts traffic. Using sustainable materials, products, systems, and technologies that reduce life-cycle costs, extend useful life, and improve constructability will allow for short construction times. Prefabrication, modular, standardized, and roll-in strategies for bridges and pavements will reduce traffic disruption and improve the level of performance of the highway infrastructure.

References

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

Method 99

Perform faster inspection and construction monitoring: Microsensors embedded in concrete

Approaches

Innovative Field Methods

Automation Equipment / Construction Technology

Innovative Software / Database

Description

Once the project has been built, it usually takes a while for it to be accepted by the inspectors before opening to the public. The inspection process can be accelerated with an innovative high-speed process to make sure the overall quality is obtained without delaying the project. Microsensors are being developed to be embedded in concrete and other materials to infer levels of deterioration and corrosion. For example, the Fred Hartman Bridge in Texas was built with acoustic sensors on a cable-stayed bridge to detect wire fatigue breakages in cable and pinpoint them within a couple of feet.

References

<http://www.ctre.iastate.edu/research/detail.cfm?projectID=525>

9.2 Access Form Displaying Methods Identified by Literature Review

MAXIMIZE WINDOW!

States using Method

- Colorado
- New York
- North Carolina
- Utah
- Oklahoma
- Oregon
- Washington

Approaches

Innovative Contracting

References

http://www.utexas.edu/uteresearch/ctr/pof_reports/4386_1.pdf
<http://www.ctre.iastate.edu/uteresearch/detail.cfm?projectId=525>
<http://ops.fhwa.dot.gov/wz/workshops/originals/StuartThompson.ppt>

Graphics (.emf, .bmp, .rle, .dib, .wmf, .ico)

Method

Incentivize contractor work progress with a lane-rental approach

Description

In order to minimize the time that roadway restrictions impact traffic flow, lane rental provisions are assessed. The contractor is subject to daily/hourly rental fees for each lane and shoulder taken out of service during a project. The lane-rental approach can be incorporated into cost plus time (A+B) contract clauses.

Case Study

"Big I" in Albuquerque
Oregon:
- Major reconstruction of a 2.08 mile stretch of a primary commuter route from the west suburbs to downtown Portland.
- ADT ranges from about 100,000 to 130,000 vpd, with less than 2% trucks.

Comments (from utexas.edu CTR report)

"mainly applicable to highly urban projects. Rental rates are critical"
"excellent for use on very special projects, but is time consuming to come with the numbers and schedule"
"using lane assessment fees rather than lane

Comments from 9/4/03 Meeting @ UK

- Tends to unbalance bids
- Good for warranty work
- Modified A+B approach including lane rental is better than just lane rental

Applicability / Limitations

- Must be explicitly described in the bid package
- Rental rates have to be significant and should address high impact lanes

Pros (+) / Cons (-)

- + Leads to innovative ideas for successful TCPs
- + Minimizes contractor impact on traffic
- Not easy to administer

Dr. Goodrum Comments

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9.3 Algorithm of Kentucky User Cost Program to Calculate RUC

Kentucky User Cost Program (KyUCP) is based on the algorithms developed in FHWA research project Life-Cycle Cost Analysis in Pavement Design (Walls, 1998). As mentioned before, there are five modifications have been made to improve the original algorithms. The algorithms of KyUCP will be expounded in the following paragraphs and a example problems will be given to show the process of determining RUC by KyUCP.

9.3.1 Introduction of Algorithm

9.3.1.1 Identify Traffic Characteristic

a. Project AADT

Equation 9.3-1:

$$\text{Future Year AADT} = \text{Base Year AADT} \times \text{Vehicle class \%} \times (1 + \text{growth rate})^{(\text{Future Year} - \text{Base Year})}$$

b. Determine Traffic Classification

Determine the percentages of passenger car, single-unit truck and combination truck in the AADT. Different type of vehicle will be allocated different rate of value of time when calculate RUC.

c. Calculate Work Zone Hourly Directional Demand

Equation 9.3-2:

$$\text{Hourly Demand} = \text{AADT} \times \text{Hourly Distribution Factor} \times \text{Hourly Directional Factor}$$

In KyUCP, users could use the default Hourly Distribution Factor and Hourly Directional Factor to calculate hourly directional demand or input actual hourly directional demand, obtained by on site measurement. Table E.5-1 shows the default Hourly Distribution Factor and Hourly Directional Factor used by KyUCP.

Table 9.3-1: Work Zone Directional Hourly Demand

AADT	--		
Hour	Hourly Traffic (%)	Directional Factor IN (%)	Directional Factor OUT (%)
0-1	1.8	50	50
1-2	1.5	50	50
2-3	1.3	50	50
3-4	1.3	50	50
4-5	1.5	50	50
5-6	1.8	50	50
6-7	2.5	50	50
7-8	3.5	50	50
8-9	4.2	50	50
9-10	5	50	50
10-11	5.4	50	50
11-12	5.6	50	50
12-13	5.7	50	50
13-14	6.4	50	50
14-15	6.8	50	50
15-16	7.3	50	50
16-17	9.3	50	50
17-18	7	50	50
18-19	5.5	50	50
19-20	4.7	50	50
20-21	3.8	50	50
21-22	3.2	50	50
22-23	2.6	50	50
23-24	2.3	50	50

9.3.1.2 Identify Work Zone Characteristics

Work zone characteristics include such factors as work zone length, number and capacity of lanes open, duration of lane closures, timing (hours of the day and days of the week) of lane closures, posted speed, and the availability and traffic characteristics of alternative routes. In this step, the road capacity has to be determined by calculation.

A. Calculate Roadway Normal Capacity

Roadway Normal Capacity is the capacity of the road under normal operating conditions. It is calculated by KyUCP according to the equation in the 2000 Highway Capacity Manual (2000HCM).

Equation 9.3-3:

$$V = V_p \times \text{PHF} \times N \times f_{\text{HV}} \times f_p$$

Where:

- V_p : 15-min passenger-car equivalent flow rate (pc/h/ln), values are 2400, 2350, 2300, and 2250 pc/h/ln at free-flow speeds of 70 and greater, 65, 60 and 55 mi/h, respectively;
- V : Hourly volume (veh/h);
- PHF : Peak-hour factor. The peak-hour factor (PHF) represents the variation in traffic flow within an hour. On free ways, typical PHFs range from 0.80 to 0.95. Lower PHFs are characteristic of rural freeways or off-peak conditions. Higher factors are typical of urban and suburban peak-hour conditions;
- N : Number of lanes;
- f_{HV} : Heavy-vehicle adjustment factor, described in equation (E.5-5);
- f_p : Driver population factor. The 2000HCM assumes that regular drivers are the substantial components in commuter traffic stream i.e. most drivers are familiar with the facility in a traffic stream. It is generally accepted that traffic streams with recreational drivers use freeways less efficiently. The adjustment factor Diver Population Factor is used to reflect this effect. The value of it ranges from 0.85 to 1.00. In general, the analyst should select 1.00, which reflects commuter traffic (i.e., familiar users), unless there is sufficient evidence that a lower value should be applied, where greater accuracy is needed, comparative filed studies.

B. Calculate Work Zone Capacity

Work Zone Capacity is the capacity of the road when the work zone is in place. It is calculated by KyUCP according to the equation in 2000HCM.

Equation 9.3-4:

$$C_a = (1,600 + I - R) \times f_{\text{HV}} \times N$$

Where:

- C_a : Adjusted mainline capacity (veh/h);
- f_{HV} : Adjustment for heavy vehicles, as described in the equation (9.5-5);
- I : Adjustment factor for type, intensity, and location of the work activity, as discussed in Table 5-2 (range from -160 to +160 pc/h/ln);
- R : Adjustment from ramps. Entrance ramps within 500 ft of a lane closure will affect capacity. If ramps are located 1,500 ft upstream from the beginning of the full closure, the effect on capacity is small;
- N : Number of lanes open through the short-term work zone.

Equation 9.3-5:

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)}$$

Where

- f_{HV} : Adjustment for heavy vehicles
- P_T : Proportion of heavy vehicles, and
- E_T : Passenger-car equivalent for heavy vehicles, as described in Table 9.5-3.

Table 9.3-2: Construction Intensity Values

INTENSITY	VALUE	WORK ACTIVITY
Low	+160	Median barrier wall, guardrail installation, shoulder construction/repair work
Light	+80	Pavement repair, spot pathing
Medium	0	Asphalt removal-milling, resurfacing, concrete slab replacement
Moderate	-80	Pavement makers, striping
Heavy	-160	Bridge repair

Table 9.3-3: Passenger-Car Equivalents on Extended Freeway Segments

Factor	Type of Terrain		
	Level	Rolling	Mountains
E _T (Trucks and buses)	1.5	2.5	4.5
E _R (Recreational Vehicles)	1.2	2.0	4.0

C. Calculate Queue Dissipating Capacity

Queue Dissipating Capacity is the capacity of the facility to dissipate traffic from a queue condition. KyUCP calculates queue dissipating capacity by the following empirical equation.

Equation 9.3-6:

$$\text{Dissipation Capacity } C_d = 0.835 \times \text{Normal Capacity}$$

D. Analyze Hourly Work Zone Traffic Flow Conditions and Determine Cost Components

After the road capacities have been established, in this step hourly comparisons between road capacity and the hourly traffic demand are carried out throughout the whole day. Then the traffic situations in each of hourly analysis intervals are determined, i.e. free flow or forced flow conditions. Based on traffic conditions, the different cost components are assigned to each of hourly analysis intervals.

E. Calculate Each of Cost Components

Each of cost components has unique calculation method and formulas, but the some common steps required to follow are listed below.

E-1. Determine Number of Affected Vehicles

Based on the results obtained from Step D Analysis hourly work zone traffic flow conditions, the specific numbers of vehicles in each hour of a day are determined, which suffer delays caused by work zone.

E-2. Assign Cost Rate

Based on the analysis in Section 5.2.1, road user costs consist of delay cost and vehicle operating cost (VOC). During calculation of these two components, the different cost rates should be applied to them respectively.

(i) Vehicle Operating Cost (VOC) Rates

Work zone causes additional cost and time to the vehicles passing through it. Table E.5-4 shows additional hours of delay and additional VOC (in 1970 dollars) associated with stopping 1000 vehicles from a particular speed and returning them to that speed for the three vehicle classes. Different additional time and cost rates are assigned to Passenger cars, Single-Unit and Combination trucks. In addition, the last row of Table E.5-4 shows the VOC rate associated with idling i.e. stop-and go pattern.

While Table E.5-4 is designed to determine stopping cost, it can also be used to determine the cost and time factors associated with slowing from a high speed to a low speed and return to the high speed. This is accomplished by subtracting the cost and time factors for stopping associated with each speed from one another.

Table 9.3-4: Added Time and Vehicle Running Cost/1,000 Stops and Idling Costs (1970 \$)

	Added Time (Hr/1000 Stops)			Added Cost (\$/1000 Stops)		
	(Excludes Idling Time)			(Excludes Idling Time)		
Initial Speed (mi/h)	Pass Cars	Single-Unit Trucks	Combination Truck	Pass Cars	Single-Unit Trucks	Combination Truck
5	1.02	0.73	1.1	0.71	2.43	8.83
10	1.51	1.47	2.27	2.32	5.44	20.35
15	2	2.2	3.48	3.98	8.90	34.13
20	2.49	2.93	4.76	5.71	12.71	49.91
25	2.98	3.67	6.1	7.53	16.80	67.37
30	3.46	4.4	7.56	9.48	21.07	86.19
35	3.94	5.13	9.19	11.57	25.44	106.05
40	4.42	5.87	11.09	13.84	29.93	126.63
45	4.9	6.6	13.39	16.30	34.16	147.62
50	5.37	7.33	16.37	18.99	38.33	168.70
55	5.84	8.07	20.72	21.92	42.25	189.54
60	6.31	8.8	27.94	25.13	47.00	209.82
65	6.78	9.53	39.06	28.63	51.43	236.41
70	7.25	10.27	50.49	32.46	54.90	261.41
75	7.71	11	65.28	36.64	59.05	287.11
80	8.17	11.74	84.41	41.19	63.21	313.85
Idling Cost (\$/Veh-Hr.)				0.18	0.20	0.22

(Source FHWA-SA-98-079 Table 2.2)

(ii) Delay Cost Rates

The values of time for highway user used in Kentucky User Cost Program (KyUCP) are obtained by combining the research of NCHRP 133 and MicroBENCOST. It selects average rates of NCHRP 133 and MicroBENCOST. The value of time for single-unit trucks and combination trucks are \$17.44 and \$24.98 per vehicle per hour (1995 dollars).

E-3. Follow Specific Equations to Calculate Each RUC Components Respectively.

The flow chart of calculating RUC by KyUCP is show in Figure 9.3-1.

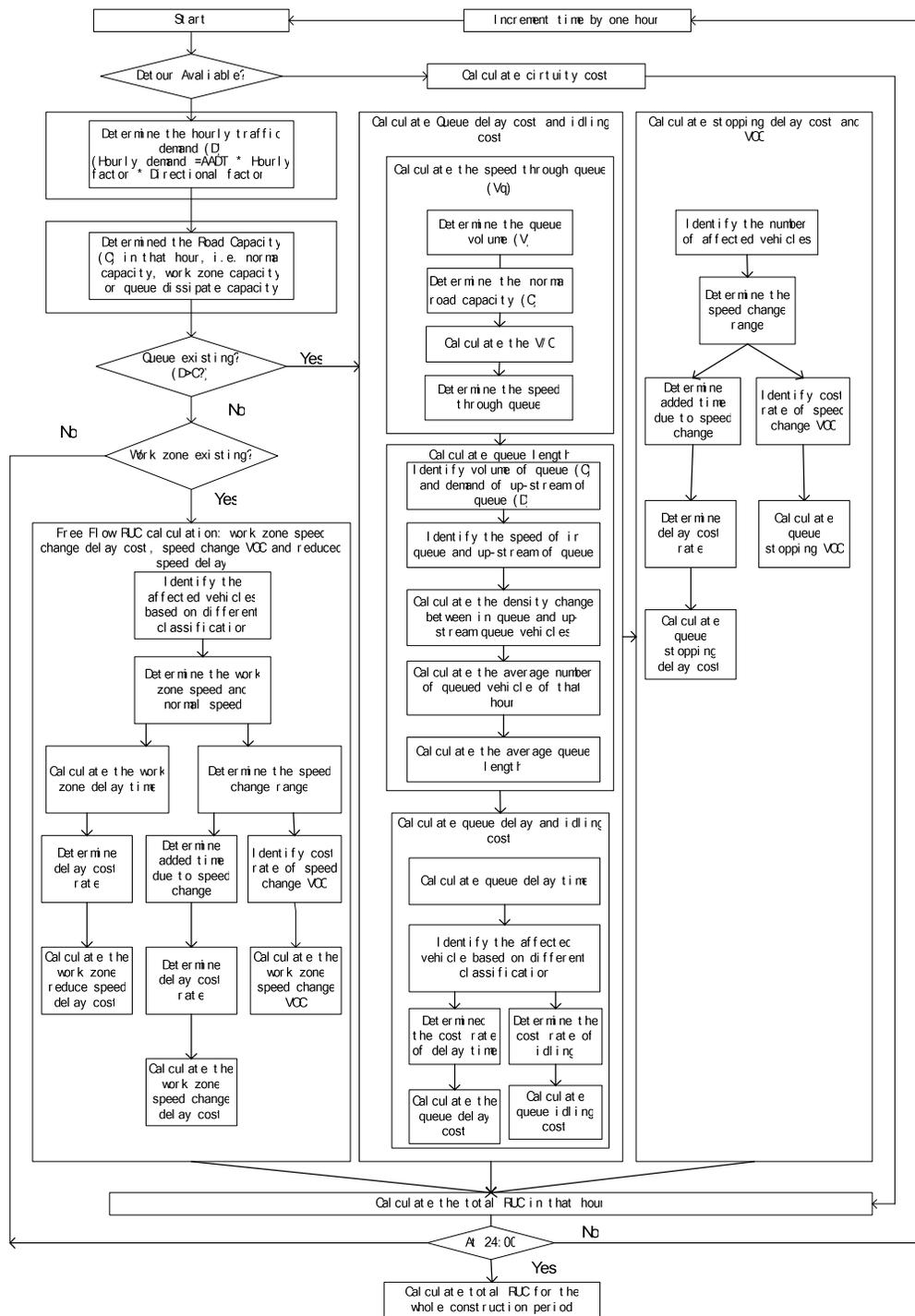


Fig 9.3-1: Flow Chart of Calculating RUC by KyUCP

10.0 REFERENCES

Annis, P. (Mar. 30, 2004). Personal Interview.

Arizona Department of Transportation (2002). "A+B Bidding Guide"
<http://www.dot.state.az.us/roads/constgrp/A+BGuide.pdf> (Oct 27, 2004).

Bailey, K. (Aug. 23, 2004). Personal Interview.

Carter, P., and Proffitt, C. (Mar. 15, 2004). Personal Interview.

Castle, D. (Jul. 29, 2004). Personal Interview.

Castler, L. B. "Analyzing Rapid Deployment: Connecticut's Latest Experience with a New Concept in Bridge Painting." *SSPC 2003 Technical Presentations in New Orleans*.
<http://www2.sherwin-williams.com/im/cs/cs-winter2003/feature.pdf> (Jul. 21, 2004).

Construction Innovation Forum. "Intellirock Maturity Monitoring System."
http://www.cif.org/nom2004/nom12_04.pdf (Aug. 9, 2004).

Daniels, G. and Ellis, D.R. and Stockton Wm. R. (1999), "Techniques for Manually Estimating Road User Costs Associated with Construction Projects", Texas Transportation Institute, Texas A&M University.

"DOTS Say Quick-Setting Concrete Patches Play a Key Role in Keeping Winter Roads Open in North Central States." GypsumSolutions.com.
http://www.gypsumsolutions.com/newscenter/news/roadrepair/cs_dot.asp (Aug. 19, 2004).

Federal Highway Administration (FHWA). "Accelerated Construction."
http://www.aashtotig.org/focus_technologies/accel_construction/related_documents/accel_const_fa_cts.pdf (Nov. 12, 2004).

Federal Highway Administration (FHWA). "Full Freeway Closures: Recent Success Stories in Kentucky." http://ops.fhwa.dot.gov/wz/workshops/accessible/LaRue_paper.htm (Oct. 24, 2004).

Gibson, H. (Jul. 1, 2004). Personal Interview.

Goodrum, P. M., Dai J., Wood C. R., and King M. (2004) "The Use of the Concrete Maturity Method in the Construction of Industrial Facilities: A Case Study." FIATECH. <http://www.intellirock.com/resources/library/FieldTrials-ConcreteMaturity-Jan04.pdf> (Aug. 20, 2004).

"Highway Capacity Manual 2000." (HCM). Washington, DC., Transportation Research Board. (2000).

Jenkins, C. (Feb. 13, 2004) Personal Interview.

Jenkins, C., and Kissinger D. (Aug. 23, 2004). Personal Interview.

Kenning, C. "I-64 Project Likely to End on Sunday." *The Courier-Journal*. Sep. 27, 2001. <http://www.courier-journal.com/localnews/2001/09/27/ke092701s77551.htm> (Aug. 20, 2004).

Kentucky Cabinet for Economic Development. <http://www.thinkkentucky.com/edis/deskbook/files/PerCapitaCnty.pdf> (Oct. 27, 2004).

Loftus, T. "\$5.3 Million Bonus for I-64 Work Draws Some Criticism." *The Courier-Journal*. Nov. 18, 2001. www.courier-journal.com/localnews/2001/08/02/ke080201s60082.htm (Aug. 20, 2004).

Martens, P. "New DURACAL Brand Cement HP Gets Nod From Maintenance Crews in St. Louis." GypsumSolutions.com. http://www.gypsumsolutions.com/newscenter/news/roadrepair/news_duracal.asp (Aug. 19, 2004).

Mitretek Systems (2002), "QuickZone Delay Estimation Program Version 1.01, User Guide"
<http://www.sha.state.md.us/Safety/oos/quickzone.asp> (Oct. 30, 2004).

Mills, R., Halloran S., Hecker R., Roach B., and Stroop N. (Jul. 20, 2004). Personal Interview.

Mohsen, J. P., Roach B., and Kessinger D. (2001). "Maturity Method Applied to Highway Construction - The Kentucky Experience." *Transportation Research Board Meeting 2001*.

New Jersey Department of Transportation, "Road User Cost Manual",
<http://www.state.nj.us/transportation/eng/documents/RUCM/> (Nov. 1, 2004).

Newman, G. (Mar. 12, 2004). Personal Interview.

Rister Brad and Graves Clark. (2002). "The Cost of Construction Delays and Traffic Control for Life-Cycle Cost Analysis of Pavement". Kentucky Transportation Center. University of Kentucky.

Smith, G. (Jun. 23, 2004). Personal Interview.

Texas Transportation Institute (1998), "User's Manual for QUEWZ-98", Report No. 1745-2, Texas A&M University.

Turner-Fairbank Highway Research Center. (2001).
"States Achieve Safety and Savings with Rapid Deployment for Bridge Painting."
<http://www.tfhrc.gov/focus/july01/rapid.htm> (Aug. 1, 2004).

US Bureau of Labor Statistics, Department of Labor.
http://www.bls.gov/oes/2003/may/oes_ky.htm#b00-0000 (Oct. 27, 2004).

US Consumer Price Index. <http://data.bls.gov/cgi-bin/dsrv?cu> (Oct. 27, 2004).

Walls, J. III and Smith, M.R. (1998), "Life-cycle Costs Analysis in Pavement Design", FHWA-SA-98-079, Federal Highway Administration.

“Weekend Shutdown Works: Kentucky Transportation Cabinet Completes I-65 and I-64 Weekend Projects in Record Time.” (2001). *I-65 Institute’s Inside I-65 Newsletter*, Nov., Vol. 2, No. 11. <http://www.i65institute.org/november.html> (Oct. 24, 2004).

William F. McFarland, Jeffery L. Memmott, and Margaret L. Chui (1993), “Microcomputer Evaluation of Highway User Benefits”, National Cooperative Highway Research Program, Project 7-12, Texas Transportation Institute, Texas A&M University.

William F. McFarland, Jeffery L. Memmott, Margaret L. Chui, Matthias D. Richter, and Alberto Castano-Pardo (1993), “MicroBENCOST User's Manual”, Texas Transportation Institute, Texas A&M University.