

Research

Results

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Annual

Report

Research and Technology
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About

this

Book

This annual report presents research findings and recommendations extracted from the 68 technical research reports published for TxDOT's research program from September 1, 2010 through August 31, 2011. For any specific project, other reports may still be pending completion, or may have been published in a previous fiscal year.

How to use this book...

Hard Copy – See the Table of Contents for a list of the reports published for each Research Management Committee (RMC). See page 6 for the focus areas under each RMC.

You may also scan the key words featured on each page to help locate reports of interest to you. A URL is included under the title of each report to help you locate a full text version on-line.

PDF – This version is fully searchable, and interactive. Clicking on an entry in the Table of Contents will take you to the summary of that report. Clicking on the URL on each summary page will take you to a full text version of the report on-line.

Where to find additional reports...

For related reports published in previous fiscal years, search the on-line catalog for TxDOT's research library at: <http://library.ctr.utexas.edu/dbtw-wpd/textbase/websearchcat.htm>. TxDOT's research library is operated by the Center for Transportation Research at The University of Texas at Austin.

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Research Management Committee

Focus Areas

RMC 1 - Construction and Maintenance

- Construction Materials
- Construction Operations
- Construction Contracting
- Maintenance Materials
- Maintenance Operations
- Maintenance Contracting
- Pavement Design
- Pavement Management
- Vegetation Management

RMC 2 - Planning and Environment

- Aviation System Planning
- Environmental Affairs Management
- Hazardous Materials
- Multi-modal & Inter-modal Freight Planning
- Ports & Waterways Planning
- Public Transportation
- Railway Planning
- Right of Way Planning, Acquisition & Management
- Roadway Planning
- Statewide, Regional & Local Transportation System Planning
- Traffic Data Collection

RMC 4 - Safety and Operations

- Geometric Design
- Illumination
- Pavement Marking
- Railroad Crossing Safety
- Roadside Safety
- Roadway Signing & Delineation
- Traffic Control Devices
- Traffic Management & Operations
- Work Zone Safety

RMC 5 - Structures and Hydraulics

- Bridge Rails & Transitions
- Geotechnical Issues
- High Mast Illumination Poles
- Hydraulics & Hydrology
- Overhead Sign Bridges
- Structures Construction & Maintenance
- Structures Design & Analysis
- Structures Management
- Structures Materials

Construction and Maintenance

results

RMC 1

RMC 1 - Construction and Maintenance Focus Areas

- Construction Materials
- Construction Operations
- Construction Contracting
- Maintenance Materials
- Maintenance Operations
- Maintenance Contracting
- Pavement Design
- Pavement Management
- Vegetation Management

CTR and TxDOT vehicles, when using the same tire type, produce essentially identical measurements. Therefore, all data collected by CTR and TxDOT using the Tiger Paw tire can be combined for analysis purposes, such as it was done in the analyses performed in this project. This also indicates that the on board sound intensity (OBSI) device, protocol, and operator training insure low variability.

The leading and trailing positions for the OBSI device produce remarkably correlated data, the trailing edge being generally louder by a very small amount. However the difference is insignificant.

The new OBSI standard test tire, the SRTT tire, though it produces a different spectrum of noise compared to the former tire, the Tiger Paw, does give a comparable A-weighted composite measurement, generally slightly louder than the Tiger Paw tire, but affected by the pavement type due to the spectral differences. The SRTT measurement can be more closely calibrated to the Tiger Paw measurement (or vice versa) using the model from this study, though more data is needed than was available to the researchers from the two noise rodeos. *This is a crucial finding as being able to model the two tires allows historical data and new data to be combined.*

Using a single probe position near the center of the tire/pavement contact point approximates and is highly correlated to the average of the trailing and leading edge measurements now commonly used for reporting OBSI measurements. Whenever speed and cost are factors (possible network level work), the OBSI probe can be mounted at the center location and reasonably accurate measurements can be taken, and/or improved using the model from this study. However, this finding requires more data to be taken to substantiate it, as only limited data was available from this project.

The use of specific, location precise environmental data for each test section over its lifetime improved the model for predicting pavement noise over time. This data is free and easy to obtain from the National Climate Data Center (NCDC), and could be made even more useful by compiling this data from “cradle to grave” for each test section from the nearest city if such data is available. Cumulative rainfall shows a strong effect, and the degree-days variable does also, especially in the summer when the asphalt would be softer and more subject to compaction and therefore void reduction/clogging/sealing. This effect should be followed up on.

Age/traffic data shows significance, but more data needs to be collected to separate age and traffic effect, specifically ESAL data if available, or, if not, percentage trucks and Average Daily Traffic (ADT).

It is essential that further noise testing include coring to determine the as-built thicknesses of Permeable Friction Course (PFC) sections, as this variable is known from several other studies to affect noise very significantly.

Key Words:

Noise, Noise Mitigation, Permeable Friction Course, PFC, Open Graded Asphalt Pavement, OBSI, Sound Intensity, Pass-By, TNM, Quiet Pavement.

The goal of this project was to understand the mechanisms of intersection pavement failures and to determine the best practices to minimize the failures at existing intersections. This project also determined how the mechanisms causing the failures at intersections can be mitigated through design and construction modifications. The outcome is an expert system that suggests solutions that can be readily and economically carried out considering type of potential or actual damage at the intersections.

The literature review described the characteristics and mechanisms of the most common types of distresses of asphalt pavements, and covered promising remediation strategies for such problems at different layers of the structure. Such remediation strategies were gathered from research and specifications by several organizations and state agencies throughout the United States and worldwide. Life cycle cost analysis as per the FHWA methodology was also described.

The matrices that link probable distresses and the appropriate remediation resourced from the literature review were created. The matrices aimed to correct distresses by proposing low-cost alternatives that would perform at their best on low volume roads in an effort to avoid common high-cost alternatives. The matrices provided cases where certain remediation is appropriate, likely or might be appropriate, not appropriate and finally not a candidate to solve the identified predominant distress.

One of the major treatment selection factors missed by highway agencies is on considering the different types of rutting separately. Rutting source may be from different layers. The different types of rutting require different types of remediation. The matrices created contains the different types of rutting (surface, instability, and structural) taking into consideration that they come from different sources and thereby should be remedied differently.

Questionnaires were distributed and interviews conducted with TxDOT personnel to:

- document the extent of the excessive distress at their intersections,
- locate the districts that perceive they can benefit from the outcome of this study,
- identify the current solutions typically used to remedy this problem,
- document the perceived performance of their intersections after remediation, and
- solicit projects that can be incorporated in this study.

The research information gathered was incorporated into an easy-to-use online expert system. The system was created to incorporate the knowledge gained as a knowledge base for the selection of remediation strategies. The expert system represents a systematic implementation of the matrix of solutions, which was intended to guide users throughout the process of identifying the proper remediation methods for flexible pavements at intersections and to perform the Life Cycle Cost Analysis (LCCA) to obtain the most economical alternatives.

A thorough explanation of the forensic investigation and the utility of the expert system was presented. Finally, the expert system was used to evaluate several intersections in various districts across Texas after having identified the source of the problem for the selection of a remediation strategy. The result based on LCCA for short term and long term solutions were presented for each intersection.

Also developed is an online guidebook that can be used by TxDOT personnel. An electronic version of the guide provides detailed information to TxDOT personnel in the field. The information is separated into four components: a) common distresses, b) common remediation strategies, c) protocol for data collection, and d) remediation strategies for common distresses.

Key Words:
Flexible Pavements,
Intersections, Evaluation,
Distress, Expert System,
Remediation Strategies,
Maintenance

Fourier Transform Infrared spectroscopy FTIR is capable of differentiating between polymer and non-polymer-modified binders. Asphalt samples with known styrene-butadiene-styrene (SBS) content from multiple suppliers were used to generate calibration curves for polymer quantification. Calibration curves showed a linear relationship between band area ratio ($966\text{ cm}^{-1}/1375\text{ cm}^{-1}$) and polymer weight percent (AASHTO T 302-05) with R^2 values close to 1.0. Both Attenuated Total Reflectance (ATR) and transmittance method of FTIR were shown to be effective in polymer quantifications with the transmittance method producing smoother traces, which affects reproducibility of the measurements. The transmittance method is more favorable over ATR due to protection of the ATR crystal (exposure of the ATR crystal to hot asphalt can potentially damage or crack the crystal). In addition, disposing of a KBr pellet used in the transmission method is much easier than cleaning solidified asphalt off of an ATR crystal.

Research was attempted on antistripping agents in asphalt emulsions of both anionic (SS-1, HFRS-2, and HFRS-2P) and cationic (CHFRS-2, CRS-2, and CRS-2P) forms. Samples were collected from multiple suppliers and analyzed. FTIR spectra of the materials received were very similar in the uniformity of the products, but did not show discernible absorption bands for antistripping agents present in these samples. The addition of 2% of a known antistripping agent (with known FTIR spectrum) to PG 64-22 asphalt binder did not yield a spectrum exhibiting expected absorption bands. It is possible that the volatility of the antistripping agent did not allow mixing with PG 64-22 during the sample preparation stage for FTIR analysis. Past research has indicated “Infrared spectroscopy is not a good tool for measuring amines in blends, especially at low concentrations.” However, FTIR spectra of cutbacks like MC 30 and RC 250 show absorption bands associated with kerosene that is a constituent of cutbacks.

Two batches of all four concrete spall repair epoxy materials were analyzed. Similar spectra for all samples in a given variety were produced, which showed uniformity of the products between batches. In addition, keeping epoxy materials at room temperature for six months was shown to not change the chemistry of these materials as evidenced by their respective FTIR spectra.

Two batches of two commercial concrete curing membrane samples were fingerprinted and a protocol was developed for preparing samples for finger printing curing membranes and evaporation retardants.

A new method for alkali quantification of concrete cement using FTIR was developed based on TxDOT XRF data from the past several years. In this research, a correlation model was developed correlating the FTIR band ratio of $750\text{ cm}^{-1}/923\text{ cm}^{-1}$ band versus equivalent alkali ($0.658 \times \%K_2O + \%Na_2O$) concentration as calculated based on XRF analysis. R^2 values of two data sets from TxDOT samples were calculated as 0.978 and 0.974.

Assigned FTIR absorption bands unique to concrete cement were identified based on available literature. Fingerprint spectra obtained will be used for future analysis of variations in concrete cement compositions. Both grades of fly ash (C and F) received from multiple sources were analyzed and as anticipated had similar FTIR spectra for both types. Two distinctive features observed included: 1) the presence of an absorption band at wave number 460 cm^{-1} in fly ash samples, while the lowest detected band for concrete cement occurred at wave number 520 cm^{-1} , and 2) the presence of a narrow (in most cases) band in the wave number range of 1384 cm^{-1} - 1388 cm^{-1} possibly due to the presence of CaCO_3 or lime in fly ash samples. Based on ASTM classifications of fly ash, type F should have 10% lime, while type C has up to 20%.

Protocols were developed for FTIR analysis of different paving materials including: polymer quantification in asphalt binders, fingerprinting of concrete curing membranes and evaporation retardants, and alkali quantification.

Key Words:

Polymer modified asphalt, emulsion asphalt, concrete curing compound, alkali equivalent, concrete spall repair epoxy, evaporation retardant, fly ash

In Phase I researchers conducted laboratory experiments to determine the influence of aggregate properties and mixture design on the skid resistance of asphalt-mixture slabs. A method was developed to predict International Friction Index values as a function of aggregate texture measured using Aggregate Imaging System (AIMS) and aggregate gradation.

In Phase II skid data from different road sections with different material and mix types were collected. Traffic, mix type, and aggregate type were the main factors considered in the analysis of measured skid numbers. To facilitate comparing different road categories in their current service life, a single factor, denoting the traffic multiplication factor, was defined. This factor, the product of annual average daily traffic (AADT) in the design lane times years in service divided by 1000 considers both traffic level and years of operation.

Data analysis showed that measured skid numbers decreased as the traffic multiplication factor (TMF) increased and they had less variation at higher TMF levels. This phenomenon could be attributed to mixtures reaching close to terminal skid condition, which is associated with aggregates approaching their equilibrium (or terminal) state of texture after a high number of polishing or loading cycles.

Researchers analyzed skid numbers measured by TxDOT skid trailers on four types of surfaces (surface treatments grade 3 and grade 4, porous friction course (PFC), and Type C). Results showed that the surface-treatment mixes generally had higher skid numbers than Type C, a conventional dense-graded mix. PFC mixes exhibited better skid resistance than Type C mixes and surface-treatment mixes. PFC mixes had the lowest variation in skid numbers, while surface-treatment mixes had the highest variability.

The effect of aggregate type was studied, and the results showed that there was high interaction between aggregate performance, the mix type in which the aggregate is used, and traffic level. In general, it is hard to classify aggregates without specifying mixture type and traffic levels. Some aggregates performed poorly in certain mixture types, while their performance was acceptable in other mixture types.

For the most part, the results of the field-data analysis were in agreement with the laboratory findings in Phase I. It was interesting to find that the same equation form (i.e., Equation 1) that was used to describe aggregate rate of polishing can be used to describe skid number versus TMF values in the field and to describe skid number versus polishing cycles in the laboratory.

Twenty five road sections were selected for testing using dynamic friction tester (DFT) and circular texture meter (CTMeter) devices. The sections covered a wide range of material types and traffic conditions, and more importantly included some of the mixtures tested in the laboratory study. Measurements were taken on the left wheel path of the farthest outside lane and on the shoulder.

Macrotexture measurements taken by the CTMeter showed that the PFC mixes had higher mean profile depth (MPD) values compared with Type C and Type D mixes. Type D had the lowest MPD values due to its finer gradation. The results also indicated that the macrotexture of PFC mixes decreased over time, and the rate of decrease in macrotexture depended on aggregate type. The macrotexture of Type C and Type D mixes was found to increase to some extent over time possibly due to removal of fine aggregates from the surface (raveling). The friction measured using the DFT, which is an indication of microtexture, showed the initial pavement microtexture depended on aggregate type.

Researchers found a correlation between the MPD values and measured skid number in Type C and Type D mixes. However, no correlation was found between MPD values and measured skid number in PFC mixes. The results also indicated that there was a fair correlation between dynamic friction at 12.4 mph and measured skid numbers for all mixes. Furthermore, a fairly strong correlation was found between the results of the measured dynamic friction at 50 mph and measured skid numbers for Type C and Type D mixes. Similar to MPD, no correlation was found between the measured dynamic friction at 50 mph and skid numbers for PFC mixes. The results of this analysis suggest measured skid numbers are affected by macrotexture in dense-graded mixes, whereas microtexture governs the frictional performance of PFC mixes.

Key Words:
Skid Resistance, Asphalt Mixture,
Aggregate Characteristics

0-6004-2

A Portable Profiler for Pavement Profile Measurements – Final Report

http://ranger.uta.edu/~walker/Reports/Final_0-6004-2.pdf

A portable profiler was developed and is available for immediate use.

An accompanying program was also developed.

A portable attachment that easily fits into commercially available receiver hitches was fabricated.

A portable holder for the distance encoder was developed and tested.

The profile and measurement process is consistent with current TxDOT data collection procedures.

The portable profiler was certified on a TTI full size pickup and a TxDOT van.

Key Words:
Profiler, Profile Measurement Laser,
Surface Pavement Profile

0-6005-1

Progress During the First Year Towards Building the Total Pavement Acceptance Device (TPAD)

http://www.utexas.edu/research/ctr/pdf_reports/0_6005_1.pdf

During the first year of project 0-6005, significant progress was made towards developing the Total Pavement Acceptance Device (TPAD). The TPAD will be a multi-function device that will be used to survey continuously along pavements at speeds in the range of 5 to 10 mph.

The test functions will include those associated with the Rolling Dynamics Deflectometer (RDD), ground penetrating radar (GPR), Distance Measurement Instrument (DMI) and high-precision differential GPS, and surface temperature measurements, as well as digital video imaging of the pavement and right-of-way conditions.

The basic moving platform for the TPAD was selected and initial prototype tests were conducted at the TxDOT Flight Services Facility at Austin Bergstrom International Airport (ABIA). Progress was made in developing: (1) improved rolling sensors and associated data analysis methods commensurate with the target testing speeds and (2) an integrated data acquisition and display system that records all test functions on the same time and distance baselines.

Key Words:
Continuous Deflection Profiling,
Testing Speed, GPR and GPS
Measurements, Video Imaging,
Single Moving Platform

Based on the laboratory results from this research project, the following conclusions can be made: The gradations of unfractionated reclaimed asphalt pavement (RAP) from different stockpiles are quite similar. Lack of finer aggregates is a common characteristic of RAP materials in Texas.

According to the unconfined compressive strength (UCS) requirement for cement-treated base materials by TxDOT specifications, the use of cement-treated mix of high RAP content as base material for roadway rehabilitation construction is feasible.

RAP content and cement content in a RAP mix has a strong impact on the properties of the mix.

For a 300-psi UCS, the statistical optimum cement contents are about 4%, 3% and 2% for mixes of 100% RAP, 75% RAP and 50% RAP, respectively.

The results from UCS, indirect tensile strength (ITS), free-free resonant column (FFRC) modulus and resilient modulus tests are consistent. Corresponding to a 300-psi UCS, the ITS, FFRC modulus and resilient modulus are about 40 psi, 1000 ksi, and 250 ksi, respectively.

RAP blended with granular base materials of relatively higher finer aggregate, particularly fines content, can improve the quality of a RAP mix.

The use of salvage base as opposed to transporting virgin aggregate can be a cost effective way to build new base courses of cement-treated RAP mixes.

Asphalt content in RAP does not seem to have a considerable impact on strength and modulus of RAP mixes.

For the mixes that meet the 300-psi UCS requirement, permanent strains up to 1000 cycles are less than 50 micro-strains.

For the mixes that meet the 300-psi UCS requirement, the average retained UCS, ITS and FFRC modulus from tube suction tests meet or closely meet the recommended value of 80% (draft TxDOT Test Procedure Tex-144-E), and the average retained UCS values from wet-dry testing are similar.

All dielectric values for cement-treated RAP mixes are much smaller than 10 (recommended by draft TxDOT Test Procedure Tex-144-E). Thus, dielectric constant measurement seems to have less meaning for cement-treated materials.

Results from initial field tests confirmed the mix design model developed in the laboratory.

A modulus-based QA/QC procedure seems to be feasible for cement-treated base courses containing high RAP content.

The applicability and effectiveness of density-based QA/QC procedures for cement-treated base courses containing high RAP content need to be further investigated.

Key Words:
Reclaimed Asphalt Pavement (RAP), Cement Treatment, Base Material, Strength, Modulus, Mix Design

The protocols used for field and laboratory testing of FDR candidate projects worked well to provide a detailed analysis of project materials and variability and for formulate FDR treatment options. Based upon industry, TxDOT, and scientific research recommendations, along with the field investigations conducted in this study, this report presents recommendations for the FDR design stage (site investigations and laboratory materials testing) and construction stage.

Recommendations for FDR Design Stage

Step 1: Evaluate project history.

Step 2: Characterize existing pavement structure with NDT.

Step 3: Verify pavement structure and obtain material samples.

Step 4: Perform mixture design.

Step 5: Perform pavement design.

Recommendations for FDR Construction Stage

- Use field sieve analysis to check that proper gradation has been obtained.
- Use a non-nuclear insertion probe, such as a Vertek probe, to check field moisture prior to compaction. A calibration must be developed for each project.
- Determine section lengths to be treated with each stabilizer load (based upon the treatment width, depth, required treatment level, and weight of stabilizer load). Use visual inspection as the first quality check for stabilizer application rate.

Ongoing work in this project includes investigating other construction-related topics, including:

- reviewing ambient temperature restrictions,
- checking field moisture contents with non-nuclear insertion probes prior to compaction,
- checking stabilizer application rate and uniformity of application and mixing,
- investigating requirements for curing base, and
- developing guidelines for adequate bond of surface treatments.

Additional findings and recommendations will be presented in future research reports. Future work in the post-construction phase should focus on performance monitoring of constructed FDR sections and revising specifications based upon results or performance problems noted.

Key Words:

Full Depth Reclamation, Full Depth Recycling, FDR, Ground Penetrating Radar, GPR, Pavement Recycling

This project started out as an evaluation of different techniques to detect organic matter and sulfate minerals in subgrade soils. There are several techniques to measure both of these constituents in soil; however, most of the techniques are spot tests that require taking samples and sending them to a laboratory for analysis. These techniques leave gaps in the subgrade where high organic contents and/or sulfate minerals may be present but not detected. TxDOT currently tests subgrades for sulfate minerals from distances ranging from every 500 ft to every 2500 ft. The soil organic matter is currently not even measured in most districts. There are many instances where the sulfates on a project may not be detected using the current methods because sampling is at specified intervals. If a sulfate-rich seam falls between these intervals, then it will not be detected until the damage is done.

TxDOT wanted a way to measure these constituents continuously so that there would not be any gaps in the data, and sulfate or organic-rich areas would not be overlooked. We started with a literature review to identify potential tools to measure sulfates and organic matter. We identified several techniques to detect sulfates, including: geologic maps, soil survey maps, visual observation, remote sensing with satellite images, spectroscopic techniques, X-ray fluorescence, ground penetrating radar, and conductivity techniques.

Most of these techniques were deemed impractical for TxDOT, and many were still spot tests. However, researchers identified two techniques that would provide continuous coverage over an area to a depth of 3 to 4 ft. These two techniques were using the Veris 3150 conductivity device that is used in precision agriculture and the EM-38DDRT electromagnetic device used in geophysical surveys to map conductivity variations.

Based on extensive testing, the researchers recommend using the Veris 3150 and EM-38DDRT devices to map soil salinity, which can be related to the sulfate content. TxDOT will still be required to collect soil samples and measure the sulfate content using Tex-146-E, but they can focus on areas that exhibit high conductivity readings instead of selecting samples based on a grid that may miss potential problem areas.

We also did a brief evaluation of an infrared (IR) device that is manufactured by the same company that makes the Veris for detection of soil organic matter. The test was poorly designed and needs to be repeated on a larger project with more variability in organic matter. This test has a lot of potential to be run simultaneously with the conductivity device so organic content and conductivity can be mapped simultaneously. One would still need to collect soil samples in the field to correlate with the values given by the infrared device. A soil organic map could then be constructed similar to the conductivity maps.

The researchers recommend that TxDOT adopt the use of the Veris 3150 to map conductivity to correlate with potentially harmful sulfate contents. We also recommend using the IR device to collect more data on projects to construct maps of soil organic matter. These two devices could help TxDOT design better stabilization strategies, which could result in savings of millions of dollars.

The absolute reduction in the Distress Score due to Patching appears to be too high for almost all pavement types. This is especially true on Continuously Reinforced Concrete Pavement (CRCP), where four Concrete Patches in a 1/2-mile section reduces the Distress Score to 69, even if the Patches are perfectly smooth and level. JCP requires 9 Patches to reach the same level, while AC pavement types 4, 5, 6, 9, and 10 require 25 percent Patching to reach this level. However, AC pavement types 7 and 8 (which involve AC overlays of stabilized base or concrete) can have 99 percent Patching and still not reach a Distress Score of 70. Patches are certainly a defect and can be an indicator of pavement structural deficiency. However, PMIS raters record distresses within a Patch. In addition, Patches can cause roughness or ride quality problems (even though they are often placed to remove distress that cause roughness), but the profile measurements record the effect of such roughness. In any case, problems that can be created by Patches are recorded separately in any case, also reducing the score.

TxDOT should consider establishing severity levels for Alligator Cracking. For example, one definition of Alligator Cracking in the PMIS raters manual is “a single longitudinal crack in the wheelpath, with small ‘finger’ type cracks protruding...” This could be considered low severity cracking where crack sealing can be effective. However, higher severity levels of Alligator Cracking can extend throughout the entire wheelpath and be well defined, which means that full-depth repair may be warranted. These two different definitions should not have the same impact on the Distress Score.

TxDOT should consider redefining Longitudinal Cracking. During the interviews, some TxDOT pavement engineers indicated that edge cracking and deterioration be separated from Longitudinal Cracking. For example, a single crack at the outside paint stripe combined with a crack at the dashed lane stripe reduces the Distress Score to 74. These cracks are not usually serious indicators of future deterioration and can be sealed easily, cheaply, and effectively; thus, they should not have such a severe impact. Edge cracks should possibly be defined and have a separate effect on the Distress Score.

It appears that sealed cracks and unsealed cracks should be rated separately according to the interview results. If they are rated separately, sealed cracks should have less of an impact on the Distress Score as unsealed cracks.

It appears that the impact of distresses for pavement types 7 and 8 (AC overlays of stabilized base or concrete) on the Distress Score should be increased. For example, 700 ft of Longitudinal Cracking (7 full length cracks) gives almost the same Distress Score for pavement types 7 and 8 (70) as the aforementioned 150 ft of cracking on AC pavement types 4, 5, 6, 9, and 10. The other distresses have similar effects.

ACP Failures, CRCP Punchouts, and JCP Failures have a significant impact on the Distress Score. For CRCP Punchouts and JCP Failures, two severity levels can be considered—low severity, where the deterioration is minor (i.e., a corner break that is not spalled or faulted), and high severity, where the deterioration is more severe.

The Condition Score calculation appears to need revision. Currently, calculating the Condition Score uses a step function to determine which ride utility curve to use. Due to the step-wise nature of the assignment of the appropriate ride utility curve, two sections with the same Distress Scores, Ride Scores, and Speed Limits could have very different Condition Scores because of a minimal difference in traffic volume. For example, Sections A and B have Distress Scores of 100, Ride Scores of 2.0, and Speed Limits of 55, but Section A has an ADT of 500 and Section B (perhaps an adjacent section) has an ADT of 501. The resulting Condition Scores would be 90 and 60, respectively, or “Very Good” and “Fair.” The Condition Score is highly dependent on the ADT. Ride Score values greater than 3.3 give utility values of 1.0 at all traffic values.

Finally, the shape of the ride utility curves leads to a possibility of having a negative utility value. Negative utility values also occur with JCP Failures. By definition, a pavement cannot have less than zero utility (usefulness). The PMIS distress and ride utility curves need to be improved to remove negative utility values.

These conclusions and recommendations are preliminary. Researchers will make final recommendations in the final report for this project. The researchers plan to discuss these preliminary conclusions and recommendations with PMIS practitioners and may be improved as research continues.

Key Words:
Pavement Management
Information System, PMIS,
Score Review

Initial performance standards and timeliness requirements for roadside maintenance were developed based on responses to an online survey of TxDOT's districts and a review of the literature.

Out of the initial 53 performance standards that were included in the survey, 41 standards were supported by at least 70 % of the respondents, 8 standards were supported by 50–70 % of the respondents, and only 4 standards were supported by less than 50 % of the respondents. These standards were later refined based on feedback from on-site interviews of maintenance personnel at the Waco and Dallas Districts.

Performance-based roadside maintenance specifications were prepared using the developed standards and condition assessment method for potential use by TxDOT

A condition assessment method for evaluating the contractor's compliance with the performance requirements was developed using the roadway level of service (LOS) concept.

Priority multipliers that reflect the importance of various roadside elements were developed based on responses received from TxDOT's districts regarding their assessment of the performance risk of these elements.

Due to the specificity of the performance standards and the relatively high number of performance standards to be evaluated, a close observation through a walking survey is needed to assess compliance with these standards accurately. Thus, random sampling of relatively short sample units (0.1-mi long) is necessary for the condition survey to be practical.

A method for developing pay adjustment formulas was developed. This method is designed to motivate the contractor to perform at the performance target specified by the agency. Pay adjustment functions were developed for five field trial sites. Pay adjustment is determined as a function of roadway LOS (measured in the field) and target LOS (specified by the agency).

Five best-value bid evaluation methods that are already in practice by the state transportation agencies in Florida, Virginia, North Carolina, United Kingdom, and New Zealand were evaluated. Researchers found that: 1) Best-value bid evaluation methods that use the adjusted price concept (i.e., NCDOT and NZTA methods) appear to be balanced with respect to price and technical marks, 2) Best-value bid evaluation methods that use direct price and technical weights (i.e., FDOT's and VDOT's methods) appear to favor low bids, and 3) Best-value bid evaluation methods that consider the maximum technical quality offered by the bidders (i.e., the United Kingdom method) appear to favor bids with high technical marks over bids with low price.

Researchers make the following recommendations based on the results of this study:

- Apply the developed performance standards, condition assessment method, and pay adjustment formulas to an actual pilot PBMC project.
- Consider using a best-value bid evaluation method (rather than the conventional low-bid method) for PBMCs. Best-value bid evaluation is critical because PBMCs extend over multiple years (typically 3-10 years) and shift the risk of failing to meet performance standards and targets to contractors.
- Link TxDOT's maintenance cost database to roadside condition databases. This will allow for verifying and improving the relationships between roadside LOS and maintenance cost, and consequently improve the optimality of the pay adjustment functions.
- Investigate extending the performance standards, condition assessment method, and pay adjustment formulas developed in this research for roadside assets to pavement assets.
- Develop a training manual and a formal training program for field inspectors to properly assess the condition of roadside assets and maintenance activities.

Key Words:

Performance-Based Specifications, Roadside Maintenance, Level of Service, LOS, Condition Assessment, Maintenance Contracts, Best-Value Bids

The primary goal of this project was to develop an Excel-based tool to assist TxDOT personnel in making efficient selection and prioritization for preventive maintenance (PM) and rehabilitation treatment projects. This tool allows users to input the project information extracted from the PMIS database along with associated weight factors to determine a prioritization score for each project. The prioritization score (ranged 0–100) is determined for each project category. The tool allows users to rank projects based on the prioritization score to identify the most needed projects in the network for treatment. The tool also allows users to identify what treatment category is needed (PM or rehab) according to the score value. For instance, a project with higher PM scoring value will be most likely a candidate for PM treatment.

The baseline for developing the Excel-based tool is the group of key factors identified during district visits. Eight key factors were selected: condition score, distress score, surface age, average daily traffic (ADT), failure, skid number, ride score, and maintenance expenditures. While the impact of key parameters in the prioritization score are varied, a set of weight factors are assigned for each key parameter. This study suggested an initial set of weight factors. However, the weight factors may be adjusted by the user if necessary to fine tune the tool for local conditions.

The Excel-based spreadsheet tool was tested. Findings from the Excel-based tool verified that it is capable of identifying and prioritizing projects with critical conditions in the network. One cycle of verifications using the visited sites during the course of the study implied that the tool matched the treatment selection with 85 percent of the projects. The verifications were conducted on Atlanta, Dallas, San Antonio, and Phar Districts.

Key Words:
Preventive Maintenance,
Rehabilitation, Project Prioritization,
PMIS

Planning and Environment

results

RMC 2

RMC 2 - Planning and Environment Focus Areas

- Aviation System Planning
- Environmental Affairs Management
- Hazardous Materials
- Multi-modal & Inter-modal Freight Planning
- Ports & Waterways Planning
- Public Transportation
- Railway Planning
- Right of Way Planning, Acquisition & Management
- Roadway Planning
- Statewide, Regional & Local Transportation System Planning
- Traffic Data Collection

Analysis of the Occurrence and Statistics of Hazardous Materials Spill Incidents Along Texas Highways and Suggestions for Mitigation of Transport-Related Spills to Receiving Waters

http://library.ctr.utexas.edu/hostedPDFs/techmrt_0-5200-1.pdf

One of the goals of this project was to identify the existence of a hazardous materials spill trap technology that does not rely on human intervention to perform effectively. However, no such technology was identified.

Records of hazardous material spill incidents on Texas highways for the period 2002-2006 were obtained from TCEQ for review. A total of 899 spill incidents were available for analysis. Materials comprising gases, solids, unknown materials, and liquid spills with no reported volume were eliminated from further analysis. The remaining 582 spill incidents were examined in detail.

Spill materials were categorized as “light” (specific gravity less than one), “heavy” (specific gravity greater than one), and “oils” (which overlaps with the “lights” to a significant extent). The 95th percentile of spill volume for lights was about 1,400 gal, heavies was about 8,900 gal, and oils about 1,200 gal. If considered together, then the 95th percentile spill volume was 2,500 gal. The San Antonio development code requires a capture volume of at least 10,000 gal for roadway projects with an average daily traffic (ADT) of 30,000 vehicles per day or more. A reasonable target for capture volume is between 10,000 and 20,000 gal (1,300-2,600 cubic ft) because this volume range will capture the volume of between 95-99% of historical spills. The proposed trap volume is a relatively small volume in comparison to typical stormwater runoff detention structures.

The potential impact of rainfall on spill likelihood was examined using a proportions test. The presence of rainfall on a spill-incident day was not statistically significant. This does not mean that the occurrence of a spill incident and a rainfall event are statistically unrelated; it means that the statistical relation could not be established given the amount of data available.

The potential for locations where clusters of hazardous materials spills are more likely to occur was examined using the database assembled as part of this project. Certain areas in Austin, Beaumont, Dallas-Ft. Worth, Houston, and San Antonio were identified as locations where more spill incidents occurred than in other areas of Texas. Although a greater number of events occurred near these locations, the events were still spread over a large distance, with clusters being defined as occurring in a 10-mile radius of a central location. The analysis was useful in that it revealed the general location of concentrations of spill incidents, but was not useful in defining the precise location of potential spill traps.

A literature review was conducted to identify potential applications of stormwater treatment technology in a spill treatment role. The review revealed that the most likely candidates for such a dual-purpose role remain those structures that capture stormwater runoff for treatment or for runoff rate control.

If neither detention nor stormwater water-quality treatment is required, then a spill trap could be placed at outfalls from local highway drainage to impound the design volume should a spill occur. These structures could be placed in either a no-discharge condition (outlet works closed requiring maintenance to release stormwater after an event) or in an open-discharge condition (requiring first responders to close the outlet work if a spill incident occurred).

If detention is required, then the detention/retention structure with the outlet structured such that a certain volume must be exceeded before discharge occurs could serve as a spill trap. If stormwater runoff water-quality treatment is required, then a portion of the incoming volume could be set aside to act as a spill trap. The outlet works consideration defined above would apply.

An alternative is to place a spill trap off line of either detention or water-quality treatment (or both) with initial flows directed to the trap by a hydraulic splitter.

The variety of approaches for spill traps presented above should provide TxDOT designers flexibility in achieving reasonable designs should it be determined that a spill trap is required.

An agency-wide decision should be made concerning the outlet works for spill traps. It is important that there be uniformity in protocol so that both TxDOT personnel and first responders know whether the spill-trap outlet works are open or closed by default.

Key Words:
Hydrology, stormwater, hazardous materials spills,

Water quality monitoring of three field sites near Austin, Texas showed a 90% reduction of total suspended solids (TSS) compared to conventional pavement. Significant reductions were also observed for total copper, total lead, and total zinc though concentrations of dissolved constituents were not significantly different. An analysis of particle size distribution showed that runoff from PFC contained fewer large particles than that from conventional pavement. Consequently, the Texas Commission on Environmental Quality has approved PFC for use as a permanent Best Management Practice (BMP) for highways.

The hydraulic properties of PFC are of interest to assess the drainage capacity of the pavement and the effects of clogging. The properties investigated in this study were the porosity and the hydraulic conductivity. Porosity was measured from core samples and found to range from 0.12 to 0.23. Hydraulic conductivity was also measured from core samples and ranged from 0.1 to 3 cm/s. A new field method for measuring the in-situ hydraulic conductivity of PFC was developed and compared to the laboratory measurements.

Predictions of the water depth on PFC roads are needed to assist designers in selecting a pavement thickness and to evaluate the effects of clogging. A Permeable Friction Course Drainage Code (PerfCode) was developed to make these predictions. Measured porosities and hydraulic conductivities were used as inputs to PerfCode. Outputs were the variation of water depth through a storm and the runoff hydrograph. The modeled hydrograph compares favorably to runoff hydrographs obtained by field measurement.

The economics of using PFC as a stormwater BMP were evaluated against the alternatives of an Austin style sand filter and a vegetated filter strip. The most sensitive variable was found to be the cost of obtaining additional right-of-way. Using construction prices from the year 2008, PFC was more economical than a sand filter and becomes more economical than a vegetated filter strip as land prices rise.

Water quality monitoring has shown that runoff from PFC is of sufficiently good quality that the overlay itself can be considered a stormwater BMP. This finding means that using a PFC overlay, which likely would already be used for splash and noise reduction, satisfies stormwater treatment requirements for many projects. Using the road itself as the BMP avoids the need to design, build, and maintain more conventional stormwater treatment facilities such as sand filters. The principle cost savings of this approach come from reduced right-of-way needs (no additional land is required for a sand filter) and forgone material costs, especially the cost of drainage piping to the sand filter.

This project has shown that drainage should be considered in selecting the thickness of PFC layers. Current practice for establishing the thickness of a PFC layer focuses mostly on aggregate size: the layer must be somewhat thicker than the largest aggregate to obtain the desired structural properties. The aggregate size approach ignores the essential drainage functions provided by PFC. A better approach would design the PFC layer to contain a design storm event (e.g. 2-year storm), and then verify that this thickness exceeds the minimum established by aggregate size.

Designing PFC layers based on drainage considerations recognizes that wet weather safety benefits of PFC—reduced splash, spray, and hydroplaning—are directly related to the drainage function of the pavement. This project has developed tools to quantify the drainage process of PFC layers for steady state and unsteady conditions, and for simple and complex roadway geometries. These tools can be used to inform the design process.

Designing PFC layers for drainage requires information about the hydraulic properties of the pavement. This study has developed new methods for measuring the hydraulic conductivity of PFC from core samples and in-situ. The field test method is suitable for confirming that new installations of PFC comply with design requirements and for monitoring the performance of PFC layers as they age.

Key Words:
Permeable Friction Course,
Stormwater quality, Hydraulic
modeling, Permeability
measurement

The research team identified several areas that could be addressed to improve vegetation establishment. These recommendations are grouped in two categories, procedural and technical issues, and are based on data obtained from the literature and discussion with TxDOT staff.

Procedural issues are those dealing more with planning and management. Many of the problems cited in establishing vegetation are rooted in conditions that prevent the right information being available and applied at the right time or due to human errors, omissions in judgment, or application. These types of problems are related to project execution rather than any technical deficiencies.

- diversity of regional climates, soils, and plant communities
- current training practices
- pay items
- preconstruction process
- compliance
- district expertise

Technical issues are items that deal directly with the type or method of installation. These recommendations will apply only to those districts where they are suited. A thorough study of each district's needs, climate, resources, and other factors affecting re-vegetation will determine applicability of these recommendations. The result will be a detailed district standard, created with division and district personnel and tailored to their specific needs and conditions.

- seeding
- seed mixes
- seeding rates
- top soil recovery

Based on the results of this project, there are gaps in training for the vegetation establishment process that need to be filled, from the designer to the contractor to the inspectors. Designers may not have the necessary knowledge in soils and plants to make design decisions regarding vegetation. There are many TxDOT research reports, existing manuals and guidance documents, and specifications regarding the vegetation process available to the designer and other personnel. However, the majority of this information is found as bits and pieces in numerous documents and searching for these can be quite overwhelming.

Not all contractors are alike in knowledge base and performance. Many other DOTs are implementing training and certification programs for their staff, consultants, and contractors. These efforts will help ensure a better measurement of performance and accountability.

Training for TxDOT district personnel, construction managers and contractors could be combined into a program and be required for contractors after the job is let/won or as a prequalification. This training should include an emphasis on vegetation establishment, how it is accomplished, its role in regulatory compliance, and the TxDOT/contractor responsibilities.

The Vegetation Establishment Guidance for Decisions Assistance Tool was developed to further educate the designer not familiar with the vegetation establishment process and incorporate the existing available information in a readily assessable manner. The Roadside Vegetation Establishment Quick Reference Field Guide was designed to meet the needs of field personnel. The researchers recommend a training program using the VEGDAT for Engineers-in-Training and other TxDOT personnel tasked with decision-making regarding vegetation. This training may consist of a formal program or be structured as a workshop.

Key Words:
Vegetation Establishment, Roadside Seeding, Re-Vegetation

The literature review revealed a number of studies that attempted to characterize toll facility users. The most comprehensive studies uncovered have been for California's SR 91 Express Lanes. These studies provided a number of interesting observations as to the typical characteristics of the SR 91 toll road user. In addition, information for the North Texas Turnpike System, Pennsylvania Turnpike, and the Georgia 400 users, as well as the potential Central Texas Turnpike users, has provided some insight and offered interesting approaches to analyzing the demographic characteristics of toll road users.

Based on these studies, there seems to be a correlation between toll road usage and higher incomes, as well as higher education levels. The findings relating to toll road usage and gender seem to be less conclusive. CA SR-91 suggested a higher level of female users, whereas more males used the Pennsylvania Turnpike. Data for the Dallas tollways seem to suggest an equal gender split of cash users, but more male electronic TollTag users than female TollTag users. Also, the studies that collected information about the ethnicity profile of toll road users concluded that the majority of the users were White/Caucasian.

A number of important insights were obtained from the statistical tests that were conducted to determine the association between toll road usage and specific demographic variables. Some of the salient findings include the statistical association at the 95% confidence level between toll road usage and household income, age, household structure, household size, the number of vehicles available to households, and employment. In addition, no statistical association was found between ethnicity and toll road usage or education and toll road usage at the 95% confidence level. Finally, the data analysis revealed a statistically significant difference between the gender profile and home ownership profile of toll road and non-toll road users. Specifically, a higher percentage of males use toll roads and a higher percentage of home owners use toll roads.

Researchers also aimed to characterize the trip characteristics of toll road and non-toll road users in Central Texas by type of trip, i.e., commuter trips, non-work related trips, and work related trips. It should, however, be noted that although respondents were characterized as toll road users it did not equate to those users using toll roads for all trip purposes or for all trips of a particular trip type. Rather, toll road users were respondents that indicated that they have used Central Texas toll roads. Some of the salient insights were the statistically significant difference between the commuting profile of toll road and non-toll road users. Furthermore it appeared that toll road users commute less frequently than non-toll road users and most toll road users that commute to work do not use a toll road for every commute trip. Also, a major reason for not using toll roads by both toll road users and non-toll road users for all three trip types were that no toll road alternative was available or a viable alternative to existing routes used. Finally, the data revealed that a higher percentage of toll road users that do not use a toll road because it was not available indicated a willingness to use a toll road alternative if one were available.

Toll roads are unique in that a substantial amount of information can be gathered from each tag that crosses a toll plaza. Acquiring and analyzing this data provides insight into the usage of the toll facility. For example, available data from toll transactions include the registered billing address, type of account (commercial or non-commercial), axle count, payment method, and time of day that the transaction occurred. Such data can thus be used to characterize the users of specific toll facilities in terms of these attributes. On the other hand, because of the nature of the available data there are some limitations to the analysis. For example, specific demographic characteristics, such as income, are often not linked to toll tag records nor are reasons for using the toll roads. These types of information can only be obtained from surveys.

Key Words:

Central Texas Turnpike System, toll roads, demographic characteristics, trip characteristics, toll road users, toll transactions

A comprehensive literature review and analysis of available commercial toll road usage data suggested substantial variability in truck toll road usage given the characteristics of the tolled facility, the truck market segment, and average trip length. In terms of the characteristics of the tolled facility, a local toll bridge or tunnel, for example, could attract a high percentage of truck users if the (a) tolled facility is on the shortest, fastest route to and from the trip's end points, (b) toll charged is comparatively low compared to the incremental variable cost to operate on an alternative non-tolled route, and (c) if everyone has to use the toll facility as no non-toll alternative exists.

To improve the robustness of truck toll road usage forecasts, it is also important to acknowledge that the trucking industry is not homogenous. The trucking industry can be divided into a number of segments based on, for example, service area, vehicle ownership, fleet size, or type of carrier/operation. Although these segments are not necessarily mutually exclusive, it is important to recognize the different segments when trying to understand a trucking company's decision to use or avoid a toll facility. An owner-operator may, for example, avoid using a toll road at all costs, while a fleet owner may weigh the costs and benefits before making a decision about using a tolled facility. Finally, in terms of trip length it was found that cost/benefit was a significant factor in the route selection of long haul truckers as these companies typically have more non-toll route choices available.

The statistical analyses conducted provide insight into the characteristics of the truck users and non-users of Texas toll roads, as well as the differences between truck users and non-users of Texas toll roads. Some of the salient findings included:

- The “type of operations” profile of truck users and non-users of Texas toll roads differ. Truck toll road users were mostly private carriers (30% of toll road users), followed by TL carriers (28%), and LTL carriers (15%). On the other hand, the majority of the non-users of Texas toll roads were TL carriers (36% of the toll road non-users), 25% comprising the “other” category, and 14% owner operators.
- There is a statistical difference in the perception of toll road users and non-toll road users as to the impact of congestion on their business. In other words, a higher percentage of truck toll road users indicated that their operation is impacted by congestion than non-toll road users.
- There is a statistical difference between the proportion of toll road users and non-toll road users that have a delivery window in which to deliver the major commodities transported by their company. A higher percentage of truck toll road users indicated that they have a delivery window in which to deliver the major commodities transported by their company than non-toll road users.
- There is no statistical difference between the proportion of toll road users and non-toll road users that transport time sensitive commodities. However, 50% of the truck toll road users reported that their company makes most of their deliveries during the morning peak hours (i.e., between 7:00 and 9:00 am) as opposed to 43% of the non-toll road users who indicated that their company makes most of their deliveries between 9:01 am and noon.
- There is a statistical association between the level of support for the construction of additional Central Texas toll roads and toll road usage. In other words, a statistically higher percentage of toll road users indicated support or conditional support for the construction of more toll roads in Central Texas than non-toll road users. Furthermore, it was found that toll road users also ranked toll roads more favorably than non-toll road users in terms of (a) providing an alternative to congested freeways, (b) having superior pavement quality, (c) providing a faster alternative, (d) toll rates being reasonable considering the benefits, (e) providing a safer alternative, (f) providing more predictable travel times, and (g) providing an alternative in emergency situations.

Key Words:

Central Texas Turnpike System, toll roads, truck market segments, toll road users, toll transactions

The marginal cost on that part of the network used by these vehicles needs to be calculated, regularly updated, and then allocated to the users benefiting from their introduction. This issue—that the beneficiaries pay—is now broadly accepted by the U.S. trucking sector. The study team found, through transportation literature, company interviews, and discussions with the study operator panel that the industry is willing to cover the marginal costs created by operating larger trucks. The reason for this willingness is simple—the ability to derive any further benefit in cost per ton-mile units from improving current truck designs is severely limited. In fact, trucks may get heavier and face reduced future payload limits. That the industry is now willing to pay the marginal costs for a range of products on key corridors should be a defining moment in the long discussion over how to allow truckers to benefit from economies of scale, as other modes have done since 1990.

The result for one type—the 90-kip double 53—was expected because the weight carried by each axle is substantially less than the fully loaded 80,000 lb vehicle currently permitted to operate over the federal system. The evidence is that very little of the pavement system would need to be strengthened and that a modest increase in permit or registration fees would cover the marginal cost for pavements impacted by the vehicles. The results of the pavement analysis are shown through the estimated changes in the annualized costs of periodically overlaying the pavements if LCVs were allowed on these routes. The cost is defined as the difference between the annual cost of pavement with LCVs and the annual cost of pavement without LCVs. Depending on the price of construction, allowing LCVs on the Dallas–El Paso and Dallas–Laredo routes could result in a savings of \$17.4 to \$53.1 million per year. The Dallas–Houston route is rigid pavement and the LCV scenario has no impact on rigid pavement life. The San Antonio–McAllen route exhibited a slight increase in cost of \$0.14 to \$.044 million per year. The researchers recommend a more detailed study encompassing several scenarios to accurately ascertain pavement impacts. Note also that the operator panel stated that some LCVs on some route segments would be running empty, and this scenario would need to be factored into the more detailed work that could be undertaken during a pilot study.

The 90-kip double 53 configuration showed no impact on the bridges of the selected case study routes for both overstress ratios. This result is one of the few occasions that an LCV operation has had no impact on bridges while an amount of truck vehicle miles traveled (VMT) is registered by trucks that cube out because of commodity characteristics. The results for the remaining types when loaded with commodities that weigh out vary by type; impacts for a 20% overstress over Inventory Rating amount to \$1.1 billion for the 97-kip tridem and \$1.0 billion for the 138-kip double 53. Impacts for a 10% overstress over Inventory Rating are higher and amount to \$2.8 billion and \$1.2 billion for the 97-kip tridem and 138-kip double 53 respectively. Another set of results were calculated using the newer bridge analysis based on the fatigue concept. This analysis showed the impacts amount to \$1.0 billion and \$0.8 billion for the 97-kip tridem and 138-kip double 53 respectively, with no impacts for the 90-kip double 53 configuration. Bridge Inspection and Appraisal Program (BRINSAP) data are extremely useful for policy analysis but those bridges that failed as part of the impact-estimating process would need to be examined in the field by a registered bridge engineer to determine, more precisely, the recommendations. Bridge replacement can be avoided in some cases by “retrofit” activities that can be undertaken under traffic—avoiding the cost of replacement and the associated user costs while the construction is taking place. If Texas were to permit LCV operations, bridge impacts would have to be addressed and remedies undertaken. But other large networks have faced this situation—the European Union (EU), for example—and the magnitude of the study bridge cost estimates on the key state corridors can be covered by fees collected over the life of the assets.

A pilot study was suggested that would allow industry representatives, highway engineers, and researchers to gain data on LCV operations while working closely with the trucking industry to devise a feasible, safe, and efficient way to allow LCVs to operate in Texas.

Key Words:

Long Combination Vehicles, LCVs, 97-kip tridem trucks, more productive trucks, heavy duty truck safety, LCV pavement impacts, LCV bridge impacts, Texas truck corridors, LCV pilot study

Radio frequency identification device (RFID) technology is a relatively mature technology that continues to improve. It is widely used in a wide variety of applications in many different sectors.

RFID technologies have been adapted to underground utility management by several manufacturers. These manufacturers' products can be installed at the time of utility installation or retroactively to indicate the presence of the underground utilities. Different products provide different levels of identification. These include: 1) A marker that emits a specific frequency. Frequencies are assigned to specific types of utilities. This provides the ability for someone to determine that a particular type of utility is located underground at that location. No additional information is provided, and 2) A marker that provides specific information that is programmed into the RFID marker at the time of installation. This type of marker is a proprietary product that requires a proprietary sensor to program and read the RFID marker.

There is an extensive system of assets in the TxDOT ROW. It would require an extensive time to mark a sufficient portion of the assets with RFID for such a system to provide benefits.

It would be expensive to retroactively install RFID for underground utilities. However, if not retroactively installed, then the status quo methods of identifying underground utilities would also have to continue to be used, providing little benefit to the use of RFID.

Other state transportation agencies are not using RFID technologies for ROW management on a widespread basis.

One state DOT has successfully used RFID technology for marking underground utilities as part of a utility relocation project that precedes a roadway construction project. This application provides the most likely means of implementing RFID for underground utilities in a manner that would be cost beneficial.

Other information delivery methods or technologies (not assessed as part of this project) could provide a more effective means of obtaining some information about ROW assets.

Key Words:
Radio Frequency Identification,
Right-of-Way Assets, Right-of-Way
Management

The majority of Federal Transit Administration (FTA) funds are allocated based on population and population density. Texas' share of the total population for urbanized areas between 50,000 and 199,999 in population has increased from 8.6 % in 2000 to 9.4 % in 2008. Texas' share of the total population for non-urbanized areas has grown from 6.8 % in 2000 to 7.2 % in 2008. Texas has seen increases in the disabled, the elderly, and low income persons. The implication of these demographic trends means that Texas will see greater demand for public transportation services.

The ratio of urban and rural population eligible for funding under the Texas Transit Funding Formula may change. The current percent of state funding allocation is 35 % to urban and 65 % to rural. This actual ratio of rural to urban population for the 2000 baseline is 38 % urban and 62 % rural. The proportion of population in state funded transit districts will increase for urban as compared to rural according to projected 2010 population.

Four transit providers in Texas are designated as "limited eligibility providers". These transit providers restrict transit eligibility to seniors and people with disabilities. The Texas Transit Funding Formula currently sets aside 6.58 % of the urban funds for limited eligibility providers based on the Census 2000 eligible population calculation. Because of changes in the data collection process, the number of eligible seniors and people with disabilities in 2010 may be less than in 2000 reducing the percent of state funds set aside for limited eligibility transit providers.

Transit investments per capita are declining. Assuming no new funds, per capita investment in transit will decline with the 2010 Census data. State funds are \$10,059,374 per year for urban transit districts and \$18,681,694 for rural transit districts. The annual allocation of Federal Section 5311 funds under the Texas Transit Funding Formula is \$20,104,753 to rural transit districts. Without an increase in funding, the growth in 2010 population means the investment in public transportation will be less per capita than the existing baseline using the 2000 population.

Funds are needed to avoid negative impacts. Without new funds, current state dollars will be reallocated to provide funding for needs and performance for new urbanized areas and to provide funds for urban and rural transit districts with higher growth rates. The same redistribution occurs for Federal Section 5311 funds for rural transit districts. Without an increase in federal funds to address growth in population, the Texas Transit Funding Formula will reallocate funds from some rural transit districts to increase the resources for other rural transit districts. The reallocation of funds means many transit districts will lose funding in order to redistribute dollars to the transit districts with higher population growth.

- Sources of Data for Allocation of State Funds for Performance – when areas that were previously part of rural transit districts become a new urban transit district, there is a history of service. TxDOT will need to develop new procedures to establish the performance statistics that will be used to generate performance funds for the new urban transit district.
- Metropolitan Planning Processes – new urbanized area stakeholders must anticipate the change in status, as new urbanized areas are required to meet requirements for the metropolitan planning process in order to be eligible for Federal Section 5307 funds.
- Gaps in Providing Transit Service – as urbanized areas expand, there are increasing possibilities that some areas are not included within the jurisdiction of a transit provider. Stakeholders should begin the conversation to determine how transit service will be delivered and funded after new urbanized areas are announced.
- American Community Survey – ACS provides frequent and timely information about the characteristics of the population. While the availability of these data will benefit planning for services, the change in the collection of these data from a once in 10 years to a continually collected survey will provide unique challenges to interpretation and use in allocation formulas.

Key Words:
Public Transit, Government
Funding, Census

Researchers found through case study research that although the environment plays some role in performance, there are other factors that management can control or influence to improve operating effectiveness and efficiency. Researchers grouped these factors into four major categories.

Factors that contribute to growing ridership include the following:

- Engage city and county officials in transit—find champions for transit.
- Actively seek out areas with transit-dependent communities.
- Work with major manufacturers, plants, and industries to serve worker shifts.
- Consistently attend and actively request to speak at community events and meetings.
- Work with colleges, universities, and school districts to provide transit routes and create cooperative agreements.
- Work with health and human services and medical facilities to serve patrons.
- Drive routes and monitor for new service needs.

Factors that contribute to managing cost include:

- Actively seek in-kind contributions to support transit.
- Work with cities and counties in supplying fuel at lower-cost bulk rates.
- Utilize fuel cards (state or private) to monitor fuel usage and cost.
- Use sub-contractors at cost-effective rates where appropriate.
- Utilize sub-contractors to provide service during low-demand times of day on a trip-by-trip cost basis.
- Ensure contract rates are appropriate and cover both operating and capital costs.
- Allocate administrative and overhead costs across programs.

Factors that contribute to decreasing vehicle miles or maximizing labor productivity include:

- Create satellite parking sites to minimize deadhead, with spares located throughout the service area (seek in-kind contributions for parking).
- Create cooperative agreements with other transit districts to utilize vehicles when in other transit-district service areas to minimize downtime/idle time and maximize productivity.
- Utilize scheduling systems to maximize grouping of trips and minimize slack time.
- Utilize vehicle locator systems to find the closest vehicles, provide quality information to patrons, map scheduled trips to ensure trip reasonableness, and verify no-shows.
- Cross-train staff to provide backup and improve staff productivity (match senior staff with new trainees).
- Monitor/manage driver overtime.
- Monitor vehicles to proactively troubleshoot late trips and take “will-call” or same-day trips to fill the slack.
- Create both full-time and part-time driver schedules to match service demand.
- Group trips without dedicating vehicles to trip types—shared-ride general public service.

Factors that contribute to improving administration include:

- Run weekly/monthly reports to monitor/manage driver productivity, passenger complaints, passenger no-shows/cancellations, absenteeism, vehicle inspections, vehicle repairs (repeats), client travel times, and client wait times.
- Require vehicle operators to turn in paperwork and fares on a daily basis, with finance staff providing receipt and reconciliation.
- Ensure quality maintenance with priority turnaround through maintenance agreements.
- Monitor preventive maintenance and fleet issues to prevent costly repairs.
- Regularly communicate to passengers rules/regulations. Create a partnership with patrons to meet vehicles on time.
- Follow up with complaints quickly to nurture the patron-transit agency relationship.

Key Words:
Benchmarking, Peer Analysis,
Public Transportation, Performance
Measurement

The research project resulted in a very powerful yet user-friendly toolkit, whose application complexity falls between a regional travel demand model and a stand-alone corridor analysis, while providing a host of new and increasingly critical outputs and costs. In this way, toolkit users obtain a preliminary estimate of system-wide project impacts, often before conducting a more detailed analysis of demand patterns using a full-network demand model.

The toolkit estimates changes in traveler welfare (accounting for changes in travel times and operating costs) as well as travel time reliability, crashes, emissions, fuel use, and tolling revenues. It summarizes individual component impacts while providing economic summary measures. This allows users to comprehensively evaluate and compare scenario alternatives in a robust and consistent framework. Such estimates can prove highly cost-effective for agency budgeting and project-targeting decisions.

The preliminary version of the toolkit provides a set of basic functions and procedures to estimate travel demand changes, assess environmental impacts from vehicle emissions, evaluate safety improvements, and conduct a comprehensive economic analysis over the design period of a variety of transportation projects on the sketch planning level. The modularization design and open architecture of the toolkit make its functionalities to readily be expanded and enhanced.

The travel demand modeling module of this toolkit can estimate travel demand pattern changes by origin and destination, time-of-day, mode, and route over networks. The capacity, cost, and other attributes are all associated links of node-link networks, while nodes only provide the network connectivity. Any supply change reflected by link attribute change can be evaluated by the current version of the toolkit. Some more detailed modeling requirements, such as lanebased toll policy (e.g., HOV/HOT lanes) or an explicit evaluation of intersection delays, need the network modeling as well as the travel demand modeling procedure on a finer level. Moreover, network changes accommodated by the current version have to be time-varying. To model a time-dependent travel demand management policy (e.g., a time-varying tolling system), the network supply model will need to incorporate the time dimension into its data structure.

This and several other meaningful improvements are envisioned for the near future, as the research team pursues related work via a TxDOT-funded implementation project and a highly related TxDOT research project, #0-6487 (which seeks to similarly evaluate operational strategies, like speed harmonization and ramp metering). Thus, the toolkit will be enhanced with more capabilities and it will be applied to a variety of Texas regions, demonstrating its applicability for a variety of contexts. It is hoped that it will one day rise to national prominence, as transport budgets tighten everywhere, and project scrutiny and modeling sophistication (and expectations) rise.

Key Words:
Sketch Planning, project evaluation, travel demand modeling, vehicle emissions modeling, benefit-cost analysis

This research identified best practices and lessons learned from interviews with airport, transportation agency, and shipper representatives, as well as the case studies and associated field observations. These best practices represent success stories that are already in place or planning processes to address future freight activity. These practices, or modifications of them, have enhanced landside freight access to airports or are planning practices that should enhance access when the time comes for implementation. These findings offer airports and related agencies ideas on how to improve their freight access. It is understandable that it may not be possible to implement all of the best practices at any single airport.

In summary, the best practices identified in this research project include:

1. Airports should include all stakeholders early in the airport freight-center development or expansion.
2. Wayfinding should include consistent signage and begin in Area of Influence 1—on the controlled-access roads farthest from the airport.
3. Intersection geometrics should be sufficient to accommodate long-wheelbase trucks.
4. Airports should minimize distances between nearest controlled-access highways and the freight center, and select connection routing with minimal incompatible land uses.
5. Airports should address intersection and access-management issues when adapting to the existing roadway network.
6. Airports should identify all potential funding sources when improving freight access, including public-private partnerships.

The research team made some field observations related to pavement conditions on roads at or near airports. Visual observations can be misleading, however, and specific studies need to be performed related to pavement design needs. Based on the Midland-Odessa brainstorming process, as well as interviews with various agency representatives, a next step would be to study and develop planning processes and associated land-use regulations related to freight-center development at airports, rail centers, and other freight-traffic generators.

Key Words:
Landside Access, Airports, Freight,
Trucks, Wayfinding, Geometrics

There is no guaranteed way to determine if a rail line will become abandoned in the future. Many short line railroads are able to operate effectively despite their less-than-ideal conditions. A change in the economic conditions or operating strategies may shift traffic back onto a corridor that was previously lightly utilized. Many potential uses exist for preserving abandoned rail corridors and the state should develop laws and policies that allow for maximum flexibility in preserving rail corridors as future transportation assets.

TxDOT and local/regional planners should continue to monitor the rail system for low-traffic freight rail lines that may be in danger of abandonment. Planners should work cooperatively with private railroad companies to explore options for keeping freight rail lines in service, but should abandonment be imminent, options for preserving the corridors should be investigated. Care and forethought must be taken in how such policies are implemented. The federal “rail banking” concept is one possible policy option for rail corridor preservation. Putting a corridor into “interim trail use” status under this program leaves the corridor susceptible to future reactivation by the railroad company when/if sufficient freight traffic in the corridor warrants. As a result, such programs must be used with prudence to ensure that large public infrastructure investments in a corridor are not later lost to rail line reactivation. On the other hand, corridors capable of being purchased as “fee simple” from the railroads or adjoining land owners have been successfully used in the past for roadway construction and expansion and transit development.

Preserving abandoned rail corridors as future transportation assets should become an accepted and promoted practice within TxDOT. Legislative changes to make abandoned rail corridor preservation and re-use more clearly within TxDOT’s authority, while desirable, are not required for TxDOT to take a more proactive role in doing so. Preserving all potential transportation corridors for rail or alternative uses will increase in importance as the state’s population grows.

Key Words:
Abandoned Rail, Corridor
Preservation

TxDOT has invested in a number of models, such as the Statewide Analysis Model (SAM), to inform transportation policies. The understanding of freight demand and the evaluation of current and future freight transportation capacity are, however, not only determined by sound models, but is critically contingent on the availability of accurate freight data. In this regard, insufficient and inferior quality data is the most commonly cited challenge in the development of freight models. In addition, this research study presented a list of recommended freight performance measures for Texas. Reliable and robust freight data are also critical to the development of these freight performance measures—whether they are used to assess concerns and deficiencies or to prioritize investments. Specifically, most of the data needed to quantify the rail performance measures needs to come from the railroad companies. Some of this information is sensitive and some stakeholders pointed out that the rail companies would be unwilling to make the information available. *It is thus recommended that TxDOT develops and populates an architecture that will facilitate the collection of reliable, comprehensive, and robust freight data.*

The requirement for data and the importance of developing appropriate freight performance measures for Texas need to be communicated with the private railroad industry and an agreement for information needs to be reached to enable TxDOT to plan and facilitate a multimodal freight transportation system that meets the needs of Texas shippers. In Texas, freight movements have and are expected to continue to increase substantially due to sustained and anticipated economic and population growth combined with Texas's optimal location along critical trade corridors. Forecasts of freight demand clearly demonstrate that freight transportation by all modes will continue to grow in Texas. Good freight planning will thus become critical to ensure that Texas's infrastructure can accommodate the estimated increases in freight demand. *It is thus recommended that the work that has been conducted as part of this research study be extended and that a detailed "standalone" freight plan be developed for Texas.*

Finally, a number of states have benefitted from engaging the private sector as stakeholders (i.e., Freight Advisory Committee/Stakeholder Working Group) when conducting statewide freight planning. The potential role of a Freight Advisory Committee/Stakeholder Working Group can be to (a) assist an agency in identifying freight transportation needs, (b) provide input on freight transportation policies and the development of freight performance measures, (c) assist in the identification of funding opportunities and partnerships between the public and private sectors, (d) assist in the prioritization of freight concerns, (e) communicate the importance of freight investments to the public, elected officials, and other public agencies, and (f) recommend freight research areas and needs. During this research study, 35 companies and agencies expressed an interest in working with TxDOT in developing and implementing a Freight Stakeholder Working Group for Texas. *It is thus recommended that the mission, purpose, objectives, and mandate of a Texas Freight Stakeholder Working Group be explored during a meeting of interested freight stakeholders.*

During such a meeting, a FHWA freight peer exchange can be hosted that would allow other state DOTs that have an established Freight Advisory Committee or Stakeholder Group to share, their mandates, roles, and objectives, as well as successes, benefits, and challenges that have been experienced. At the conclusion of the peer exchange, attending stakeholders can work together with TxDOT to decide on the concept for Texas, as well as the mandate, role, and objectives of a Texas Working Group.

Key Words:

Freight Planning, Texas Commodity Flows, Freight Performance Measures, Freight Stakeholders, Economic Generators

Review of Technical Design and Engineering Requirements for Utility Accommodation in Texas

In general, piping systems should be designed to perform from 50 to 100 years since both government and private sectors cannot generally afford to replace pipe systems at less than 50-year intervals. The service life is not just a function of pipe material itself, but is mainly tied to the loading or environmental conditions to which the pipe system is subjected.

Preliminary Assessment of the Utility Accommodation Rules (UAR) Adequacy to Deal with Overweight Loads on Buried Utilities

The sensitivity analysis found that depth of cover was the most significant factor for predicted damage ratio. Modeling HS-20, HS-25, and HS-30 design trucks typically used for bridge design, the researchers found that typical 24-in. pipes under an unpaved surface require a minimum depth of cover of 36 in. With a depth of cover of 24 in., the damage criterion was exceeded for both HS-25 and HS-30 trucks. The researchers predicted similar results for PVC, ductile iron, and clay pipes. As a result, the current exception for existing water and sewer lines at a depth of 24 in. may not provide sufficient depth of cover to adequately protect the buried utility facility. The current requirement of 30 in. minimum depth of cover below highway ditches may be sufficient for HS-20 and HS-25 axle weights, but is probably insufficient for HS-30 axle weights. The analysis also confirmed the increase of the required depth of cover for new utility installations in 2009 was warranted, and may have to be increased further in the future. The results also provide that utility facilities installed before 2009 are at a potential risk of damage, and facilities installed before 1979 even more so.

Preliminary Assessment of Potential Impact of Overweight Loads on Buried Utilities

This outreach effort did not identify any incidence of damage to buried utilities within the right of way due to overweight loads. Thus, in lieu of case studies, researchers conducted a sensitivity analysis to evaluate the effects of various risk parameters on the potential damage to buried utilities due to overweight loads. This sensitivity analysis used existing design criteria obtained from a review of current specifications. The general finding from this Phase 1 analysis suggests that current design standards appear to be adequate. However, in light of the fact that piping systems are typically designed to perform about 50 to 100 years, some piping systems in place today may have been installed before rules for underground utilities were codified in the Texas Administrative Code in 1979, and thus may have been installed using a lower standard. Although the outcome of the outreach effort that did not identify any incidence of traffic-associated damage to buried utilities within the right of way implies that current design standards are adequate, it is unclear to what degree these standards protect buried utilities from repetitive overweight loads. Determining the impact of such repetitive loads on buried utilities is subject to the Phase 2 utility damage evaluation in the second year of this project.

Preliminary Recommendations for a Business Process for TxDOT Overweight Routing Coordination

The research team found that currently, there is no organizational unit within TxDOT that could provide data on critical, buried utility infrastructure. Furthermore, the team was thus far unable to identify locations of critical, buried utility infrastructure with the help of utility stakeholders, although the research team took several steps to reach out to the utility community.

The researchers conducted several outreach efforts and research activities to identify cases of buried utilities damaged by overweight loads. However, these efforts did not produce any cases where damage to buried utilities was attributable to overweight loads. Since the research team was unable to find any such cases, there was no opportunity to develop a preliminary business process for TxDOT overweight routing coordination to protect critical buried utility infrastructure. Instead, the research team proposed a modification to the research plan to include the development of this process in the second project year, if needed, as more information from the Phase 2 Utility Damage Evaluation becomes available.

Key Words:
Utility Accommodation Rules, UAR, Underground Utility, Utility Damage, Pipes, Heavy Load Damage, Overweight Load

To effectively implement the framework, policy makers and the public must understand and buy into its benefits. Travelers require a fundamental understanding of what measures are being used to determine performance and how changes in those measures affect their daily travel to motivate them to support traffic management projects. Since the general public does not have the technical knowledge that subject matter experts have, this information must be communicated in a way that is easily explained and easily understood. This project created tools that communicate to the policy-makers and the general public what performance measures are, why they are used, and how they may lead to operational changes. The guiding principles and detailed decision framework was translated into reader-friendly, layman's terms. Much as the performance measures must be meaningful to enable successful operation, the communication of the principles must be meaningful to the ultimate audience. The traveler must understand that operations may be altered to ensure the promise of superior performance.

Researchers produced a user-friendly toolkit aimed at educating policy-makers on how to best explain the performance promise and ROI concepts to the general public. The toolkit is designed to be modular so that each individual component may be modified as situations require and individual components may be used independently of one another. Further, to make the purpose of the framework meaningful to the public, the team dubbed it the Traffic Thermostat™ due to the similarity of its function as a regulating tool to the thermostat of a central heat and air conditioning system.

These tools explain the purpose of the Traffic Thermostat™ and its importance to facility operations, as well as provide sample documents for district engineers and others to use in describing the benefits of the framework to policy makers and the general public. The tools developed are:

How-to Guide for Using the Traffic Thermostat™ Managed Lanes Decision Tool Software - This document guides users in using the software, which allows operators to input data to determine potential solutions for operational problems. This is the technical piece of the toolkit and most likely will not be utilized by the public. However, it is available for the policy-makers and public should they care to delve deeper into software.

Talking points - These comprise the essential concepts and messages aimed at helping the public understand the value of performance measures, how they help to objectively regulate policy development, and how the public can benefit from policy guided by the Traffic Thermostat™.

PowerPoint Presentation - This presentation emphasizes the rationale behind the Traffic Thermostat™, the need for performance measures, and how these effectively guide policy-making. The presentation is flexible and modular in design, suitable for presenting to policy makers and the public alike.

Sample Press Release - Policy-makers can adapt this sample press release to promote traffic management to the public in their local areas. Core messages in the sample press release coincide with those presented in the Talking Points and PowerPoint Presentation.

FAQsheet - This FAQsheet emphasizes the rationale behind the Traffic Thermostat™, the need for performance measures, and how these effectively guide policy-making.

Feedback Framework - This sample survey of questions will help TxDOT secure feedback regarding the efficacy of the Traffic Thermostat™. The survey is flexible and adaptable to rural and urban environments. It suggests the kinds of questions to ask for use in evaluating how the Traffic Thermostat™ and performance measures are useful in a particular area. Moreover it provides a valuable feedback mechanism to test the public's understanding of the rationale for various policy decisions and their reaction to those decisions.

Key Words:
HOT, HOV, Managed Lanes,
Operations, Tolls

The issue of urban gaps is significant. Based upon the 2000 Census, 2.9 million Texans fell into urban gap areas, representing 14.1 percent of the state's population. Notwithstanding the creation of new urbanized areas, the estimated size of the urban gap that will emerge from the 2010 Census grows to 4.2 million Texans. Almost one-quarter of the residents in urbanized areas will reside in urban gap areas. About 15 percent of those people will be living in poverty status (defined as 150 percent of the federal poverty standard).

The largest gap areas are found in the major metropolitan areas. However, several smaller urbanized areas already have sizable gap areas, and those areas are likely to grow. At the same time, Texas has several examples of communities finding ways to provide transit services within these gaps. Texas is not alone in facing this issue. How are gaps filled? The list below offers suggestions:

Urban/Rural Joint Providers. One of the most straightforward ways to fill the gap is to dissolve the urban/rural boundary and have a single operator for the region. Service is provided across the entire region without regard for city or urbanized area boundaries. This is consistent with the state's desire to improve transit coordination.

County Sponsorship. In the case studies, there are several examples of county governments that rallied to fill in the serve gaps within their region. Harris County, Texas, is one location where county government took up the task of serving residents who were not served by the major regional transit authority. These agencies typically contract with private and/or public transportation providers to deliver services.

Existing Transit Operator. Existing operators often have at least the partial infrastructure to provide service in gap areas. In the Dallas/Fort Worth urbanized area, CCART is providing service to a portion of the urban gap. Houston METRO provides commuter services in Harris County through an extension of nearby park and ride services. The T in Fort Worth serves as the coordinating agency for services in Tarrant County outside the transit authority's jurisdiction.

Lack of sustainable funding is a key barrier to service in urban gap areas. In order to develop transit services in urban gap areas, transit agencies often use Section 5316, 5317, and CMAQ funding as seed money for demonstration projects for periods of one to three years. These funding sources do not provide sustainable funding beyond the initial grant term. When funds expire, transit services in an urban gap may end if the transit provider does not identify other sources of sustainable funding.

By definition, urban gap areas have no agency that is inherently responsible for public transportation. There must be an individual or agency that is the champion for the transit service. Harris County Transit exists as the result of the County Judge's concerns about non-emergency medical transportation throughout the county. He convened a task force of transportation, social service, and health care representatives to explore options for meeting needs outside the Houston METRO service area (and, in some cases, even within the service area). Those efforts led to the creation of Harris County RIDES and later Harris County Transit.

The service champion's role has been to generate support. Urban gap service (outside of the cases of joint urban/rural transit agencies where the gap is eliminated) is not directly operated by the champion agency. Instead, champions recruit the assistance of existing public and private providers through service contracts.

One particular benefit of service partnerships is reducing the cost of services. Harris County Transit commuter services are operated by Houston METRO as extensions on existing METRO commuter services. The cost to Harris County represents an incremental cost essentially to add the new stop; if Harris County operated these services separately, the cost would be significantly higher.

Key Words:
Public Transportation, Transit,
Funding

Listed below are selected key findings from a review of funding needs, sources, and scenarios:
There are no dedicated funds for rural planning organizations (RPOs) from federal sources.

RPOs in Texas are voluntary organizations and do not currently receive dedicated state funding.

Rural planning activities in other states are generally funded using State Planning and Research (SPR) funds. The level of funding for RPOs varies among states.

The most likely source for funding RPOs in Texas is from an existing source such as SPR funds or State Highway funds.

The possible funding categories that RPOs can use for projects under the TxDOT Unified Transportation Program (UTP) are:

- Category 4: Rural Connectivity.
- Category 8: Safety.
- Category 11: District Discretionary.
- Category 12: Strategic Priority (pass-through toll).

Funding for RPOs in Texas should include a combination of sources:

- State funding.
- RPO member contribution, dues, or in-kind contributions.
- In-kind contributions from partnering and host organizations such as councils of government (COGs).

The level of funding in Texas for RPOs should be commensurate with the preparation of planning and programming work products, and meeting planning requirements.

- Most rural planning and programming duties and responsibilities are currently conducted by TxDOT districts and divisions.
- An RPO's estimated need would be \$10,000–\$25,000 per year to accomplish RPO *Scenario I*. This scenario would include policy board meetings, public involvement, and coordination activities with TxDOT districts performing the required technical planning and programming functions. The RPO *Scenario I* would function primarily as a volunteer decision making forum and public involvement venue and vehicle.
- An RPO's estimated need would be \$25,000–\$75,000 per year for RPO *Scenario II*. This scenario includes having the RPO conduct technical planning, programming, and public involvement functions in addition to functioning as a decision making forum. Planning work products would need to be approved by TxDOT.

RPOs should continue to be voluntary organizations.

RPOs should be composed of local elected officials, TxDOT district engineers, and public transportation representation.

RPO boundaries should be flexible and honor existing and historical rural transportation planning relationships and jurisdictions. The geographic and demographic diversity in Texas would not support a one-size-fits-all approach for jurisdiction and administration.

RPOs should be:

- Decision making forum.
- Policy committee with elected representatives.
- Public involvement vehicle.
- Elevate the RPO's role from consultation with TxDOT to cooperation with TxDOT in the development of transportation plans and programs.

Key Words:
Rural Planning Organization, Rural Transportation Planning

This report reviewed the technical, legal, and political considerations of shifting more transmission development into the ROW or along highway corridors. The report illustrates the technical challenges of co-location and also the perceived benefits in terms of increasing land utilization, reducing environmental impacts from transmission construction and reducing conflicts with private landowners. Researchers also examined the current state of technological trends for transmission development and explored the policies that have been enacted in other states to spur or enable transmission development alongside transportation corridors.

The researchers conclude that at present, the location of transmission alongside transportation is a reasonable and achievable goal. While there are *incongruencies* in the comparative planning regimens of TxDOT and transmission developers, none seem to present an unbreachable barrier to successful joint development. There are numerous examples of successful installations around the country. In most cases, these alignments are placed just outside of the highway right of way on private land, though in a few cases they have also been placed within the ROW. Avoiding conflict with landowners and preserving landscapes was found to be the primary motivation for co-location.

If TxDOT wants to take a stronger role regarding transmission line development, three main elements would be required before TxDOT could shift to purchasing ROW and effectively and efficiently developing transmission lines within ROW. These are:

1. Federal and state codes would need revising if TxDOT wanted to purchase extra ROW to accommodate utilities.
2. Relationships with the utility developers, PUC, ERCOT, and other groups would need to be developed so that TxDOT could develop internal mechanisms for facilitating utility development.
3. Safety, engineering, and other liability elements would need to be reviewed to develop administrative and other in-house guidance for both TxDOT and utility entities.

Given the policy focus of the FHWA 2009 longitudinal guidance, there is now greater latitude for states to program for the installation and accommodation of utilities (especially to achieve RPS policies) within their transportation planning activities. The research team recommends TxDOT develop a procedure to include utility development and construction in its transportation planning process.

In light of the FHWA's 2009 guidance, researchers recommend that TxDOT request the legislature to place within regular transportation code in Chapter 224 the language regarding purchase of ROW for utility development that is currently found in Chapter 227 of the Texas Transportation Code. The allocation of ROW for transmission would then become part of the duty of the transportation commission and commissioner's courts as part of their planning processes. This would allow TxDOT and local jurisdictions to develop a multi-modal infrastructure network to perfect and extend an integrated system of multimodal infrastructure networks.

TxDOT already has a highly developed and well articulated utility accommodation manual and process for utility accommodation. This should be updated to reflect the FHWA 2009 guidance on longitudinal accommodation. This would also set the stage for continued collaboration between renewable energy transmission line developers and TxDOT, and continued planning to achieve the state's renewable production standards and air quality goals.

Utilize the exception carved out in 23 CFR.1.23 (c) which allows other use or occupancy – that is both temporary and permanent – to utilize ROW, including airspace for a non-highway purposes. This exception allows occupancy, if the use is in the *public interest* and does not impair the highway or cause safety issues. Clearly transmission line development falls within this exception, is without doubt in the public interest, and if properly developed, maintained and takes advantage of new technologies to assure safety, would provide the requisite level of comfort to both the transmission line developer and TxDOT.

Add a policy preamble into transportation utility code that planning for a multi-modal system could assist the state in enhancing delivery of renewable capacity that would improve air quality. By facilitating and assisting in the development of transmission routes, TxDOT could aid the state in developing its renewable energy capacity (which is extensive) to reduce reliability on fossil fuels.

Key Words:
electric power transmission,
renewable energy, wind energy,
transmission lines, department of
transportation, right of way, utility

Transit-Oriented development (TOD) is increasingly recognized as a desirable land form for urban and suburban development. Demand for TOD by residential and commercial tenants has increased greatly in a relatively short time in Texas, and there is every indication that this demand will continue to increase. The findings of our survey of TOD residents show that their choice of housing is influenced most greatly by factors associated with proximity to work and lifestyle choices. The lifestyle choices include convenience to dining, shopping, and entertainment venues, availability of parking, and living in a residence that represents an “urban lifestyle.” Though somewhat lower than these factors, proximity to a rail transit station is considered important. Whether residents move into TOD specifically for convenient access to transit services or because of other characteristics of TOD living, the findings presented in this report clearly show a substantial shift in transportation facility use, route choices, and VMT after moving into TOD residences.

Overall, residents moving in TOD properties reduce average household miles driven by about 3,500 miles per year, a 15 percent reduction. Though there are substantial differences in the total reduction of VMT among the three study areas examined in this research, all showed a drop in both highway and non-highway miles driven with implications for TxDOT facility usage and motor fuel tax revenues. Based on our inventory of TOD properties, there are about 8,000 TOD residential units in the service area of DART, the Fort Worth TRE, and Capital Metro suggesting that the total current effect of TOD on VMT is a reduction of about 28 million miles and that total fuel tax revenues are lowered by just less than \$200,000 per year. While the total effects are comparatively small at this time, continued growth of TOD suggests that the attendant reduction in highway use by TOD residents be taken into consideration by TxDOT for planning, modeling, project design, and issues related to TxDOT revenues. Relatively few state transportation agencies across the U.S. are involved in issues dealing directly with TOD. Most of the state agencies involved in TOD address issues dealing with the statutory and regulatory development environment for TOD, offering planning guidance to cities, MPOs, and others, and providing funding for planning and/or development activities. California and Florida are also engaged in research and information sharing activities concerning the development of TOD projects.

Recommendations

TOD can be one of those solutions that alter traditional relationships in travel behavior, and therefore, there may be opportunities to modify the *Project Development Process Manual* to promote future TOD projects. There are at least two key areas from TxDOT’s planning perspective where it can promote TOD development. First, the increasing incidence of TOD and its impact on travel behavior calls for enhanced integration of efforts between TxDOT and regional transit authorities, especially those transit agencies that have, or plan to have, significant transit rail components in their systems. Second, is in regards to the availability of funding for planning. Section 1370 of the *Project Development Process Manual* could be amended to include specific language encouraging planners to seek planning and implementation funding based on the presence of TOD.

The TxDOT Design Manual could be expanded to include specific operating and safety characteristics associated with TOD that impact effective and efficient roadway design.

Additional research into the potential for TxDOT to participate in public, and public-private partnerships that support the development of TOD, as a part of an integrated solution to transportation challenges, could specifically examine relevant models in other states and recommend approaches for TxDOT’s financial participation in TOD under state law and regulation.

These findings could prove beneficial to managers, planners, and engineers in TxDOT offices across the state. Disseminating the findings will potentially support improved understanding and decision making when including TOD properties in plans and interactions with local planners and private developers.

Key Words:
Transit-Oriented Development
Vehicle Miles Traveled
Transit Rail
State DOT Roles in TOD

This research examined the SB1266 Act and three implementation examples in the State of Texas. One of the key findings from the implementation examples was a lack of standardized procedures and/or guidance for Transportation Reinvestment Zone (TRZ) development. The research team explored data quality and standards across the state, and developed procedures and tools for TRZ stakeholders interested in TRZ development. Three cost effective tools were developed to assist in various stages of TRZ development and to provide guidance on pursuing a TRZ—an initial simple screening tool for determining TRZ worthiness, a preliminary revenue assessment tool, and a GIS toolkit to aid in TRZ zone development. These tools are compliant with TxDOT standards. The revenue toolkit as currently developed allows only for preliminary revenue assessments, but is also suitable for more advanced studies only when combined with additional local inputs and regional study. One important finding from data gathering was that approximately 46% of regions in Texas may be data ready for TRZ development. Various other support factors in the region and general regional visions are more important in getting planning tools like TRZ's underway since they require a significant amount of interagency coordination, political will and support for facilitating various aspects of TRZ planning.

A second critical finding was a general lack of awareness of TRZ and provisions of SB1266. In order to meet these objectives, the research team undertook an extensive outreach effort across various organizations in Texas through web-based surveys followed by telephone calls. The interested individuals were invited to attend a TRZ implementation workshop, which included a variety of stakeholders ranging from city officials, to county stakeholders, TxDOT, Regional Mobility Authorities (RMAs), and consultants who had TRZ implementation projects underway.

A third finding included an identification of various areas where existing legislation may be modified. Several recommendations are suggested to amend SB1266 so as to make it less onerous and confusing for implementing agencies. These specific recommendations were driven by implementer experiences and driven from discussions and include specific topics that need to be addressed in SB1266 including but not limited to: a) TRZ boundary changes and contiguity requirements, b) 100 percent set aside in increment accounts, c) Need to consider other prior increment agreements and other incentive agreements, d) Specific role for TxDOT, and d) Amending the Road Utility Districts (RUD) provision for county TRZs.

One provision that should be investigated more thoroughly is the decoupling with pass-through (PT). This provision generated a lot of discussion among respondents. While it may seem onerous, as long as TxDOT does not change requirements frequently causing confusion, dropping the PT requirement may have additional cost consequences for TxDOT. In regard to transit projects, SB1266 is noted to have very limited indirect application to transit since it is primarily intended to benefit transit (but not explicitly) only through surplus provisions once the primary highway project is paid off. It is only of value to regions that already have a TRZ in place or propose to have a TRZ. It is also only applicable to on-system transit like the BRT systems in San Antonio and El Paso. SB 1266 leaves out a large category of transit systems and regions that cannot benefit. These include several off-system transit systems and new types of transit technologies that could be applicable in future.

On the other hand, Texas and other states have employed value capture finance in the past and even currently through tax-increment-reinvestment zones (TIRZ) and Tax Increment Financing (TIF). The vast majority of TIRZ operators use the increment revenue sources for local capital improvements, not transit system development. Successful stories from other states; documented positive evidence of transit impacts on property values; and growing interest in transit in Texas calls for further innovative legislation for transit and highway financing including TRZ for transit either on- or off-TxDOT systems as well as perhaps Transit Revitalization Investment District (TRID) for transit, which allows both development and capital costs to be financed from increments.

Proactive legislation to provide for local matching funds could provide positive signals for enhancing transit investments and in federal screening and reviews such as those conducted for discretionary grants. In this connection, the SB898 with appropriate modifications, or the Pennsylvania (TRID Act) may serve as the needed framework for transit finance.

Key Words:

Value Capture, Highway Projects, Transit Projects, Transportation Reinvestment Zones, Innovative Finance, Land Development

Other Survey Types - The use of survey types such as household, workplace, and commercial vehicle surveys appeared on the surface to offer a majority of inputs on the model used in this project. However, given the limited number of external-related trips that are obtained from these survey types, the statistical validity of these estimates would be suspect. Current survey sample sizes would need to be increased two to three times in order to develop reasonable estimates of external-related traffic. Additionally, the estimates derived from this method would be limited to external local trip types. While it is possible for these surveys to capture external through trip movements during the conduct of the survey, the observed frequency of this occurring is extremely rare.

The External Urban Links Analysis (EULA) Application in the Statewide Analysis Model (SAM) - Like the use of other survey types, the EULA application of the SAM appeared to provide estimates of a majority of model inputs. The primary input that it lacked was the ability to estimate the amount of non-resident travel within a study area. However, another significant obstacle is the base and forecast years of the model. In order to provide estimates for years in between these years, it would require analysts to extrapolate the data. This could degrade the accuracy of the estimates. Additionally, due to the differences between urban area and SAM zone structures, methods would need to be devised to develop average trip lengths for external local trips.

Logit Model - The implementation of two logit models produced estimates of all of the model inputs except non-resident trips and external local trip tables. Additionally, without the ability to produce external local trip tables, it is not able to produce average trip lengths for external local trips. Despite these limitations, the logit model approach appeared to offer more robust estimates than either of the other two methods.

In addition to the methods analyzed in this research, there are several other methods that researchers identified as potentially having some utility in the future. These methods are briefly reviewed in the sections below.

Internet-Based Travel Surveys - The use of internet-based travel surveys is not a new concept, and it is a method that TxDOT has implemented in the past. However, as with most methods, there are some issues that would need to be addressed before implementing the method. A primary issue is the recruitment of eligible participants that is performed in a manner that has minimal sample bias. Additionally, the identification of persons that would be making external related trips on the survey day would be a difficult task to accomplish.

Postcard Surveys - Postcard surveys have been implemented in various parts of the United States with varying degrees of success. One primary negative associated with this method is the response rate. It is not uncommon for postcard surveys to have a 10 percent or less response rate. Developing a method to disseminate the postcards is also a significant consideration. If the postcards are distributed on the roadways, then traffic control plans must be developed in order to provide for safe conditions for motorists and survey personnel. Postcard surveys can be combined with internet-based surveys by including an internet website on the postcard, thus allowing survey recipients the opportunity to complete the survey online.

GPS Enabled Cellular Phone Data - Using GPS data from cellular phones to develop travel estimates is an area that is gaining increasing interest from planners and modelers in the United States. Given the large percentage of Americans that own cellular phones, this technology offers a lot of promise. However, privacy and legal issues related to the use of the data present a significant challenge to people interested in the data. Additionally, deciphering the raw data can be challenging for analysts. For example, the raw data do not provide information on the trip purpose, the type of place at a trip end, or the vehicle occupancy. There have been a number of successful programs in the United States that have recruited people in metropolitan areas for ongoing access to their cellular phone GPS data for the purpose of monitoring traffic congestion and travel times. In these instances, the recruitment process offers more of an incentive to the potential recruit in that there is a perceived immediate benefit.

Conclusions - Through the course of the research, it was revealed that there are a multitude of methods available for developing external travel estimates in urban areas in Texas. Each method has advantages and disadvantages. While the methods reviewed to collect travel data using new means appear to have the capability to collect detailed travel information similar to that of the roadside survey, the primary difficulty was in the implementation of the method.

Key Words:
External Survey, Transportation
Planning, External Local, External
Through, Trip Tables

The general opinion of contractors is that the American Recovery and Reinvestment Act (ARRA) funds have saved jobs in many contractor organizations even if they have not created new jobs. ARRA has kept the industry alive and ready to respond when the private sector has enough confidence to start investing again.

Government spending is usually 10–20% of contractor activity. But with the disappearance of private spending in the last 2 years, all contractors have had greater reliance on public spending. In that respect Texas has been better than other states, and a number of out-of-state companies have been competing fiercely for TxDOT work, driving down prices.

The ARRA funds were spent at the best time: low prices have bought more projects than usual.

The companies interviewed were all dependent on TxDOT work and benefit when TxDOT lettings increase. They voiced support for more funding for TxDOT. Many like TxDOT work because of the predictability of the volume, and the certainty/quality of TxDOT specifications.

Contractors feel morally obligated to their employees and families: each job saved supports perhaps three more people (a spouse and two children).

Most contractor employees rely on overtime for spending money (which supports jobs in the wider economy), and in a tight economy without overtime, they have not been spending.

Suppliers are intimately aware of how their businesses impact their local economy. In one case the supplier knew how many school teachers were being supported by taxes generated by their company.

The cost of transport is a significant element of highway projects, and location of material sources and suppliers gives advantage to specific contractors. Given the competitive environment, materials suppliers close to job sites have benefited from ARRA funds. However, most of them do not know the funding sources of the business they receive.

Contractors are maximizing equipment usage. More equipment is being utilized now that the workforce at most of the companies is lean. An indirect benefit here could be that the industries that make products utilized in maintenance and operation of such equipment are being supported. The construction support sector could be considered as one where ARRA funding has had a positive indirect impact.

Contractors were asked how they would stimulate the economy and create jobs, and most of them could not suggest anything other than more government spending. They felt that of all government spending, infrastructure is the best because tangible assets are created, they improve economic efficiency, and ultimately create jobs.

Direct jobs from ARRA are being accurately tracked, but indirect/induced jobs are very difficult to quantify due to the unique economic circumstance at present. Current commercial models would give misleading answers. Imposing additional reporting requirements on downstream companies would be impossible because most have no idea how most of their work is funded.

Due to data limitations and the enormity of interdependence among different industries across different projects, accurate estimation of indirect labor usage is difficult. However, it is clear that indirect benefits definitely accrue to secondary and tertiary industries. Similar opinions were echoed by those interviewed, i.e., even if ARRA funds did not create any new visible employment opportunities, it did help save a large number of existing jobs.

Key Words:

ARRA, stimulus funds, construction labor, contractors, labor usage.

Safety and Operations

results

RMC 4

RMC 4 - Safety and Operations

Focus Areas

- Geometric Design
- Illumination
- Pavement Marking
- Railroad Crossing Safety
- Roadside Safety
- Roadway Signing & Delineation
- Traffic Control Devices
- Traffic Management & Operations
- Work Zone Safety

Development of a Model Performance-Based Sign Sheeting Specification Based on the Evaluation of Nighttime Traffic Signs Using Legibility and Eye-Tracker Data

<http://tti.tamu.edu/documents/0-5235-1-VOL1.pdf>

<http://tti.tamu.edu/documents/0-5235-1-VOL2.pdf>

Preliminary Phase I Findings

The data revealed that drivers on a closed course do not view signs the same way as those on the open road. The drivers tended to normalize their viewing behavior on the closed course due to their decreased workload. The Runway Course was very isolated and subjects were able to concentrate on sign legibility without interference or distraction from other vehicles or roadway stimuli. This may justify why high luminance signs on the closed course exhibited longer glance durations than signs on the open road.

Content in the sign legend greatly influenced the subjects' glance patterns. The conventional speed limit signs that displayed "40" and "70" in the legend achieved the longest legibility distance, the fewest number of glances, and the shortest glance duration regardless of luminance level. Drivers anticipate numeric speed limit signs that are in increments of 5 mph. Correctly identifying sign content of "46" or "Y2" was more of a legibility task as opposed to anticipating and recognizing "40." The researchers concluded that non-conventional or alphanumeric sign content was more beneficial in identifying true sign legibility.

Phase II Findings

The findings from Phase II demonstrate several important aspects. The legibility results from the internally illuminated signs were as expected in terms of the effect of brightness on legibility. This finding is important to note because of the differences between these internally illuminated signs and signs made with retroreflective sheeting materials. Knowing that the legibility results were as expected provided faith in that additional analysis can be conducted on the legibility data without being concerned that the signs were so different that the results may not be transferable.

Phase III Findings

The results of the legibility data provide additional details to refine the performance-based specification. The smaller ranges of luminance used in the internally illuminated signs proved to be significant in terms of legibility, demonstrating a critical range in luminance that can be used to separate performance in a luminance driven performance-based specification.

The results from the legibility data, including evaluations conducted with both the low beam and high beam illumination settings, show that there is a point in luminance where performance with respect to legibility decreases. The eye-tracking data provide an explanation of this in that when the sign becomes so bright, drivers begin their last look much before their visual acuity threshold can discern the critical detail of the sign legend. The result is a longer last look duration for the extremely bright signs that begins before visual acuity thresholds and leads to shorter legibility distances. As noted, these results are applicable for rural settings with long sight distances.

The eye-tracker data also showed that the retroreflective levels of the signs used in this study had no statistically significant impact on the number of glances or the number of glances within the LOOK3 region. The only eye-tracking metric that showed any statistical significance to the retroreflective levels was the last look or legibility look duration. This metric was deemed statistically significant for bright signs viewed in rural conditions and with long sight distance—the street name signs with high retroreflective level material on the open rural road and the regulatory signs viewed on the closed-course facility under high beam illumination.

Using the results of the data, the researchers developed an example of a performance-based specification for retroreflective sheeting materials based on nighttime legibility and derived from empirical data applied to common signing situations.

Key Words:

Performance Based, Retroreflective Sheeting Materials, Eye Tracking, Luminance, Retroreflectivity, Traffic Sign, Specification, Legibility

Geometric Design Recommendations:

- Thoughtfully select design speed for mainline roadways, ramps, and interchanges.
- Use low maximum grades on vertical alignment.
- Include climbing lanes to minimize truck loss of speed and potential speed differentials.
- Avoid use of long downgrades.
- Increase the lengths of vertical curves to increase sight distance for truck drivers.
- Lengthen acceleration lanes from entrance ramps to provide trucks adequate space to reach mainline design speeds.
- Lengthen deceleration lanes to exit ramps to allow trucks to fully exit before decreasing speeds from mainline design speeds.
- Use larger radii on curves in ramp systems to better account for vehicle dynamics of trucks negotiating multi-curve ramp systems.
- Consistently provide full 12-ft travel lanes.
- Use adequate lane widening in horizontal curves.
- Consistently provide full 12-ft shoulders for truck use.
- Provide adequate parking at rest areas and connecting facilities.
- Provide adequate curve radii, curb return radii, and storage for left-turn and right-turn lanes at intersections at the end of ramps from toll roads or managed lanes.

Traffic Operation Recommendations:

- Give proper consideration of the truck demand and truck classes expected to use a toll road or managed lane.
- Use static dual speed curve warning signs to alert truck drivers to the appropriate speed in negotiating ramps and direction connections.
- Provide informational signing and variable message signing in proper placement for better visibility for large trucks.
- Use continuous, longitudinal rumble strips to assist in alerting truck drivers to the edge lines of traveled ways.
- Use barrier curve delineation systems on curves needing special attention from truck drivers to negotiating ramps and direct connections.

System and ITS Recommendations:

- Explore automatic vehicle identification technology for trucks in Texas to be interoperable with other systems in North America.
- Install active curve warning systems for truck drivers to warn of approach speeds exceeding the design speed of ramps and direct connections.
- Provide a comprehensive, coordinated incident management program that can respond to truck incidents and can minimize the impact of incidents on traffic flow.
- Consider active traffic management techniques to proactively manage traffic flow on corridors for more stable and reliable operation.
- Use ITS technologies to manage traffic flow and communicate unexpected delays to all users of a facility.

Key Words:

Geometric Design, Highway Operations, Truck Operations, Toll Roads

Based on the results from this research, we make the following recommendations:

If in-lane long line deck is to be used, the five line design should be used. The seven line design does not provide additional advantages and does not capture wheel path locations as well. This recommendation is based on strong correlation and similar retroreflectivity values between corresponding lines.

Transverse line decks can in general replace long-line deck in-lane because not only are the correlations strong, the retroreflectivity values between locations on transverse lines and corresponding long lines are similar.

When a transverse line deck is used, the near skip line readings are typically close to those on actual skip lines. The readings on wheel path locations have a generally strong relationship with the actual readings on skip lines.

Hot tape field testing typically does not yield consistent results. Caution should be given when evaluating field performance of hot tape products because the readings are highly influenced by the installation.

When installing field decks, comparisons should be made between products that are installed with the same application methods. This study revealed that different application methods, extruded vs. sprayed, or handcart vs. long line truck, may affect field performance for some pavement marking materials (PMMs).

At the Bryan deck, results for some correlation analyses were inconclusive, due to the fact that readings were rather flat during the 2-year evaluation period. When designing a test deck, a higher average daily traffic (ADT) value is preferred. Otherwise, a longer evaluation period will need to be adopted for durable products.

Installation quality critically affects field performance of PMMS. This is very evident when comparing the performance of the same product installed by a regular contractor and by the manufacturer. Quality control of installation is highly recommended.

Key Words:
Pavement Marking Materials,
Retroreflectivity, Correlation,
Transverse, Longitudinal

In this report, the eligibility criteria for Texas' Major Traffic Generators (MTGs) are identified based on a fuzzy logic-based algorithm from the review of practices and manuals from other states, and from an engineer survey. The types of symbols, location, and size of symbols/signs are identified based on the literature review of practices of other states, engineer survey, MTG survey, and simulator and slide show tests. The recommended warrants and symbol design were submitted to TxDOT as a reference for MTG guide signing in Texas. The achievements of this report do not end the study of MTG guide signing. Future work is recommended in the following areas:

Taking unexpected situations during driving into consideration would help the driving experience in driving simulator tests have a truer feel, such as a truck blocking drivers' sight when reading MTG guide signs, lane changing, distracting factors, etc.

Driving workload should be evaluated when MTG signs supplement the information on multiple sign arrays or more information is added to MTG signs, which might lead to safety issues. Besides the driving information load model, the NASA (National Aeronautics and Space Administration) Task Load Index might be beneficial in conducting the workload assessment.

In addition to laboratory experiments, selecting a typical MTG for a field test is possible with the support of TxDOT. For example, researchers could install Toyota Center signs on adjacent freeways in downtown Houston, use video cameras to record traffic data, and carry out a before-after analysis.

The efforts of this research and future work should contribute to guidelines for MTG guide signs, as a supplement to the TMUTCD. The guidelines should contain the MTG criteria for judging the application of MTG signing, sign standards for designing, installing, and maintaining appropriate signs to direct drivers efficiently, etc.

Therefore, further testing is recommended using more symbols and scenarios on selected MTGs as pilot studies, together with a more comprehensive evaluation of the impacts on drivers' workload, travel time, and safety. The research efforts in this project, together with the corresponding future work, will yield guidelines for MTG guide signing for Texas as a supplement to the TMUTCD.

Key Words:

Major Traffic Generator, guide signing, symbol, warrant, driving simulator

As a result of the statistical analysis, researchers developed 12 accident modification factors (AMFs) related to frontage road conversion for different crash types or crash severity. All of the AMFs indicate a reduction in the given crash type or severity because they show a value of less than 1.0. Users of the AMFs are encouraged to review the full report for additional AMFs, more specific information about how the AMFs were developed, associated caveats, and how to apply the AMFs.

Findings of the hot-spot analysis include several specific segments and interchange intersection locations along conversion sites where crashes per year decreased from the before period to the after period. It is hypothesized that these changes are due, in large part, to the conversion of the frontage roads to one-way.

Of the economic data sources investigated, only the appraisal data and survey data were specific to the corridor of interest. In general, researchers found that the appraisal values increase over time for the years studied. From the aggregate appraisal data analyzed, it does not appear there are substantial overall negative effects on appraisal values along the conversion sites in the long term.

From a limited sample of surveys, researchers found that when frontage road conversions are planned, there is interest from the business community to do conversions as soon as possible, as quickly as possible, and with construction of the support infrastructure (e.g., U-turns, bridges, signage) before the frontage road conversion. It appears perceived economic impacts may be related to timing of additional infrastructure placement and construction.

Key Words:

Frontage Road, Frontage Road Conversion, Crash Reduction Factor, CRF, Accident Modification Factor, AMF, Safety, Economic Impact.

At a congested intersection approach with a left-turn bay, interactions of through and turning vehicles near the bay entrance often cause loss of valuable capacity. In this research project, the researchers conducted controlled simulation experiments to study the impacts of such interactions on signal capacity. Specifically, these simulation experiments studied the impacts of cycle length, phasing sequences, distribution of left and through vehicles, and length of turn bay on the capacity of left and through vehicles sharing a lane upstream of the bay. For the single-lane case, the impacts of fixed-time and fully actuated control were studied. Due to time limitations, researchers studied the dual-left bay case only for fixed-time control. Analysis of results from these experiments provided useful insights. Key observations from this analysis are:

The worst scenario occurs when there is equal distribution of left and through vehicles in the lane feeding traffic to the left-turn bay.

When blocking occurs, increasing cycle length decreases capacity.

When appropriate cycle length and phasing sequence are selected: 1) a 500-ft single-lane is sufficient to provide the maximum capacity, which is 95 percent of the ideal capacity, and 2) a 400-ft dual-lane bay is sufficient to provide up to 99 percent of ideal capacity.

For fixed-time control: 1) lead-lag and lag-lead phasing sequences perform better for 100-ft bays, and 2) for bay lengths of 200 ft or more, lag-lag and lead-lead phasing sequences perform better, with their benefits diminishing for bay lengths of 500 ft or longer.

For actuated control (tested for single-lane bays only): 1) lagging the phase with heavy demand movements improves throughput, 2) choice of phasing sequence has bigger impact on capacity than that for fixed-time control, and 3) larger cycle lengths decrease capacity, but the adverse impact is less with properly selected phasing sequence settings.

Key Words:
Traffic Signals, Traffic Congestion,
Guidelines, Queue Management,
Traffic Simulation

The Texas Department of Transportation and other state departments of transportation as well as cities nationwide are using video detection successfully at signalized intersections. However, operational issues with video imaging vehicle detection systems (VIVDS) products occur at some locations. The resulting issues vary but have included:

- camera contrast loss resulting in max-recall operation,
- failure to detect vehicles leading to excessive delay and red-light violations, and
- degraded detection accuracy during nighttime hours.

This research resulted in the development of a formalized VIVDS test protocol and a set of performance measures that agencies can incorporate in future purchase orders and use to uniformly evaluate VIVDS products. It also resulted in the development of a VIVDS video library and conceptual plans for a field laboratory for future projects to deploy a range of VIVDS products at an operational signalized intersection. Researchers evaluated alternative VIVDS stop line detection designs and developed methods for enhancing the operation of VIVDS through adjustments in controller settings for day versus night versus transition periods, zone placement, and camera placement.

Key Words:
Stop Line Detection, Video
Imaging, VIVDS, VIP,
VID, Traffic Signals

Exit Ramps within Freeway Lane Closures

The following are the researchers' recommendations regarding the design and delineation of exit ramps that remain open within a work zone lane closure.

The minimum exit ramp opening within a work zone lane closure should be at least equal to the suggested maximum spacing of channelizing devices on a tangent shown in Table 6C-4 of the Texas MUTCD, with two times the channelizing device spacing on the tangent being preferred.

Use of drums spaced (in feet) equal to one times the speed limit (in mph) on the lane closure tangent 240 ft immediately upstream of the exit ramp opening and 120 ft immediately downstream of the exit ramp opening on a high-speed, limited-access facility.

Use of continuous LCDs on both the tangents and tapers in the immediate vicinity of an exit ramp for either of the following conditions:

- When a high number of deliberate intrusions into the work zone to access the exit ramp are expected to occur or have occurred while using the standard drum treatment.
- In situations where the exit ramp opening (in feet) is less than or equal to two times the posted speed limit (in mph) (i.e., the channelizing device spacing on the tangent), workers and equipment are in the work area near the exit ramp opening, and there are concerns that drivers may unintentionally enter the work area trying to access the exit ramp.

For this research, "immediate vicinity" was defined as 120 ft immediately upstream of the exit ramp opening and 60 ft immediately downstream of the exit ramp opening.

Continuous LCDs in the immediate vicinity of an exit ramp should follow TxDOT standards with respect to delineation; however, the maximum barrier reflector spacing should be 18 ft. In addition, adequate delineation is needed at the apex of the downstream LCD tangent and LCD taper to demarcate the ends of the LCDs.

Taller LCDs may block the view of the exit ramp opening when used in the upstream tangent and taper, which may cause confusion due to a lack of positive guidance. In addition, taller LCDs might block the view of a stalled passenger car on the exit ramp. Thus, the height of the LCDs should be considered to ensure positive guidance of the intended travel path and adequate visibility of any hazards that may be located on the exit ramp.

Lane Closure Merging Tapers

Researchers do not recommend the use of continuous LCDs to form a lane closure merging taper.

Researchers also do not recommend that single barricade style LCDs be used to form a lane closure merging taper.

Driveways

The following are the researchers' recommendations regarding the use of LCDs to delineate driveways (and minor roads) within a work zone.

Continuous LCDs may be used to delineate the edge of a travel lane in a work zone on an urban roadway. However, the height of the LCDs should be considered in applications where motorists need to be able to detect approaching vehicles (i.e., intersecting driveways and minor roads).

LCDs 21 inches tall or less should be used where it is desired for drivers to be able to view an approaching vehicle's headlamps over the LCDs.

Continuous LCDs may also be beneficial on urban roadways when a high number of deliberate intrusions into the work zone to access driveways or minor roads are expected to occur or have occurred while using the standard drum treatment.

Key Words:

Longitudinal Channelizing
Devices, Longitudinal Channelizing
Barricades, Work Zones,
Channelizing Devices, Traffic
Control Devices

Researchers found that published studies are very limited regarding the design and operation of triple left-turn (TLT) lanes and almost nonexistent for dual right-turn (DRT) lanes. There is a lack of detailed guidance for multiple turn lanes. Researchers received a good response from national and state agencies to determine which factors are important to TLT and DRT performance. Of 66 completed surveys, less than 25 percent indicated formal guidance on either type of multiple turn lane and only four respondents had done evaluations. The respondents indicated that the most important installation criteria were turn lane volumes, intersection capacity, adjacent development, and safety.

The field studies in Texas collected both static (e.g., lane widths, grades, pavement markings, traffic signs, upstream and downstream conditions, signal timing) and dynamic (e.g., volumes by lane, saturation flow, critical events) data in order to evaluate design and operational performance. Researchers collected these data at five TLT and 20 DRT lane sites, primarily in the Dallas–Fort Worth and Houston urban areas. Some key findings for TLT lanes:

- Lane utilization patterns were varied for each of the five sites studied.
- All sites were T-intersections with peak-hour volumes from 646 to 2,846 vehicles.
- Lighted pavement markers that were used to delineate the lane lines between the TLT lanes were effective at reducing violations and well received by the public at one site.
- Saturation flow rates in Texas were consistent with earlier published national values.

Some key findings of the operational analysis for DRT lanes were:

- Most vehicles use the outside lane (closest to the curb) to make their right turns.
- Peak-hour volumes ranged from a low of 200 to a high of almost 1,000 vehicles.
- Lane utilization (inside vs. outside) is comparable when the right-turn volumes are high.
- Saturation flow rates are higher in the inside lane [average = 1,717 vehicles per hour (vph) versus the outside lane at 1,668 vph] and also generally lower than those at TLT sites.
- Impact of trucks in the inside lane is greater than when in the outside lane.

Researchers evaluated safety performance by investigating the crash history of the 25 sites using three techniques: collision diagrams, field conflict study, and comparison study. The results revealed that TLT lanes do not experience any major safety issues and also concluded that, in general, a well-designed DRT lane does not cause significantly higher crash frequency or severity compared to single right-turn lanes.

Based on this research, TxDOT and other agencies should be confident that well-designed TLT and DRT lanes can be implemented to address heavy turning demand at key intersections. The evaluation of these multiple turn lanes revealed that they perform well from both operational and safety standpoints. Some of the key recommendations based on the research include:

- TLT lanes should be considered when turning volumes exceed 600 vph.
- DRT lanes should be considered when turning volumes exceed 300 vph.
- Clear turning guide lines (a.k.a, ‘puppy tracks’) are highly recommended for both sides of the inside right-turn lane when the intersection has a turning angle greater than 90 degrees.
- Narrow DRT lanes (turning roadway \leq 30 ft) with channelization should not be used.
- Right-turn on red is not advised for the inside lane when there are more than two receiving lanes.
- Designers should avoid installing DRT lanes near access points (e.g., corner gas stations).
- If an auxiliary receiving/acceleration lane is provided for the curb right-turn lane at channelized dual turn lanes, its length should not be less than 150 ft.
- For closely spaced intersections, if a downstream intersection uses dual right-turn lanes, the outside (curb) lane should not be aligned with any through lane at the upstream intersection.

Key Words:

Triple, Dual, Left-Turn Lane, Right-Turn Lane, Signal, Intersection Design

Exit gore signs present a significant maintenance challenge for TxDOT. There is particular concern regarding the safety of personnel working in gore areas to replace these signs, and the resources necessary for continual maintenance. In addition to exit gore signs, other roadside signs that are located near the travel lanes due to lack of available clear zone are also prime high-impact candidates.

The objective of this research was to identify and evaluate alternative signing methods that may reduce the number of sign hits as well as the costs and resources required for sign replacement and maintenance. Researchers identified and visited several sites with safety problems related to unusually frequent sign hits, and determined the major factors that typically contribute to these sign crashes. The most common factors belonged to at least one of the following categories:

- Geometric Design Characteristics.
- Driver Behavior.
- Sign Location and Placement.
- Pavement Markings Conditions.
- Poor Night-Time Visibility.

Researchers recommended potential treatments and countermeasures to address some of the issues identified in these categories. The list also included some simple treatments such as relocating or eliminating the exit gore signs at those locations where sufficient advance signing for the exit is provided, the exit gore is well delineated, and there are no sight distance and visibility issues. Several districts have implemented sign relocation farther back in the gore, but the feasibility of sign removal has not been studied. The project advisors expressed a particular interest in evaluating the impact of eliminating exit gore signs at locations where:

- Appropriate advance warning with overhead exit signs are provided.
- There are no visibility and sight distance issues.
- There is no major drop between freeway speed and advisory ramp speed.

Since MUTCD requires exit gore signs, removing these signs for the purpose of field evaluations was not possible. Therefore, researchers took a different approach by taking advantage of events when vehicles knocked down exit gore signs. Once a vehicle hits a sign, the time until reinstallation provided researchers a good opportunity to collect data without violating MUTCD requirements. Field studies were conducted at two freeway exits in Corpus Christi, Texas. The impact of the absence of exit gore signs was evaluated based on vehicle speeds at the exit gore, deceleration profiles of exiting vehicles, and erratic vehicle maneuvers near the gore area.

Based on the results of field data collections at the two study sites in Corpus Christi, the following observations were made in terms of speed characteristics and erratic maneuvers:

- Exiting vehicles began reducing their speeds earlier upstream when the exit gore sign was missing.
- No statistically significant difference in the frequency of erratic maneuvers at either of the two study sites.

The lack of exit gore signs at the two freeway exits did not have any negative consequence in terms of vehicle speeds, deceleration behavior, and erratic maneuvers. The field study results suggest that there are locations where overhead exit signs provide sufficient advance warning and exit gore signs may not be needed. If the MUTCD would provide more flexibility in determining the need for the signs, these could probably be eliminated at several freeway exits, thus helping reduce the number of sign hits as well as the costs and resources required for sign replacement and maintenance.

Key Words:
Exit Gore, Exit Gore Sign, High-Impact Signs, Frequently Hit Roadside Signs

Based on the findings from the literature, review of current practices, analysis of field data and crash data, and simulation conducted in this project, researchers recommend the following guidelines for use of Super 2 corridors in Texas:

The use of average daily traffic (ADT) as an upper limit on the installation of passing lanes should be eliminated. As budget, terrain, and other factors allow, passing lanes may be added or lengthened to provide additional passing opportunities regardless of volume. There is, of course, the proviso that as passing lanes are added and lengthened, the highway more closely resembles a four-lane undivided alignment and the incremental cost and operational benefits of each added lane diminish.

While ADT need not be a limiting factor in installation, it can be used to prioritize candidate sites for passing lanes, particularly when considering truck volumes. A traffic analysis of candidate sites will help the designer to determine which locations may receive greater benefit from lengthening existing passing lanes or installing new passing lane sections.

Where terrain, available budget, and other considerations allow, the addition of another passing lane is preferred over adding length to an existing one. Passing lane lengths over 2 miles show less incremental benefit than higher frequency of lanes, particularly for ADT less than 10,000 vehicles per day (vpd). Regardless of volume, passing lanes longer than 3 miles should be used sparingly, and lengths of more than 4 miles should be avoided.

In lieu of guidelines related to specific ADT values, other general principles should be used to assist designers in the decision to install Super 2 corridors. Key principles are as follows:

The designer should consider existing width of right-of-way (ROW), terrain, and structures to evaluate the feasibility of a Super 2 corridor and determine the best locations to install passing lanes with a minimum of ROW acquisition, earthwork, and structure widening.

The location of major traffic generators, such as intersections with other state highways or driveways to large developments, should be identified as the proposed alignment is planned. It is preferable to avoid locating high-traffic intersections and driveways within the boundaries of a passing lane. When such generators are unavoidable, it is preferable that they be located near the midpoint of the passing lane to provide as much separation from the opening and closing tapers.

Avoid locating passing lanes at locations with restrictive geometry (e.g., sharp horizontal curves) or other impediments to traffic flow (e.g., approaches to urbanized areas). However, providing passing lanes downstream of these features is beneficial for dispersing platoons.

Where passing lanes are terminated, sufficient sight distance must be provided to avoid conflicts with oncoming traffic or constraints such as guard rail, guard fences, or narrow bridges. Stopping sight distance is recommended.

Key Words:
Super 2, Two-Lane Rural Highway,
Passing Lane, Safety, Empirical
Bayes, Simulation, TWOPAS,
IHSDM

Midwest Roadside Safety Facility (MwRSF) has run several tests where attachments have been mounted on the top of a barrier. As part of this research, a review of previous crash tests was conducted on crash tested bridge railings and median barriers with attachments such as signs and luminaires. Based on this review, zones of influence (ZOI) were established at test levels provided in the National Cooperative Highway Research Program (NCHRP) Report 350 guidelines. Three test levels were studied: TL-2, TL-3, and TL-4. Next, a field investigation was conducted to determine the types of traffic barrier attachments currently in place. The attachments were classified according to the level of hazard they were believed to present. Finally, recommendations for placement and/or design of the attachments were made based on the combined results from the crash test review and field investigation. The goal of their research was to provide quantitative definition on how far behind and above a barrier a designer should place attachments and to make some general suggestions on how to design attachments to eliminate safety concerns.

The purpose of this project was to develop a TxDOT standard for mounting traffic control signs and devices on concrete traffic barriers in construction work zones. For this project the TxDOT Type 2 Portable Concrete Traffic Barrier (PCTB) (2)-04 was selected as the concrete barrier used to support the new sign support connection developed for this project. This barrier type utilizes a steel grid slot connection fabricated using #8 grade 60 reinforcing steel. This barrier type and connection is most common in the current TxDOT inventory. The TxDOT Type 2 PCTB consists of 30 ft barrier segments.

TTI researchers considered the information from the ZOI study performed by MwRSF. The recommendations from the MwRSF study resulted in general guidelines for the placement of attachments within a given ZOI. At the time of the study, the information provided in the report was based on the best available engineering judgment and limited full-scale crash data. At the time of the report, there were only a few crash tests of actual barrier attachments on which to base this judgment. The ZOI information developed from the study was suggested and further research was recommended to produce final criteria for the placement of attachments on barrier systems.

In summary, the intrusion zones for TL-3 concrete barriers (with a sloped face 30 inches to 32 inches in height) consisted of an area above the barriers that is 18 inches wide and extends above the barrier to a height of 78 inches above the pavement surface. For TL-4 railing systems with barrier heights in the range of 28 inches to 42 inches, the intrusion zones for the truck cab consisted of an area above the barriers that is 34 inches in width and extends above the barriers to a height of 96 inches above the pavement surface. The height and width of the ZOI is 120 inches and 80 inches, respectively for the box van cargo box. Based on this study, it was recommended that the impact performance of an attachment and its placement that does not follow these suggested criteria can only be verified through the use of full-scale crash testing.

Based on the information from this study, reducing the roll of the vehicle and the likely interaction of the vehicle with the sign was important to the success of the sign mount connection and sign support developed for this project. Removing the sign and sign connection out of the recommended ZOI for TL-3 from the MwRSF (18 inches) was not possible considering the attachment of the sign to the top of the portable concrete barrier used in a median application with traffic on both sides of the barrier. Therefore, reducing the intrusion of the vehicle (ZOI) over the barrier immediately after impact and reducing the roll of the vehicle over the barrier was important to the success of the sign mount and connection developed for this project.

The sign support and sign mount connection anchored to the top of the TxDOT Type 2 CTB and tested for this project performed acceptably for MASH test 3-11. Steel straps added to the barrier connection at the sign mount connection as well as at the joint upstream and downstream of the sign mount connection improved the performance of the vehicle by minimizing the intrusion of the vehicle over the barrier (reducing snagging of the vehicle on the sign support and sign mount connection). In addition, the steel straps and sign mount connection helped in minimizing the roll of the vehicle over the barrier (also, reducing the snagging of the vehicle from rolling into the sign post, sign, and sign support connection).

Key Words:

Sign Supports, Longitudinal Barriers, Portable Concrete Barriers, Concrete Traffic Barriers, CTB, Crash Testing, Roadway Safety

Facilities where operating speeds are approximately 70 mph and work is occurring immediately adjacent to travel lanes, intrusion crash costs savings alone can justify portable concrete barrier (PCB) protection once the roadway average daily traffic (ADT) approaches 40,000 vehicles per day (vpd) over a year-long work zone, so long as there are constant hazards in the work space being protected by barrier. This ADT value can then be extrapolated to other work zone durations. If all hazards are removed from the work space after each work shift, PCB use cannot be justified strictly on intrusion crash cost concerns. Similarly, if actual travel speeds are lower (i.e., 50 mph), PCB use does not appear justifiable at any ADT levels.

For work zones in which drop-off conditions are also of concern, consideration of the potential for other types of intrusion crashes does reduce the vehicle exposure thresholds at which PCB can be justified. The extent to which the thresholds are affected depends on the amount of time intrusion hazards are present in the work space. When present only during normal work activity/typical work schedule, vehicle exposure thresholds are only slightly lower. However, if the intrusion hazards in the work space will be there continuously, the exposure thresholds at which PCB can be justified will be 15 % or more below those for drop-off conditions alone.

Analysis of steel or mobile barrier technologies to create small, protected work spaces showed that the technologies are fairly expensive and so will generally be justifiable only on high-volume, high-speed facilities. However, as these technologies become more common and production increases, their prices will decrease. Even at current prices steel barrier appears capable of justifying its cost in terms of reduced intrusion crash cost potential within a year or two. Mobile barrier technology may require longer to recoup its investment cost but may be able to do so for agencies with a significant amount of high-volume, high-speed roadways.

Analysis of rear-end crash potential with work vehicles in mobile and short-duration operations indicates that truck-mounted attenuators (TMAs) are highly effective in reducing rear-end crash severity and crash costs. Each crash with a TMA results in a crash cost savings of \$174,490 relative to the crash costs that would have occurred if no TMA were present. Based on current TMA prices, agencies can recoup their costs in less than a year of daytime work shifts on facilities serving 20,000 vpd or more and of nighttime work shifts on facilities serving 50,000 vpd or more.

For work zones that do not serve enough traffic to warrant consideration of positive protection devices, a number of exposure control techniques and other traffic control measures are available to reduce intrusion crash risks. Techniques that reduce the total duration of a project are especially effective in reducing work zone crash costs. Working at night also reduces vehicle exposure and work zone crash costs that are incurred for a given duration of work. Reducing the total number of vehicle trips through the work zone via travel demand management is another way to reduce work zone crash costs. However, these types of techniques must actually reduce the number of vehicle-miles driven in the corridor. Techniques that divert traffic from the work zone to alternative routes in the corridor may also reduce work zone crash costs, but increase crash costs on those alternative routes due to increased vehicle exposure on those routes.

Finally, the use of law enforcement in work zones is another technique that is believed to offer work zone crash cost reduction benefits. The roadway ADT levels at which it is believed that enforcement presence is offset by reduced work zone crash costs varies by time of day, expected magnitude of crash cost reductions, and cost of enforcement. Roadways with ADTs as low as 5,000 can justify enforcement use under a favorable set of assumptions. On the other hand, higher enforcement costs and a more conservative assumption

Key Words:
23 CFR 630 Subpart K, Portable
Concrete Barrier, Truck-Mounted
Attenuators, Steel Barrier, Mobile
Barrier

Assessment of Need and Feasibility of Truck-Mounted Changeable Message Signs (CMS) for Scheduled and Unscheduled Operations: Technical Report

<http://tti.tamu.edu/documents/0-6167-1.pdf>

The final set of guidelines was developed to address the issues of design and application for the use of TMCMS during scheduled and unscheduled operations. These guidelines can be used by TxDOT personnel responsible for providing critical driver information during mobile and short duration operations. The guidelines were developed based on the results of both a human factors laboratory study and the field evaluation of the information alternatives.

Researchers determined many key points regarding motorist interpretation of TMCMS messages. The following summarize these points:

The accident symbol was well understood and showed a benefit in the motorists' ability to recall the situation in very limited viewing time situations.

A roadwork symbol that is a variation on the traditional Man Working sign was well understood by motorists. Researchers recommend using the Man Working figure without the symbol outline as this had the best reaction time by study participants.

Lane blocked symbols similar to the traditional TxDOT sign for this application was found to work well in communicating with drivers.

In defining wet paint lines during striping operations researchers recommend the following phrase usage:

- Two-lane, two-way facility: WHITE LINE WET or WET EDGELINE.
- Two-lane, two-way facility: YELLOW LINE WET or WET CNTRLINE.
- Multi-lane facility: WHITE LINE WET or WET EDGELINE (for right shoulder line only).
- Multi-lane facility: WHITE LINE WET (for lane dividing lines).
- Multi-lane facility: YELLOW LINE WET (for median/directional dividing line).

When using an action statement at a lane closure, researchers recommend that either STAY IN XX LANE or USE XX LANE would be appropriate.

Based on these findings and supporting evidence from the field studies, researchers prepared recommended guidelines for TMCMS use during different scheduled and unscheduled operations. Although researchers are recommending the use of symbols as part of TMCMS messages, text alternatives for all symbols are provided in case the TMCMS available to the practitioner does not have graphics capabilities.

Key Words:
Changeable Message Signs, Truck Mounted, Scheduled Operations, Unscheduled Operations

TxDOT has historically pursued a number of alternative safety rest area development strategies in the state including but not limited to the provision of secondary commercial services such as wireless Internet access, the use of non-traditional funding sources such as FHWA's Transportation Enhancement funds, joint public development in partnership with TxDOT's Travel Information Division, and pursuit of targeted cost savings related to maintenance labor and utilities (water/energy).

To ensure sustainability of existing facilities and continued development and expansion of additional safety rest area facilities, TxDOT should continue to pursue a wide range of strategies related to commercialization/public-private partnerships, non-traditional funding sources, joint public development, and targeted cost savings. Based on recent experiences in other states, promising opportunities may include the following:

Constructing/renovating new or existing facilities along privately funded toll roads, along non-Interstate routes, or Interstate interchange locations outside of the federal right-of-way that can subsequently support the provision of primary commercial services (e.g., food and beverage sales, fuel sales, etc.). Such efforts may be supported under FHWA's Interstate Oasis Program.

Supplementing existing safety rest areas with infrastructure to support the use of electric vehicles and generate power using solar or wind technologies. Such efforts may be supported through various non-traditional funding sources or public-private partnerships.

Partnering with private truck stop owners to cooperatively meet the commercial motor vehicle parking demand while concurrently meeting the needs of general safety for rest area patrons. Such efforts may be supported under FHWA's Interstate Oasis Program, FHWA's Corridors of the Future Program, or other.

Expanding public-public partnerships to include state or local park agencies, Tribal Nations, or state or local law enforcement agencies.

Although a focus on securing funding is key to sustainability and growth, TxDOT may also want to consider opportunities to "multi-purpose" safety rest area facilities to broaden their real or perceived value. Other states have successfully involved additional public or private sector partners and increased facility functions to include commercial service activity, law enforcement activity, power generation, etc. as a means to ensure safety rest area sustainability. In pursuit of these opportunities, it is important to maintain the basic function of safety rest areas, which is to encourage motorists to take a break from the driving task and subsequently increase traffic safety.

Key Words:
Safety Rest Area, Travel Information
Center, Benefit, Cost

There were four primary activities and two secondary activities. The four primary activities were: developing a temporary sign support with cross bracing, providing technical support on an AASHTO retroreflective sign sheeting material specification, conducting human factors research on sign sheeting materials, and monitoring lead-free pavement marking test deck performance. In addition, the researchers also provided support for hurricane evacuation routing and started a research activity focused on identifying traffic signs with supplemental light emitting diodes (LEDs).

Temporary Sign Support - The perforated square steel tube support with rigid sign substrate performed acceptably and met all of the required evaluation criteria. Use of perforated steel tubing makes the frame lightweight (compared to wooden construction) and easy to assemble. The galvanized steel provides good durability and resistance to environmental attack without the need for painting, which is a maintenance requirement for wooden systems. The vertical sleeves incorporated into the design provide a degree of height adjustability to accommodate varying site conditions such as placement on a cross slope.

The new perforated square steel tube sign support system with diagonal braces is considered suitable for implementation as a temporary sign support as it was successfully tested with 4 ft × 4 ft × ½-inch thick plywood sign substrate. The use of “rigid” sign substrates (i.e., plywood and aluminum) makes the system stiffer and more durable. In addition to the impact performance benefits, the incorporation of diagonal bracing into the frame structure provides inspectors with a readily identifiable means of differentiating this system from a previously tested system that is constrained to use with corrugated plastic sign substrates.

Conducting Human Factors Research on Sign Sheeting Materials and a New Specification - The specific activities that were conducted as part of this research were to host an AASHTO sign sheeting demonstration and to develop recommendations for retroreflectivity levels that would better represent nighttime drivers’ needs than the retroreflectivity tables in ASTM D4956. Each participant viewed six sign locations 10 times, creating 720 observations, 600 were single sign observations. It is important to note that the luminance changed as the participant approached the sign and the sign was read at the distance the individual participant could read it. This distance does not necessarily correspond to the minimum luminance required to read a sign at the specific distance, as it was believed that at some higher level of luminance the sign may become too bright and the legend would be washed out, thus reducing legibility distance. Also, using high beams provided much more luminance but did not improve the legibility index, suggesting that the legibility index flattens out at a certain point and possibly begins to decline if a sign is too bright.

Continued Evaluation of Lead-Free Thermoplastic Pavement Markings - The lead-free material appears to perform in a manner that is consistent with the standard TxDOT leaded material with respect to retroreflectivity and 45/0 Illuminant A color readings. The lead-free material appears to differ in 45/0 Illuminant D65 daytime color readings from the leaded material, the difference is that the lead-free material color is closer to white than the leaded material (less saturated). The nighttime 30 meter color measurements also differ, as the leaded material provides a more saturated yellow than the lead-free material but to a lesser extent than the daytime color difference.

Support for Hurricane Evacuation Routing and Identifying Traffic Signs With Supplemental Light Emitting Diodes (Leds) - These 2 studies are still on-going.

Researchers hope to have significant results within the next year.

Key Words:
Traffic Control Devices,
Retroreflective Sign Sheeting,
Hurricane Evacuation, Pavement
Marking, Crash Test, Temporary
Sign Support

This project was established to provide a means of conducting small-scale research activities on an as-needed basis so that the results could be available within months of starting the specific research. This report summarizes the research activities that were conducted between September 2009 and August 2010. There were five primary activities and five secondary activities. The five primary activities were: studying the impact of using high brightness retroreflective sign sheeting in rural areas, synthesizing the technologies available to potentially automate no-passing zone markings, providing hurricane evacuation support for the Corpus Christi District, monitoring lead-free thermoplastic pavement marking test decks, and demonstrating daytime and nighttime operations of traffic signs supplemented with light emitting diodes (LEDs). In addition, the researchers also provided support for specification revisions, prototype traffic control device evaluations, technical support for Traffic Operations Division, and initiated a study on contrast pavement markings.

Researchers tested retroreflective sign sheeting materials to determine if they can be too bright in rural areas. A human factors study was designed and conducted. The research is described but the analyses are continuing.

Researchers reported on the latest technologies available to potentially automate no-passing zone markings. The two-vehicle is still the most common method to mark no-passing zones in the U.S. Technologies are available that show promise in terms of being able to automate the marking of no-passing zones.

Researchers provided district support for hurricane evacuation routing working with the Corpus Christi District to provide assistance as directed. Work will continue with this effort in the following year with the Corpus Christi District and potentially other coastal districts.

Researchers monitored lead-free thermoplastic pavement markings. The night-time color of yellow lead-free thermoplastic has fallen out of TxDOT's color box and is approaching limits of the more forgiving FHWA color box. Researchers will continue to monitor the existing lead-free thermoplastic pavement marking test decks.

Demonstration traffic signs with supplemental light emitting diodes involved both daytime and night-time observations being made of a wide range of traffic signs. Some configurations work better than others. Some LEDs are overpowering. Additional work is needed.

Other research activities performed included pavement markings and prototype traffic control devices. Researchers revised pavement marking specifications, developed estimates for thermoplastic durability, studied pavement marking raw material shortage, initiated a study on contrast pavement markings, and evaluated a prototype automated flagging assistance device. Study on contrast pavement markings is continuing.

Key Words:
Traffic Control Devices,
Retroreflective Sign Sheeting,
Hurricane Evacuation, Pavement
Marking Retroreflectivity, Contrast
Marking, LED Signs

An assessment of the test based on the applicable MASH safety evaluation criteria is provided below.

Structural Adequacy

Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.

Result: (PASS) - The T101 bridge rail contained and redirected the test vehicle. The vehicle did not penetrate, underride, or override the bridge rail. Maximum dynamic deflection of the bridge rail during the test was 2.2 ft.

Occupant Risk

Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.

Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in MASH: (roof ≤ 4.0 inches; windshield ≤ 3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤ 9.0 inches; forward of A-pillar < 12.0 inches; front side door area above seat ≤ 9.0 inches; front side door below seat ≤ 12.0 inches; floor pan/transmission tunnel area ≤ 12.0 inches).

Result: (PASS) - No detached elements, fragments, or other debris from the bridge rail were present to penetrate or to show potential for penetrating the vehicle, or to present hazard to others in the area. Maximum occupant compartment deformation was 1.5 inches in the firewall to passenger seat area near the toe pan on the right side.

The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Result: (FAIL) - The vehicle rolled 97 degrees after loss of contact with the bridge rail, and then uprighted itself as it came to rest.

Occupant impact velocities should satisfy the following: Longitudinal and Lateral Occupant Impact Velocity, Preferred = 30 ft/s or Maximum = 40 ft/s.

Result: (PASS) Longitudinal occupant impact velocity was 14.4 ft/s, and lateral occupant impact velocity was 20.3 ft/s.

Occupant ridedown accelerations should satisfy the following: Longitudinal and Lateral Occupant Ridedown Accelerations. Preferred = 15.0 Gs or Maximum = 20.49 Gs

Result: (PASS) - Maximum longitudinal ridedown acceleration was 12.1 G, and maximum lateral ridedown acceleration was 12.0 G.

Vehicle Trajectory

For redirective devices, the vehicle shall exit the barrier within the exit box.

Result: (PASS) - The vehicle exited within the exit box.

Conclusions

Impact performance of the T101 bridge rail was unsatisfactory for MASH test 3-11 as the vehicle overturned after losing contact with the barrier. Currently there is no implementation date for adopting MASH. If continued use is desired, researchers recommend that an in-service performance evaluation be conducted to assess whether or not the T101 bridge rail field performance is satisfactory or a new barrier system that satisfies the same key design criteria as the T101 bridge rail can be developed and tested under future research. Considerations should include efficient hydraulic characteristics, use of existing hardware components, and ability to retrofit existing T101 bridge rail installations as well as rails on older curbed bridge structures.

Key Words:
Roadside Safety, Bridge
Rail, Crash Test, MASH

Concrete median barriers (CMBs) are commonly used to separate opposing lanes of traffic on highspeed, urban freeways with high average daily traffic (ADT) and narrow medians. The resulting long, continuous runs of CMBs limit access of emergency and maintenance vehicles to the other side of the roadway or managed lane. Periodic implementation of crashworthy median barrier gates can maintain the desired level of median protection for motorists while offering improved cross-median access for authorized vehicles.

TxDOT has been using an Emergency Opening System (EOS) developed in the early 1980s to satisfy this need. The EOS was recently crash tested in accordance with the latest guidelines for the impact performance of roadside safety features contained in the AASHTO *Manual for Assessing Safety Hardware*. The gate failed to comply with *MASH* due to excessive occupant compartment deformation inside the vehicle.

A new crashworthy median barrier gate was developed to replace the EOS and meet the continuing needs of TxDOT. Three crash tests were performed to evaluate the impact performance of different aspects of the median barrier gate. Test 3-11 evaluated the strength of the median barrier gate and its ability to function as a longitudinal barrier. Tests 3-20 and 3-21 assessed the transition of the median barrier gate to the adjacent concrete median barrier. The new median barrier gate passed all of the required evaluation criteria for each test and meets the Test Level 3 (TL-3) impact performance requirements of *MASH*.

Key Words:

Median Barrier, Gate, Roadside Safety, Crash Test, *MASH*

Structures and Hydraulics

results

RMC 5

RMC 5 - Structures and Hydraulics

Focus Areas

- Bridge Rails & Transitions
- Geotechnical Issues
- High Mast Illumination Poles
- Hydraulics & Hydrology
- Overhead Sign Bridges
- Structures Construction & Maintenance
- Structures Design & Analysis
- Structures Management
- Structures Materials

Moderate use of high-calcium fly ash (e.g., 20 to 40% by mass of cementitious materials) showed poor sulfate resistance. Deterioration tended to increase as the dosage of Class C fly ash was increased. However, the incorporation of a second SCM (silica fume, slag, UFFA) helped substantially improve sulfate resistance as did the addition of small amounts of gypsum (not a viable option in the field as excessive additions of gypsum can cause an adverse effect). Increasing the Class C fly ash dosage to higher levels (e.g., 60 to 70% by mass of cementitious materials) resulted in satisfactory sulfate resistance, regardless of the CaO content of the fly ash.

Characterization of fly ashes was carried out successfully by using XRD and SEM techniques. Results showed good insight into reasons behind satisfactory performance of Class F fly ashes and poor performance of Class C fly ashes. A good link between chemical composition of the glass in fly ashes, mineralogy of the crystalline components, and sulfate resistance was established. The glass composition of a fly ash expressed by its location in the mullite, anorthite or gehlenite field on the Dunstan's Ternary diagram, reveals its performance more precisely than its bulk composition. The Rietveld method of analysis was used as the technique to determine the crystalline portion.

Quantitative analysis of the hydration products formed in fly ash mixes confirmed that fly ashes generating more ettringite than monosulfate before exposure to sulfates solution, yielded better sulfate resistance. However, fly ashes generating more monosulfate than ettringite prior to exposures offered poor performance. Using this method makes it is possible to predict sulfate resistance of a given fly ash by determining its ettringite potential. The overall sulfate resistance of a fly ash may also be indicated by other parameters such as SO₃ content and CaO/SiO₂ which are closely related to the CaO content of the corresponding fly ash.

Concrete prisms placed in sodium sulfate expanded the quickest and showed faster deterioration than prisms placed in magnesium and calcium sulfate. Prisms in submerged sodium sulfate conditions deteriorated quicker than control prisms kept indoors at 73 °F. Prisms in magnesium sulfate ultimately expanded the greatest of all the sulfate types and showed large cracks rather than deterioration/expansion observed in sodium sulfate prisms.

Prisms in different calcium sulfate conditions did not expand at 18 months but did show signs of deterioration on the surface of the prisms. Sulfate concentration in the trench matched the total sulfate in ppm from the sodium sulfate trench (33000ppm SO₄) which is far beyond the solubility limit of gypsum. At the outdoor calcium exposure site, prisms only showed deterioration below the soil level. Due to visible damage, prisms in the indoor calcium solutions were kept for 2 years, after which they began to expand confirming that concrete exposed to external sources of gypsum can, in fact, suffer from sulfate-related deterioration.

XRD Rietveld analysis highlighted the strong impact that water/cementitious materials (w/cm) has on sulfate resistance of concrete. In lower w/cm mixtures, less destructive products, such as ettringite, formed as a function of distance from the exposed surface. For higher w/cm mixtures, levels of ettringite were nearly the same for milled powder samples taken from the exposed surface and similar samples taken from within the bulk of concrete prisms.

The w/cm ratio was found to be the most important factor that determines the susceptibility of mixtures to combined (chemical and physical) sulfate attack. Concrete specimens cast with w/cm of 0.50 and 0.70 undergo a significant level of deterioration in both static and cyclic exposures to Na₂SO₄ and static exposure to CaSO₄. Sulfate attack cannot be prevented by limiting the w/cm of concrete to 0.45. Reducing the w/cm to 0.40 can provide satisfactory sulfate resistance to the concrete mixes with Type I cement, or Class C fly ash mixes containing 20% fly ash. However concrete produced with a low w/cm of 0.40 and with 40% Class C fly ash can still undergo deterioration during the combined (physical-chemical) sulfate attack of Na₂SO₄, in the form of scaling, mass loss, and cracking.

The use of ASTM C 1012 is still the recommended test for determining the sulfate resistance of concrete mixtures. It uses sodium sulfate solution which did prove to be the most aggressive solution in the majority of testing.

ASTM C 1580 is recommended as a suitable test method for measuring sulfates in soils.

Key Words:

Sulfate, sulfate-resistance, sulfate attack, delayed ettringite formation, DEF, concrete distress

The following conclusions were made from this research:

Based on the flexural test results of small beam specimens, the recommended maximum dosage of Dramix steel fibers to be used in full-scale prestressed steel fiber concrete (PSFC) beams considering strength and good workability of concrete mix, is as below:

- Dramix Long Fibers - Dosage of 0.5% by volume of concrete.
- Dramix Short Fibers - Dosage of 1.5% by volume of concrete.

PSFC panel tests showed that the tensile stiffness and concrete softening characteristics of PSFC improves with an increased Fiber-Factor.

With regard to the PSFC panel tests steel fibers causes an increase of concrete compressive strength under sequential loading to determine the constitutive models. In the case of proportional loading for pure shear testing, a factor W_f which is a function of fiber factor (FF) is proposed for incorporation into the softening coefficient of prestressed steel fiber concrete. W_f takes care of the effect of amount of steel fibers on concrete compressive strength.

The shear behavior of PSFC beams was critically examined by full-scale tests on six TxDOT Type-A beams and six modified Tx-4B20 box-beams with web-shear or flexural-shear failure modes.

From the experimental results of six PSFC I-beams, steel fibers were found very effective in resisting the shear loads and mild steel shear reinforcement (stirrups) can be completely replaced with steel fibers.

Test results of PSFC box-beams also demonstrated the effectiveness of steel fibers in resisting shear forces. It was also found that local failures in these beams, such as penetration of web-shear cracking into the top flange, have to be taken care of so as to achieve the ultimate shear capacity in the PSFC beam. From the test results of all twelve PSFC beams it was found that 1% by volume of Dramix short steel fibers (ZP 305) was an optimum dosage in prestress concrete beams as shear reinforcement.

Using the constitutive laws of PSFC established in this research, an analytical model was developed and implemented in a finite element program framework (OpenSees) to simulate the shear behavior of the PSFC beams. Using this computer program, the load-deflection curves of all the beams are simulated with acceptable accuracy.

A new shear design equation was developed using the results of the PSFC beam tests performed in this research. Four design examples were presented to illustrate the use of the developed design equations for PSFC girders.

Future research in this area are suggested as follows:

To obtain a better understanding of the tensile behavior of PSFC, researchers recommend performing a series of sequential load panel tests. A target compressive strain would be imposed on the panel and held constant. The tensile load and strain would then be increased until failure.

To extend the constitutive properties of PSFC for use of other types of fiber, researchers would utilize the characteristics derived from relatively simple beam tests.

Tendon embedded in PSFC has a greater stiffness than tendon embedded in concrete without steel fiber. To assure ductile design of PSFC, researchers recommend further study of ductility of embedded tendon in PSFC to preclude dominant cracking and the resulting failure of tendons at the crack.

Steel fiber concrete can be applied to the end zones of prestressed concrete girders, where shear bond failure may occur.

Key Words:

Beams, constitutive models, shear provisions, prestressed concrete, steel fiber concrete, membrane elements, full-scale tests, design equation

The development of general guidelines to ensure girder stability during lifting, erection, and early stages of construction is complicated by the wide range of variables that impact the behavior of the girder system. These variables include girder proportioning, partially installed bracing, crane positioning, the use and positioning of temporary supports, as well as several other factors.

To aid in assuring girder stability, two analytical tools were developed as part of this research project. The analytical tools consist of a spreadsheet program (UT Lift) for evaluating girder behavior during lifting, and a finite element program (UT Bridge) for analyzing the behavior of I-girder bridges at various stages of erection and during construction of the concrete bridge deck.

While the guidelines presented herein have been developed to assist in producing a stable system, the reader is encouraged to use the analytical tools, UT Lift and UT Bridge, or other suitable analytical packages, to evaluate bridge girder systems during construction.

UT Lift and UT Bridge are available at:

<http://fsel.engr.utexas.edu/software/index.cfm>

Key Words:

I-Girder, Curved Bridge, Lifting,
Erection, Construction

The results of this research demonstrated that the split pipe stiffener cross-frame connection is much stiffer than the bent plate connection detail. In general, using the stiffer split pipe connection will help limit girder end twists compared to the traditional bent plate connection detail. In addition to a stiffer connection, the split pipe stiffener offers warping restraint to the end of the girder which significantly increases the girder torsional stiffness and therefore significantly increases the girder elastic buckling strength. This increased buckling strength permits the safe use of larger unbraced lengths. Therefore, using the split pipe stiffener to increase the girder buckling capacity near the supports will likely allow the nearest row of intermediate cross-frames to be moved farther away from the supports. Doing so will move the intermediate cross-frames into a region of smaller differential girder deflections and therefore reduce the live load forces induced in the cross-frames and mitigate the potential for associated fatigue cracking. The higher buckling strength of girders with split pipe stiffeners may also allow a reduction in the total number of cross-frames needed in a bridge. Overall, the increase in girder torsional stiffness and buckling capacity that results from the use of the split pipe stiffener will enhance the safety of the girder at all stages of construction: during transportation, lifting, erection, and placement of the concrete deck.

This research also found out that cross-frame layout has a large impact on live load induced forces in the cross-frame members. The staggered layout results in significantly lower force levels in cross-frame members, compared to the more conventional continuous layouts. Therefore, the staggered layout is generally recommended in skewed bridges when the fabrication and installation costs are justified.

Key Words:

Skewed steel bridges, bracing, lateral torsional buckling, connection details, bracing layout

The literature-derived results were compared to the physical model experiments conducted at Texas Tech University. Both sets of data (literature-derived and experimentally determined) were analyzed using HEC-22 procedures and regression analysis to produce guidance for predicting inlet hydraulic capacity. Additionally, the U.S. EPA SWMM model was used to analyze selected experimental results in an effort to develop guidance for using that tool as an alternate performance prediction method.

The researchers found that the TTU experiments were consistent with similar experiments found in the literature with respect to inlet capture capacity and its relationship to approach conditions. Type-H inlets, as studied, performed similar to HEC-22 expectations when the weir-type conditions are assumed (Equation (4-26) in HEC-22). The TTU researchers were unable to produce sufficient approach depth for orifice-type flow equations to explain observed behavior.

Power-law models using the dimensionless groups identified by Cassidy (1966), with the slopes omitted, provided a reasonable explanation of inlet behavior. The model was fit using the TTU experiments then extrapolated to the literature-derived conditions, with reasonable fidelity to the literature-derived results. Likewise, when fit to the literature-derived conditions, then extrapolated to the TTU experimental conditions, reasonable fidelity to the experimental observations was preserved. The power-law model, because it is regression derived, tends to under predict inlet capacity in cases where the inlets are known to achieve full capture. As such the power-law model can be considered a lower-support prediction tool for inlet design.

The U.S. EPA SWMM program was investigated as a predictive tool by comparison of a simplified SWMM model to selected TTU experimental results. The modeling approach used predicted performance reasonably well. The SWMM model was perceived by the researchers to be better at predicting when full-capture would occur, but at the expense of having a minor-loss coefficient that reflected a throttle plate which certainly would not be used in practice.

Considering collectively the findings and experimental conditions the researchers conclude:

Type-H inlets, whether grate-top or lid-type will behave according to the HEC-22 weir-type equations under most operational conditions until the approach depth is sufficiently deep—the researchers speculate that the requisite depth is on the order of the inlet equivalent diameter (i.e. the short dimension on a rectangular inlet). A six-inch ditch block, as suggested in the HEC-22 document to increase ponding and hence capture efficiency may not be sufficiently tall in many cases. The TTU experiments suggest that greater heights may be more appropriate.

Type-H inlet performance can be predicted using HEC-22 methods.

Type-H inlet performance can be predicted using the power-law model, with the caveat that the power-law model does not predict full capture; even in cases where it might occur.

Type-H inlet performance can be predicted using SWMM modeling procedures. The ability of the analyst to directly code inlet performance into SWMM was not used in this research; the SWMM performance prediction was based on strictly hydraulic considerations.

Key Words:

Type-H Inlets, Inlet Hydraulics,
Physical Model

Evaluation of TxDOT's Culvert Load Rating Practices and Procedures - This project initially focused on articulating a clear and repeatable, production-oriented load rating procedure that would yield reliable load ratings. More sophisticated analyses could conceivably reduce excess over-conservatism in the load ratings by considering the effects of soil-structure interaction. To this end the *Culvert Rating Guide* was developed.

Culvert Rating Guide - The guide articulates a clear and repeatable load rating procedure designed to satisfy current AASHTO specifications and provide for 4 levels of increasing demand modeling sophistication. These 4 levels are: Level 1, culvert specific frame analysis programs typified by CULV-5; Level 2, two-dimensional general frame analysis programs as typified by RISA-2D with spring subgrade support; Level 3, two-dimensional finite element soil-structure interaction programs as typified by RISA-2D with linear elastic finite elements; and Level 4, higher order generalized programs including non-linear two-dimensional models and three-dimensional models. The guide provides specific direction for load rating using the first 3 methods.

Evaluation of TxDOT Culvert Designs and Analysis Methods - In task, 100 TxDOT culvert designs representative of the full population of TxDOT's culvert inventory were load rated using the first 3 analysis levels. The results showed that in general, the Level 2 analysis produces marginally higher load ratings than the Level 1 analysis. It also showed that the Level 3 method can produce much higher load ratings if the soil is sufficiently stiff. However, if culvert backfill is of poor quality, the higher-level load rating may be less than that determined by CULV-5.

This work also revealed that the presenting problem upon which TxDOT commissioned this research study may in fact be real. That is, for cases where in-service culverts must be lengthened or reconfigured, unless the culvert backfill soil is sufficiently stiff, the culvert may require load posting or replacement. Generally, the newer the culvert is, the more likely the culvert will load rate acceptably.

Parametric Analysis - The findings of this analysis were incorporated into the *Culvert Rating Guide*. The recommended values for the modulus of subgrade reaction were found to be acceptable. The Level 3 analysis was found to be relatively insensitive to Poisson's ratio and a typical value of 0.3 is appropriate for all but deep fill culverts beneath clay soils. The study also showed that CULV-5 can be used conservatively to load rate culverts with 5 or more 4 barrels by modeling the culvert with only 4 barrels. The load rating is not very sensitive to the lateral earth pressure, therefore AASHTO's equivalent fluid weight values are recommended.

Culvert load ratings were found to be highly sensitive to the modulus of elasticity for the soil in the Level 3 analysis. The depth of fill is also a highly sensitive parameter; therefore, culverts should be load rated at their actual depth of fill and culvert designs should be evaluated at both their maximum and minimum depths.

Instrumented Load Tests on 3 In-Service Culverts - Field instrumentation and load tests were limited to 3 in-service TxDOT culverts, the key objective being a comparison of measured versus predicted live load moment demands. This work primarily evaluated the reliability of analytical modeling approaches recommended in the *Culvert Rating Guide* to predict live load demands. The instrumented load test data indicated that the culvert load ratings for each model were conservative. The higher level models yielded slightly unconservative results at some critical sections. However, these are not the controlling critical sections for the load rating. Therefore, the most important finding from the field study is that all models may be conservatively used for load rating. Relative to culvert design, however, only the lowest order model, *i.e.* CULV-5, should be used.

The very limited dead load evaluation indicated that the distribution of moment demands due to dead load is not well understood. An appropriate way to further explore this would be to instrument a newly constructed culvert.

Site-specific soil testing performed as part of this study highlighted the order of magnitude difficulty associated with obtaining soil elastic modulus values for Level 3 analytical modeling purposes. Several methods are available to determine soil elastic modulus, but values determined by these methods vary widely within a given soil stratum.

Key Words:
load rating, culvert, soil-structure interaction

Experiments performed in the laboratory showed that the accelerometer and tiltmeter can be used in scour monitoring events since both give a warning of impending bridge failure successfully. However, the instrumentation of two bridges (US59 over the Guadalupe River Bridge and SH80 over the San Antonio River Bridge in Texas) did not show great hope for the use of accelerometers to predict bridge scour because of lack of efficient excitation from traffic. Another issue with the accelerometer was the high power consumption during the transmission of the data, which could not be satisfied with an ordinary solar panel. Tiltmeters could provide the integral behavior of bridges in the field, therefore tiltmeters are recommended for scour monitoring.

Besides accelerometers and tiltmeter, sonar sensors, water stage sensors, float-out devices, and tethered buried switches were also used in the project. Of all those instruments, the tethered buried switches are recommended as a complement to the tiltmeters because they are reliable, relatively low cost to purchase.

Two large scale laboratory experiments were performed in the Haynes Coastal Engineering Laboratory at Texas A&M University. In the shallow foundation experiment, one column, 1.5 ft in diameter and 13.1 ft long, was embedded to a depth of 1 ft in fine silica sand in a two-dimensional flume. Two concrete slabs, each roughly 1.75 ft wide by 6.75 ft long, placed end-to-end on the column simulated the bridge deck. In the deep foundation experiment, the bottom of the column was reconstructed to form a pile foundation. The column was embedded to 1.5 ft in the sand with 0.5 ft of column and 1 ft of pile foundation. Accelerometers, tiltmeters, water stage sensors, floatout devices, tethered buried switches, and sonar sensors were installed to monitor the simulated bridge. An acoustic doppler velocimeter was mounted in the flume to provide the water velocity.

Both the shallow foundation experiment and deep foundation experiment indicated that the accelerometer can be used to predict impending bridge failure as well as tiltmeters and sonar sensors. The Fast Fourier Transform (FFT) approach as well as the ratio of Root Mean Square approach was proven to be effective to analyze the accelerometer data as they showed a significant change when the scour depth reached the bottom of the column and the column started to settle and rock. The tiltmeter was reliable, stable, and robust. Both the float-out device and tethered buried switch worked very well during the experiment; both devices showed great potential to be applied in the field to monitor scour events. The sonar sensor worked well as long as the minimum water depth of 2 ft was met. Note that the sonar sensor cannot predict scour depth if the sonar sensor is attached to the column and the column starts to settle. Indeed, then the sonar sensor also settles. If this is not a problem, the sonar sensor can be used to monitor scour depth at that location. The water stage sensor did not work very well in these two experiments. The two laboratory experiments indicated which monitors to use in the field scour monitoring experiments.

The threshold for tiltmeters can be established based on two points of view: the tilt of the pier and the tilt of the deck. The threshold for Tiltmeter1 and Tiltmeter2 on the deck of US59 over the Guadalupe River Bridge was 0.38° for checking the bridge, and 0.76° for closing the bridge. The threshold for Tiltmeter3 and Tiltmeter4 on the pier of US59 over the Guadalupe River Bridge was 0.46° for checking the bridge, and 0.93° for closing the bridge. Data analysis for tiltmeters on US59 over the Guadalupe River Bridge showed that the bridge has been safe.

The threshold for Tiltmeter1 and Tiltmeter2 on the pier of SH80 over the San Antonio River Bridge was 0.5° for checking the bridge, and 1° for closing the bridge. The threshold for Tiltmeter3 and Tiltmeter4 on the deck of SH80 over the San Antonio River Bridge was 0.75° for checking the bridge, and 1.5° for closing the bridge. Data analysis for tiltmeters on SH80 over the San Antonio River Bridge showed that the bridge has been safe.

Tiltmeters are reliable, simple, and relatively inexpensive to purchase and to install. They are recommended as sensors that integrate the overall behavior of bridges and can give warnings when failure approaches.

Key Words:

Scour, Bridges, Monitoring, Accelerometer, Tiltmeter, Tilt Sensor, Motion Sensor, Realtime

In their basic structural mathematical forms, the rational and modified rational methods remain appropriate models of small watershed Texas hydrology when used with careful consideration of uncertainties. The most important source of uncertainty is the specification of characteristic time (a watershed property). The URAT methodology is a defensible attempt to mitigate this uncertainty.

The drainage area limit for application of the rational method appears unidentifiable from analysis of observed rainfall and runoff. Further, the clever equivalence of time used to develop the Unified Rational Method, provides no additional insight in the upper drainage area limit. The authors suspect that for simple watersheds the upper limit could be extended from the community accepted value of 200 acres to 640 acres. The critical assumption for applicability of the rational method is whether the steady-state assumption can hold for multi-hundred acre watersheds.

The granularity or resolution suggested in tabulated ensembles of the runoff coefficient from the literature is difficult to justify. The literature coefficients are conceptually inverted runoff coefficients, although there are some volumetric coefficients in the runoff coefficient database.

The authors suggest that it unnecessary to break a watershed into subbasins for purposes of computing a runoff coefficient, as there is not much precision in the coefficient in light of the previous comment, and composite runoff coefficient values for a watershed are an obfuscation. A caveat is that C^* in its strictest sense is a composite coefficient of two types of runoff contribution areas, the authors suggest that should composite values be used two or three runoff contribution areas should be more than sufficient.

The modified rational method can use tabulated coefficients and generate runoff hydrographs. Conceptually, the modified rational method is a unit hydrograph method, and hence the runoff coefficients are conceptually volumetric coefficients. Analysis of rainfall-runoff data in Texas indicated that when the modified rational method is employed, the runoff coefficients derived from the literature are on average too large by a factor of about 2.

An alternative to the conventional rational method was developed; the Unified Rational Method. The method eliminates probability adjusted runoff coefficients (and land-use based coefficients entirely). The method collapses all probability estimation into the specification of time and consequent intensity.

The Unified Rational Method provides the first tuned version of the rational method for the intensity-duration frequency and flood-flow frequency equations in Texas.

The runoff coefficient of the Unified Rational Method is comparable to other incarnations of the rational method. However, how to adjust this coefficient for watershed slope and intensity of rainfall (recurrence interval) is unknown, and instead these considerations are included by having watershed time dependent on slope and recurrence interval.

Where possible, additional methods for estimation of peak discharge should be consulted as part of standard design practice—this theme is the point of the regression equation adjustments.

The researchers suggest that the Unified Rational Method is a substitute for the conventional rational method. URAT substitutes considerable land-use specification subjectivity, slope influence, and probability adjustments to runoff coefficients by a simple area-weighted coefficient based on functional impervious cover and pervious cover. URAT incorporates the effect of slope and probability adjustments in the specification of the watershed time of equivalence—a characteristic time that makes rational peak discharges and regression equation peak discharges equal at some specified recurrence interval—a tuning that eliminates the implicit probability equivalence assumption in the conventional rational method.

The researchers suggest that URAT minimum characteristic time be limited to 10 minutes for essentially the same reasons as in conventional rational method—to prevent unrealistically large intensities.

The modified rational method is unchanged except for the use of the URAT approach to parameterize the hydrograph generation model.

Key Words:

Hydrology, hydraulics, rational method, modified rational method

The concept of using conventional precast, prestressed panels to construct an overhang was verified. Current TxDOT bridge capacities have sufficient reserve strength over the required AASHTO loads. The full-depth precast panels also showed sufficient strength in both interior bays and overhangs.

The stiffness of the full-depth precast, prestressed panels was comparable to the conventional cast-in-place (CIP) deck. Overhang failure loads were made critical by loading at the edge of the panel and seam joint. It is evident that the introduction of the seam decreases the overall strength, when only the bottom longitudinal steel is discontinuous. Nevertheless, some positive (and negative) moment strength is still available due to the CIP panel-to-panel joint that has a single layer of link bars. Although this is weaker than the full-depth overhang, overall reduction of load carrying capacity is only in the order of 14 percent. It should be noted that the overhang systems evaluated in this research did not contain barriers.

The interface shear capacity of the existing R-bar system used in present practice seems to be sound. From the tests the inferred coefficient of interface friction between cracked concrete-concrete interfaces that exist within the haunch of a prestressed concrete slab-on-girder bridge is at least 1.0.

The apparent coefficient of sliding friction in the cracked grout-bed that exists between the precast concrete slab and concrete girder, based on the present test data, has a dependable coefficient of friction of 0.4. This result is lower than expected and is believed to be attributed to the relatively smooth shear interface between the soffit of the precast panels and the grout in the haunch.

Based on two threaded-rods per pocket, as tested, the interface shear system to connect the precast concrete slabs to the concrete girders via a grout bed, as proposed by TxDOT engineers in collaboration with the research team, *does not* have sufficient shear capacity as expected by the *initial* design.

The relatively low resistance provided by the interface shear using the haunch can be improved by using more pockets and fasteners than originally planned.

The shear resistance may be enhanced by increasing the coefficient of friction via surface roughening as noted in the 2007 AASHTO LRFD 5.8.4. Adding a reasonable number of shear pockets can also help distribute the shear load more evenly.

Several grouts were shown to exhibit adequate strength and adequate flow characteristics to fill the haunch.

A combination of a flexible polyethylene foam and an adhesive can be used to produce an adjustable haunch form that is able to resist the lateral pressure from the gravity-fed concrete and/or grout used to construct the precast overhang system.

The overhang system has significant potential to increase economy and safety of bridge construction in Texas. Additional research is being performed in Phase 3.

Concrete codes typically recommend roughening of interfaces to improve the coefficient of friction for sliding interface shear. For example, if the surface is intentionally roughened, providing an amplitude of more than 0.2 in., a coefficient of friction of 1.4 can be assumed, by design. Lesser values are recommended for smoother surfaces, such as 1.0 and 0.7 for a roughness amplitude of greater than 0.08 in. and laitance-free non-roughened surfaces, respectively. Several tests need to be conducted to explore the optimal trade-off between constructability and surface roughness.

Key Words:

Precast, Prestressed, Bridge Overhang, Grout, Constructability, Bridge Deck Panel

Mechanisms: For the shear connector/coupler systems documented in this report, there were five distinct stages up to failure. These stages included the initial adhesion loss, shear key action, shear key action failure, dowel action of the shear connectors at the sustained load, and final failure of the system.

Mechanisms: The roughened surface on the girder surface provided a stronger adhesion between the haunch material and the adjacent girder surface in the push-off samples. The unroughened surface on the underside of the precast deck panel exhibited weaker adhesion to the haunch material. Surface roughening improves the adhesion of the system but the surface adhesion (V_{loss}) was not used in determining the shear resistance of the interface plane. After adhesion loss, the main source of shear resistance was provided by shear key action near the shear pocket (shear connectors/couplers, filling materials, and a confinement system) until the peak load was achieved. The sustained load seems to be a result of the dowel action of shear connectors.

Confinement Effect: Test result indicated the #3 (M10) hoop confinement system (S2-0.62-IO) seemed to be effective only when the 0.75-in. diameter shear connector/coupler system was used. The steel tube system provided both improved shear key action and dowel action and resulted in higher peak and sustained shear loads.

Design: This research resulted in the development of a new design equation for estimating the shear capacity of girder-haunch-deck systems. Based on this proposed equation, results indicate that pockets containing 1.25-in. diameter shear connectors with steel tube confinement require the least number of pockets. Note that the design uses 80 percent of the sustained load (V_{sus}). This may be conservative. Using a percentage less than 100 and the peak load (V_{peak}) may result in even further reductions in pockets and connectors. For Tx 28 girders (girders with the highest demand), results indicate that three shear pockets are required for end panels. It should be noted that the research in this report only assessed the shear capacity of systems with single pockets under lab conditions. Issues related to fatigue, incorrect construction, non-uniform stress distributions, and other potential influencing variables were not assessed. Care and good engineering judgment should be used when designing overhang panels with the proposed equation.

The research findings indicate that high strength shear connectors with an appropriate confinement system can reduce the number of shear pockets required in precast overhang panels.

TxDOT should use appropriate friction factors and cohesion factors considering the diameter of the shear connectors and the effectiveness of confinement. When large diameter shear connectors are proposed, the friction factor should be reduced. When a confinement system is proposed, the cohesion factor can be increased. However, the cohesion factor should be limited to achieve sustained ductile behavior. The design should be executed to the bar failure mode without deck and shear pocket failure.

The grouping effects of the shear connectors in pockets should be further investigated for both R-bar systems and shear connector systems. Additional testing containing two shear connectors confined by the steel tube would be beneficial to assess grouping effects.

To prevent interfacial failure between the steel confining tube and the deck concrete, holes should be cut into the steel tube or protrusions should be welded to the outside surface of the tube. This will likely resist slip in the vertical direction.

The full-scale tests with multiple shear pockets are necessary to verify the proposed design equation.

Key Words:
Shear Friction, Push-Off Test,
Composite System, Anchor Type

Site selection and soil characterization showed that the upper strata contained soils that could be characterized as expansive in nature. The volumetric swell strains of Soil Layers 2 and 3 were 11.1 percent and 7.7 percent and the linear/volumetric shrinkage strains were 12.1/6.8 percent and 8.4/5.22 percent, respectively. These results indicated that the present soils close to the surface were indeed expansive.

The load test design included a design of the reaction and the test shaft configuration and spacings between them. Preliminary LPILE analyses conducted on these reaction and test shafts using the hypothetical lateral loads estimated from tensile loads in the cables showed that a spacing of 20 ft between each reaction and test shaft for the given testing condition resulted in lesser influence of the reaction shaft movements on the test results.

The load tests in the inclined configuration were successful and the field load testing went smoothly as per the design. Ultimate inclined loads were successfully obtained for the majority of the tests conducted. Though the channel section to which the Dywidag bar was connected had yielded in one test, this incident was quickly corrected with additional splicing, resulting in the completion of the test. Subsequent tests on all of the other test shafts were conducted by providing the same additional splicing at each of the steel channel pieces. Overall, the inclined load tests were conducted successfully in these north Texas soil conditions.

Tests under inclined loads showed different failure modes at different seasonal periods including large lateral and vertical movements for smaller diameter shafts to breaking of the shafts near the ground surface zones due to high tensile stresses being developed from the loadings.

Tests conducted on shafts of identical dimensions in summer and winter conditions showed that the load-displacement response in the hot and dry season condition was close to the “brittle” failure condition. In the wet and cold season condition, however, the response was close to the “flexible” failure condition.

Ultimate loads on smaller test shafts appeared not to be influenced by weather condition. However, 2 ft diameter shafts yielded higher ultimate loads in the summer condition tests than in the winter condition tests. This research also presented models to be used for the analysis, design, and construction of drilled shafts used as foundations for cable barrier systems. A few models for the ultimate uplift capacity and the lateral load were used to compare and generate a graph to assist in design selection.

Models that were used in this study were separated into 2 axes. The ultimate uplift capacity was used for the vertical direction and the ultimate lateral load was used for the horizontal direction. From the comparisons between the field test results and the developed models, the uplift capacity of Das and Seely’s model provided reasonable results with an average ratio between the field test and the predicted results at 0.22 and 0.28 for 0.5 in. and 1.0 in. criteria. For the ultimate lateral load, the p-y Method using the LPILE program provided the best-fit results against the field test results with over-predicted results at 1.21 and 1.20 for 0.5 in. and 1.0 in. criteria.

Researchers also developed a construction guideline that shows the schematic of drilled shaft construction located in expansive soil used at the ends of the cable barrier systems. In addition, a few recommendations used for construction in dry and wet seasons and maintenance programs are explained.

Key Words:

Drilled Shaft, Deep Foundation, High-Plasticity Clay, Cable Barriers, Lateral Load, Uplift, Inclined Load

Texas Department of Transportation (TxDOT) project 0-6348, “Controlling Cracking in Prestressed Concrete Panels and Optimizing Bridge Deck Reinforcing Steel,” started on September 1, 2008 and is scheduled to end on August 31, 2012. This report summarizes research progress to date and lists the following principal findings:

TxDOT specifications for precast, prestressed panels currently require an initial prestress of 16.1 kips per 3/8-in. strand. Because measured prestress losses are less than half those assumed in design, test data acquired in the study indicate that the initial prestress could be reduced to 14.4 kips per 3/8-in. strand. Such a reduction would lessen stresses that lead to collinear panel cracks (cracks that form along prestressing strands).

The propagation of cracks that form along the prestressing strands can be controlled by supplementary reinforcing bars placed at the panel edge and oriented perpendicular to the prestressing strands

Design of top-mat reinforcement is governed primarily by requirements for control of crack widths. Currently, required longitudinal reinforcement is already at the minimum amount necessary to control crack widths and probably cannot be reduced. Transverse reinforcement, in contrast, might be reduced. Different ways of doing this, including welded-wire reinforcement, are being checked with a field study at a TxDOT bridge near Waco.

High-performance steel fibers might replace conventional reinforcement under some conditions. To use these fibers effectively, it is necessary to have reliable and cost-effective tests for evaluating the stress-strain behavior of concrete reinforced with high-performance steel fibers. The “double-punch” test shows promise for this. Standard protocols for performing it have been developed by study researchers, and are being evaluated for reliability.

Key Words:
bridges; concrete precast
prestressed panels; cracking;
reinforcement; fibers

Summary

Two full-scale crash tests with an 80,000-lb van-type tractor-trailer impacting an instrumented, simulated bridge pier at 50 mi/h were performed. Ballast in the trailer consisted of bags of sand on pallets distributed throughout the trailer. Force data were collected from load cells installed on the bridge pier, and high-speed digital videos of the collisions were recorded. The data were analyzed to arrive at an equivalent static force for strength analysis/design of bridge piers subjected to collisions by large trucks. Analyses of the data indicate the equivalent static force is as much as 700 kips over a very short time duration. For trucks of more rigid construction and for trucks carrying more rigid cargo, the force would be expected to be higher.

Conclusions

An instrumented, simulated bridge pier was constructed, and two full-scale collisions with an 80,000-lb van-type tractor-trailer were performed on it. The trailer was loaded with bags of sand on pallets. Force-versus-time data were derived from load cells that support the simulated pier. The load cell data, when filtered with a 0.050-sec moving average, indicate an equivalent static design force of 400 kips. Refined analyses of the data indicate that an equivalent static design force at the interface of the truck and pier should be approximately 600 kips.

Implementation

Information has been developed that indicates revisions should be made to selected sections of the *AASHTO LRFD Bridge Design Specifications*. Recommended revisions include the magnitude of equivalent static force, direction of application of force, and height of force above ground. The recommended revisions should be submitted to the appropriate AASHTO subcommittees for consideration. Recommended revisions are as follows:

- Change equivalent static force from 400 kips to 600 kips.
- Change direction of applied force from “any direction” to “zero to 15 degrees with the edge of the pavement.”
- Change height of force from 4.0 ft above ground to 5.0 ft above ground.
- Incorporate the crash risk analysis methodology from Phase I of this study.

Key Words:
Bridge Piers, Abutments,
Vehicle Collisions, Load
Resistance Factor Design,
LRFD, Heavy Trucks, Single-
Unit Trucks, Bridge Design

To assess the performance of a twin steel box-girder bridge in the event that one of the fracture critical tension flanges suffers a failure, engineers require structural analysis models capable of representing the complex behavior that occurs under such conditions. One such model is the simplified modeling approach. The initial steps of the procedure define strength checks that are needed to evaluate the redundancy of a twin steel box-girder bridge.

The strength checks that require evaluation are as follows: (a) intact girder has adequate shear and moment capacity, (b) deck has adequate shear capacity, and (c) shear studs have adequate tension capacity. If the bridge under investigation satisfies only the first two conditions, it is still possible that it can sustain load without collapsing. Under these conditions, a yield line analysis can be used to evaluate the ability of the deck to transmit load to the intact girder without the shear studs connecting the deck to the fractured girder. In the event that the capacity predicted from the yield line analysis is not adequate, a more refined analysis can be performed.

To develop more refined finite element models for this research, various simulation techniques were utilized to capture important response mechanisms that were expected to develop in a severely damaged bridge. These techniques were utilized to construct analysis models simulating the full-scale bridge fracture tests. These models were successful in capturing prominent bridge behavior and component failures observed during the experimental program. Various bridge models constructed in the same way as the bridge test simulation models were then used to investigate how changes in several of the design variables and bridge geometry affect the remaining load-carrying capacity of twin steel box-girder bridges following the full-depth fracture of one girder.

Through three full-scale tests, the Ferguson Structural Engineering Laboratory (FSEL) test bridge performed much better than the AASHTO Bridge Design Specifications suggest, particularly given the fact that it was a simply supported span, had expansion joints in its railings, and had all external cross-frames removed. After sustaining a full-depth fracture in its exterior girder, the test bridge demonstrated sufficient redundancy through alternate load paths to maintain loads far exceeding those for which it was designed. Detailed finite element studies considering a wide range of design parameters confirmed the redundancy of these types of bridge systems.

After additional research is carried out, revisions to the current AASHTO specifications should be considered so that the behavior of these bridges following the failure of a critical tension flange can be accurately predicted and so that appropriate inspection and maintenance requirements can be prescribed. Given the demonstrated redundancy in these systems beyond that for which they have been credited, the current requirement for bi-annual inspections does not appear to be an effective use of labor or financial resources.

Key Words:

Bridges, fracture critical, design guidelines, finite element analysis

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