

Research Implementation Report

Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2009-01	2009	41.80	Evaluation of Alternative Anti-Icing and Deicing Chemicals Using Sodium Chloride and Magnesium Chloride as Baseline Deicers	Roberto DeDios	YES	This project evaluated potassium acetate, sodium acetate/formate-blend deicers, and potassium formate as alternative anti-icing and deicing compounds relative to sodium chloride (NaCl), salt-sand mixtures, and magnesium chloride (MgCl ₂) currently used by CDOT. Deicers may pose detrimental effects to Portland cement concrete infrastructure and asphalt pavement, cause corrosion damage to the transportation infrastructure, or have significant impacts on the environment. CDOT evaluated the performance of several alternative deicers compared with traditional chloride-based deicers. The negative effects of deicers on metals and concrete were investigated both in the laboratory and in the field. It was estimated that the implications of chloride-based deicers on the service life of steel-reinforced concrete might be significant.	This study provides definitive justification for the use of deicers. It encourages environmental compliance and exploring options for infrastructure preservation. Encourages maintenance to routinely clean out the liquid-holding tanks prior to introducing different liquid deicer products. This study helped CDOT understand the need to fund more research related to winter maintenance best practices in a proactive manner.
2009-02	2009	n/a	CDOT's current procedure for life cycle cost analysis and discount rate calculations	Roberto DeDios	n/a	This report provides information on life cycle cost analysis (LCCA) as applied to CDOT roadways. It describes the current method CDOT uses to select a discount rate. It also summarizes data collected from several states listing their HMA overlay cycles and discount rates.	NOTE: This is a courtesy publication; not a research study. The discount rate will be calculated annually by the HQ Materials Pavement Design Unit and distributed to the Pavement Design Engineers in each Region for use in their LCCA.
2009-03	2009	99.01	Work Zone Speed Control	Rich Sarchet	YES	Traffic in the lanes next to work zones presents a continuous hazard to workers. By reducing the speed of the traffic through the work zone, the hazard can be mitigated somewhat. Accurate data on the effectiveness of the simultaneous use of radar detection devices and law enforcement support in work zones would be valuable information for equipment purchasing and budgeting purposes. A literature search found 17 studies relating to work zone speed control and investigating the use of variable message signs (VMS), presence of law enforcement, and various signing methods. However, none provided current documentation of the effectiveness of the use of a VMS in conjunction with the presence of a law enforcement officer who was ticketing violators.	This research provides CDOT with methods for more reliable control of traffic speeds near work zones, improving safety for both the workers and the traveling public. Safety and Traffic engineers and Maintenance planners are using it to plan effective traffic control in work zone areas. The presence of law enforcement at work zone locations is recommended. This is especially true for work zones requiring more than a 10 mph reduction in traffic speed. As the reduction below the normal speed limit increases, the presence of law enforcement becomes more important. If a long work zone is necessary, more than one officer and patrol car may be needed to ensure compliance throughout the work zone. Speed reductions of more than 20 mph should be used only in extreme cases. The speed limit through the work zone should be raised to the highest safe speed as soon as practical. Speed reductions should be established for the shortest distance that is practical to protect workers and drivers.

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2009-04	2009	34.80	Functional Assessment of Colorado Wetlands (FACWet) Method	Vanessa Henderson	YES	Section 404 (b)(1) guidelines of the Clean Water Act (CWA) require that impacts to wetlands be avoided or minimized to the extent practicable. If impacts to wetlands are unavoidable, compensatory mitigation of those losses is generally required under the Act. In particular the CWA calls for impact mitigation to compensate for the wetland functions lost as the result of a federally-permitted action. This requirement necessitates a means of assessing and denominating wetland functioning, which CDOT did not have. To address this, CDOT assembled a joint agency study panel and funded a study called FACWet (Functional Assessment of Colorado Wetlands Method) to develop a functional assessment methodology for CDOT and the State of Colorado.	This report led to validation, refinement and comment by experts, and is now known as FACWet v.3, managed by the CDOT EPB Wetlands Program. So far it has led to the training of over 300 CDOT staff and wetlands professionals, and is considered a model by US Army Corps of Engineers.
2009-05	2009	13.00	Analysis of Using Reclaimed Asphalt Pavement (RAP) as a Base Course Material	Roberto DeDios	YES	The Colorado Department of Transportation (CDOT) has used Reclaimed Asphalt Pavement (RAP) as a base on many projects as a reconstruction strategy. CDOT's specifications allow RAP to be substituted for unbound aggregate base course (ABC). The laboratory- tested properties of reclaimed asphalt pavement are similar to CDOT's aggregate base course specifications. Conclusions are: RAP has pavement design properties similar to aggregate base course; a suggested gradation specification band is presented for RAP; RAP requirements for PI and LL may be the same as ABC Class 6, PI not to exceed six and LL not greater than 30; the stiffness strength properties obtained from laboratory testing shows that RAP has stiffness strength above an unbound ABC Class 6 ; and the permeability of RAP showed a slight increase over an unbound ABC Class 6.	The practice reduces the use of virgin aggregate and its haul costs. CDOT records do not track the quantities or price of ABC RAP separate from virgin material, but a rough estimate of saving over five years is \$340,000.
2009-06	2009	35.00	Tire/Pavement and Environmental Traffic Noise Research Study: Interim Report - 2007 Testing	Roberto DeDios	n/a	The research study was conducted in response to CDOT's interest in traffic noise in general, and the tire/pavement interaction in particular. Following a rigid set of testing protocols, data was collected on highway traffic noise characteristics along with safety and durability aspects of the associated pavements. The overall goal of this research project was to develop and execute a comprehensive, long-term study to determine if a particular pavement surface type and/or texture could be successfully used in Colorado to help satisfy FHWA noise mitigation requirements.	NOTE: This is an interim report; research continues. The information included in this report highlights the second in a series of four measurements to be collected over a five year period. While some of this information can be used immediately for decisions related to pavement design and specification, it is recommended that caution be exercised as the results from future testing will help further define the long term acoustical durability of these pavement surfaces.
2009-07			Number not used.				

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2009-08	2009	22.80	Concrete Deck Performance Relative to Air Entrainment	Roberto DeDios	YES	Damage to concrete due to freeze-thaw (F-T) action is a serious concern for agencies in cold regions of the United States. The most effective method to protect concrete from F-T damage is through the addition of an air entraining agent as an admixture that creates a well distributed, closely spaced, small sized air void system in the concrete. Air content measurement in fresh concrete is a routine quality control and acceptance test procedure that helps to ensure good durability characteristics in the concrete structure. Between 1993 and 2008, CDOT changed its specifications due to safety considerations of the field personnel. Air content measurements were performed at the point of delivery during this period. It is not clear whether the pumping and the placement operations altered the air void distribution. For planning future maintenance activities, CDOT was interested in evaluating the relative condition of bridge decks built under the point of delivery specification and verifying if they indeed possessed good F-T durability.	CDOT does not need any additional change of plans with bridge deck maintenance activities. This confirms that good materials and construction practices were used and there is no alarming difference in the quality of bridge decks built under the two specifications. However, CDOT has to take additional steps to ensure that bridge decks built in the future possess the air void distribution required for good durability.
2009-09	2009	12.69	Short-Term Crack Sealant Performance and Reducing Bumps and Transverse Cracking in New Hot Mix Asphalt Overlays over Crack Sealants	Roberto DeDios	n/a	Results of performance evaluations indicate that the crack sealants failed at a surprising rate after only one winter. However, subsequent performance surveys after 12 months and 21 months indicate a tendency for sealants to heal. Routing the cracks prior to filling appears to provide the best performance when the filler is overbanded, and filling the cracks to within ¼ inch of the surface instead of flush with the surface or overbanding produced the poorest performance. Bumps and transverse cracking occurred over the crack sealants when a new hot mix overlay was placed after the crack sealants had been in service two years. They were exacerbated by using steel rollers with vibration on breakdown of the hot mix asphalt overlay. The number of passes of the vibrating steel rollers further exacerbated the presence of the bumps and cracks. The same rollers used in static mode reduced the effect, and pneumatic rollers used for breakdown eliminated it. The ambient temperature and substrate pavement temperature during construction appears to have little effect, as the same bumps and cracking occurred during vibratory breakdown after a small rain shower moistened the substrate pavement surface prior to the overlay hot mix asphalt placement.	NOTE: This is an interim report; research continues.

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2009-10	2009	90.72	Safety Performance Functions for Intersections	David Reeves	YES	Road safety management activities include screening the network for sites with a potential for safety improvement (Network Screening), diagnosing safety problems at specific sites, and evaluating the safety effectiveness of implemented countermeasures. The efficient, state-of-the-art methodologies for conducting these activities make use of statistical models to predict expected accident frequencies using traffic volumes and other site characteristics as the input to the models (known as Safety Performance Functions or SPFs). CDOT's research and safety engineers are in the forefront of national efforts to develop methods using SPFs to screen large networks to find sites with a potential for accident reduction/safety improvement, which include freeway and rural roadway segments. This report documents the data collection, modeling efforts, and findings of a research project to develop SPFs for 10 categories of intersections.	Safety Performance Functions now form the basis for selecting and analyzing safety improvement projects. In 2014 there were about 51,000 crashes at intersections with 100 involving fatalities. The SPFs help insure that the 90 million dollar annual expenditure on highway safety addresses the highest priority locations. If only one improvement resulted from this research, the benefit would be over one million dollars.
2009-11	2009	106.01	Development of New Corrosion/Abrasion Guidelines for Selection of Culvert Pipe Materials	Aziz Khan	YES	The literature survey identified the pertinent parameters in estimating the service life of various pipe materials. Following the literature survey, field visits to culvert sites were made to collect data. Selection of culvert sites was jointly made by engineers from Staff Bridge, Staff Hydraulics, and members of the study panel. Field surveying of 21 sites where failed pipe installations were observed was conducted in Colorado along I-70, I-25, and SH 58 to obtain a good cross-section of soil type samples. Soil and water samples were obtained and soil resistivities were determined using applicable Colorado Procedures, AASHTO test methods, or ASTM test methods. These samples were analyzed for sulfate/chloride level concentrations, and pH levels. Relevant culvert inspection was obtained and used in the analysis where needed. Data collected from literature searches, the Staff Bridge database, actual field surveys, and other unbiased reliable sources was analyzed. The service life was correlated with various parameters including type of material, pH level, chloride and sulfate level concentrations, specific resistivity, and abrasion data (steep pipe slopes, high sediment loads, high flow velocity).	A new service life chart for steel pipes was developed based on the information collected from the field observations and data analysis. Data from Colorado pipe failure cases was used in relating service life of pipes to soil resistivity. Pipe failure criteria were established in accordance with the ongoing culvert evaluation procedure. For the steel pipe failure cases, the previously published service life predictors for steel pipes deviated from observations by as much as 10 times. Service life multipliers to account for steel pipe thickness effects had been greatly exaggerated. For aluminum pipes, the research identified chloride and sulfate concentrations as factors that reduced the service life of these pipes dramatically

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2009-12	2009	93.00	Worker Safety at the Colorado Department of Transportation	Rich Sarchet	YES	The Colorado Department of Transportation (CDOT) is currently investigating approaches to reduce the frequency and severity of work-related injuries. The incident rates for CDOT are significantly higher than those achieved by some private organizations (e.g., Kiewit) and comparable DOTs. One element in determining the current state of safety practices within CDOT is evaluation of Job Safety Analysis Forms (JSAs) and their current use. This study examined the effectiveness of these forms in terms of worker perspectives and the overall organizational strategies associated with the forms. Study results indicate that CDOT has a mixed record for implementing JSAs. There is a very positive attitude towards the JSAs and a strong willingness by workers to enhance the safety record. However, this positive is balanced by an equally strong negative aspect in terms of actual usage of JSAs in relation to the intent of the program.	Along with other factors, this research led indirectly to the creation of the “Excellence in Safety Program”. Since its inception in 2011, CDOT has seen a 26% reduction in worker’s compensation claims.
2009-13	2009	21.81	Lateral Vehicle Accelerations Due to Longitudinally Tined Portland Cement Concrete Pavement	Roberto DeDios	NO	The objective of this study was to determine, via field measurements, the vibration characteristics of vehicle squirming (a.k.a. groove wander) – a phenomenon whereby vehicles experience lateral vibrations due to interaction between tire tread grooves and longitudinal pavement grooves. The most effective sensor location to capture vibrations due to vehicle wander proved to be the passenger’s head. This location takes advantage of the human body’s amplifying and filtering characteristics.	The study was unsuccessful in providing a scientific tool to evaluate variations in tining specifications.
2010-01	2010	80.26	Accelerated Curing and Strength Modulus Correlation for Lime-Stabilized Soils	Aziz Khan	YES	This research sought to identify the equivalent 105°F curing duration for lime-stabilized soil (LSS) that will yield the equivalent unconfined compressive strength (UCS) to that resulting from 28-day, 73°F curing. Both 5-day and 7-day 105°F (or 100°F) curing have been used in practice. The study also sought to characterize the relationship between resilient modulus (Mr) and UCS for LSS soils, since the prevailing correlation between Mr and UCS for LSS – based on Thompson (1966) – was not developed from cyclic loading and has been validated with only limited data. The study revealed that the 5-day, 105°F accelerated curing yielded UCS values more representative of 28-day 73°F UCS than did the 7-day, 105°F curing regime. However, there is no universal equivalent accelerated curing duration for LSS; therefore, 5-day 105°F curing can yield erroneous estimates of 28-day 73°F UCS. The study recommends verification of the equivalent 105°F curing duration for each LSS to gage the most representative accelerated curing duration. Based on experimental Mr – UCS data, the relationship $Mr \text{ (ksi)} = 0.124 \text{ UCS (psi)} + 9.98$ was found to be conservative in its prediction of Mr from UCS.	This study resolved the conflict between 7-day cure in the pavement design manual and the 5-day cure in the Construction Specifications Manual. There is no significant difference between the two methods. This study led to a manual revision.

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2010-02	2010	86.00	Comprehensive Risk Analysis for Structure Type Selection	Rich Sarchet	YES	Structure type and construction duration are the important decision variables with respect to user costs, and these two are related. User cost can be reduced by shortening the construction duration for a particular type of structure, or selecting a type that inherently has shorter construction duration. For those bridges with an ADT value less than 10,000, the user cost was no more than about 10% of the construction cost. Also, for construction durations under 20 months the user cost was no more than 30% of the construction cost. For CDOT, concrete box girder prestressed bridges built with current construction practices exhibited user costs more than twice as large as construction costs.	This study led to a design methodology change in the preliminary bridge assessment to determine the consideration of user cost in bridge design. The information provided by this study helps take into account delay costs, as they become significant as a ratio to bridge costs when ADT exceeds 10,000, or construction duration exceeds 20 months, or wheather concrete box girder prestressed bridges are built with current construction practices. One example of consideration of user cost is the ABC approach (Accelerated Bridge Construction).
2010-03	2010	10.50	Evaluation of the Performance, Cost-Effectiveness, and Timing of Various Pavement Preservation Treatments	Roberto DeDios	TBD	This research study evaluated the performance of various pavement preservation treatments over time and under different environmental conditions to quantify the economics of each treatment type. There are three primary techniques utilized in Colorado for preservation of asphalt pavements and three for concrete pavements. For asphalt pavements these are crack sealing, chip seals, and thin hot mix asphalt overlays. For concrete pavements the treatments are joint resealing, cross-stitching, and microgrinding. Test results indicate that continuation of crack sealing, chip sealing, and thin hot mix overlays is justified for asphalt pavements. Performance results of the preservation treatments for concrete pavements were not as successful. The crack propagated into the adjacent slab in the cross-stitching test sections. Microgrinding concrete pavements does not appear to be effective at reducing cracking and may be detrimental to performance. The disappointing results of the joint resealing test sections indicated that a review of the specifications should be considered.	TBD. Recommended future research. The report did not provide any definitive findings to implement. Evaluation of the test sections were inconclusive. This research represents a good start to developing actual field performance for the preservation techniques used in Colorado. However, not all of the test sections established have begun to fail, so a clear understanding of the life-cycle of some of these treatments is lacking.
2010-04	2010	40.11	Investigation of Reuse Options for Used Traction Sand	Roberto DeDios	NO	CDOT uses approximately 24,000 tons of traction sand annually, especially in mountain locations. Once traction sand is applied, street sweepers reclaim approximately 50% of the sand, which is either stockpiled at a maintenance facility or disposed of in a landfill. The remaining 50% is left on the roadway and can collect in water quality ponds and rivers due to precipitation events. This research project consolidated physical and chemical characterization data on reclaimed traction sand from multiple mountainous areas in Colorado. The Principal Investigator determined that heavy metal contamination in the reclaimed sand is within naturally occurring levels and does not pose a risk to human health.	Recovered traction sand could be combined with coarse aggregate supplement to make it suitable for reuse. However, prior to the use of any salvaged traction sand material, federal and state regulations require that the material be approved by the CDPHE because of possible hazardous material in the recovered sand.

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2010-05	2010	84.14	Evaluation of CDOT Specifications for Class H and HT Crack Resistant Concrete	Aziz Khan	YES	This study examined the performance of concrete mixtures designed to increase cracking resistance for Colorado bridge decks. The current CDOT Class H and HT concrete mixtures and nine other mixtures were investigated. Compressive strength, permeability, freeze-thaw resistance, and restrained shrinkage cracking were evaluated and documented in this report. Lower w/cm resulted in high early compressive strengths and rates of strength and strain development. Increasing the w/cm to 0.44 and Class F fly ash replacement levels up to 30% was beneficial in controlling strength gain. A low cement content mixture with increased w/cm and fly ash replacement proved to be beneficial. When SCMs were not used a low cement content of 6.0 bags was beneficial. When SCMs were used, increased cement content helped to maintain the same properties. A high dosage rate of a shrinkage reducing admixture was extremely beneficial in controlling both the development rate and ultimate strain of the mixture, while maintaining adequate development of ultimate strength at all ages. An average dosage rate of a set retarder only retarded the initial strength development slightly. After one day of age, the development of strength and strain was substantially increased.	Some of the recommendations were incorporated into the Construction Specifications as a Standard Special Provision for class H and HT concrete, resulting in material that has less cracking potential and may even cost less. In 2012 and 2013, 1,576 Cu. Yd. of class H concrete was used at a total cost of \$717,000.
2010-06	2010	80.09	Strategic Evaluation of Different Topical Protection Systems for Bridge Decks and the Associated Life-Cycle Cost Analysis	Aziz Khan	NO	Bridge decks deteriorate faster and require more maintenance and repair than any other structural components on highway bridges. This study evaluated topical protection systems commonly used on highway bridge decks in Colorado, including low-permeability concrete overlays and waterproof membranes with asphalt overlays.	The researchers strongly recommend that at least one more inspection be conducted on the five selected bridges.
2010-07	2010	41.76	Bird Nesting and Droppings Control on Highway Structures	Vanessa Henderson	YES	This report provides a comprehensive literature survey of permanent and temporary deterrents to nesting and roosting, a discussion of risks to human health and safety from exposure to bird nests and droppings and recommended protective measures, and the results of a multi-year field study to test temporary nesting deterrents judged to be most effective. An extensive survey of the literature was conducted on the following: Measures used to deter roosting and nesting of pigeons, and to temporarily deter nesting of swallows (primarily cliff and barn swallows); the nesting requirements of these species to better enable evaluation of the efficacy of these measures; and the biology, diseases, and parasites of these species to enable evaluating and minimizing the risks of human detriment from exposure to these birds, their nests and droppings.	The counter measures have been recommended to Maintenance. The Maintenance personnel take care of their health by using proper protective equipment. A discussion of risks to human health and safety from exposure to bird nests and droppings and recommended protective measures, as well as the results of a multi-year field study to test temporary nesting deterrents, is judged to be most effective.

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2010-08	2010	74.90	Optimization of Stabilization of Highway Embankment Slopes Using Driven Piles-Phase I	Aziz Khan	TBD	This study determined the feasibility of using driven piles to stabilize highway embankment slopes. The results of this study show that driven piles can be a cost-effective solution to stabilizing highway embankment slopes. The literature review shows that several DOTs have used driven piles, including plastic pins, to stabilize highway embankment failures and most of these DOTs would recommend future use. The cost comparison analysis showed for a particular slope, driven piles would cost \$41 per linear foot of road stabilized. This was compared to drilled shafts and launched soil nails which had estimated costs of \$32 and \$130 per linear foot, respectively. The finite element study showed the factor of safety for a stabilized slope could be significantly improved with pile installation.	TBD. Phase II is underway as Study 74.91
2010-09	2010	87.40	Study on the Use of Self-Consolidating Concrete on the Interstate 25 Bridge Replacement in Trinidad, Colorado	Aziz Khan	YES	As part of a national experiment sponsored by the FHWA under the Innovative Bridge Research and Construction (IBRC) program, CDOT used self-consolidating concrete (SCC) to construct abutments, piers, and retaining walls on a bridge replacement project. The purpose of this study was to determine the procedures and possible benefits associated with flowing concrete. It was determined that SCC was used successfully in the I-25 bridge replacement project in Trinidad. Unfortunately, the all-around lack of experience with SCC resulted in numerous aesthetic problems that are atypical of the material. Despite numerous visual defects that required patching and repair, it is believed that each component has the required structural integrity necessary for safe highway transportation projects.	The self-consolidated concrete (SCC), has been used for caisson foundations in two major bridge projects. Parker Road. over Arapahoe Road, and Richmond Road over US 285. SCC minimizes the possibility of voids formed in caissons. Such conditions are hard to test and difficult to remedy. In 2014 CDOT spent \$5 million in caissons. A 1% savings would be \$500,000 each year.
2010-na	2010	105.82	New Design Procedure for Type C and D Inlets	Aziz Khan	YES	The purpose of this research was to develop a program for physical modeling of type C and D inlets for storm drainage of highway medians. The objective of the proposed model studies were as follows: Construct an appropriate physical model to incorporate a total of eight configurations of the type C and D inlets; quantify the hydraulic capacities of each inlet configuration with varying grate angles and debris conditions; prepare a project report summarizing the test program and all the results.	A new chapter for CDOT's Hydraulic Manual was developed along with design charts for highway inlet designs. A software was developed and it has been downloaded an average of 140 times per month. Since this study focused on the most economic size for type C inlet, it is expected to save at least 5% of installation cost.

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2011-01	2011	35.00	Tire/pavement and Environmental Traffic Noise Research Study: Interim Report – 2009 Testing	Roberto DeDios	TBD	This interim report was conducted in response to CDOT’s interest in traffic noise in general, and the tire/pavement interaction in particular. Following a rigid set of testing protocols, data was collected on highway traffic noise characteristics along with safety and durability aspects of the associated pavements. The overall goal of this research project was to develop and execute a comprehensive, long-term study to determine if a particular pavement surface type and/or texture can be successfully used in Colorado to help satisfy FHWA noise mitigation requirements. The study is needed to accomplish the following: Determine the noise generation/reduction characteristics of pavements as functions of pavement type, pavement texture, age, time, traffic loading, and distance away from the pavement; determine a correlation between source measurements using on-board sound intensity (OBSI), and statistical passby (SPB) and time-averaged wayside measurements; and accumulate information that can be used for validation and verification of the accuracy of the FHWA Traffic Noise Model (TNM) to use on future Colorado highway projects.	TBD. This is an interim report; research continues. See report 2012-05.
2011-02	2011	41.71	Improving the Performance of Roadside Vegetation	Bryan Roeder	YES	The purpose of this study was to determine the impact of a magnesium chloride-based deicer, a sodium chloride-based deicer, and the major salts contained in these deicers on seed germination and seedling growth and development of 15 species of grasses and forbs native to Colorado. Seven of the 15 species performed well at the low and medium concentrations of the salts and solutions; these are plants that can likely germinate in roadside areas. An increase in the concentration of chloride or sodium ions, or both, revealed a greater impact on the proportions of normal and abnormal seeds and seedlings. A few species were more negatively impacted by a particular salt type or formulation. Eight of the 15 species tested had too few plant counts at either field site or in different soils and treatments to conduct individual data analysis on the impact of salt treatments. Salt treatments had no impact on the average numbers of plants for the remaining seven species, except the two fescue species, which were negatively impacted by high concentrations of salt treatments in topsoil. In general, all species had more plants and greater growth on topsoil than sand, and sand was better than gravel. The salt concentrations in the field plantings were diluted by precipitation during the study indicating the impacts were probably less than what would be seen with consistently high concentrations.	CDOT is using species with the highest germination rate along highways treated with deicing products. Also, planting of grasses is done in the fall. The recommendations were incorporated into the specifications and the seeds mixes were changed.

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2011-03	2011	32.06	Assessment of Colorado Department of Transportation Rest Areas for Sustainability Improvement and Highway Corridors and Facilities for Alternative Energy Use	Bryan Roeder	YES	The research project focused on two sustainability-based elements associated with the CDOT Maintenance operations, namely rest areas and right-of-way (ROW) utilization. The Colorado State University-Pueblo Team focused on the following areas: existing site conditions, materials recycling and reuse, existing environment, air quality, water quality/usage, energy, and public/motorist/trucking outreach and services. Rest area carbon footprints were calculated and carbon reduction strategies developed primarily for long term idling trucks. Cost-effective sustainable recommendations were provided that focused on efficient use and consumption of natural resources. A second element was to evaluate the potential use of CDOT ROW for alternative energy applications, like solar, wind, biomass, and geothermal sources.	CDOT is working on a guideline to use solar power in the ROW. The use of alternative energy at rest areas could reduce greenhouse emissions and could save CDOT financial resources in the long term. Some maintenance units are starting to use mulching mowers to leave the grass as compost, thus reducing water consumption.
2011-04	2011	34.24	Use of Waste Tires (Crumb Rubber) on Colorado Highways	Roberto DeDios	TBD	The objective of this interim report is to provide a synopsis of the progress made after one year on the feasibility of using waste tires (crumb rubber) in the construction of asphalt pavements. As part of the evaluation, two pilot test sections and one control section were constructed. Two pilot test sections were built containing crumb rubber modified (CRM) asphalt. One process uses ground tire rubber blended with hot asphalt cement at an asphalt plant to form the hot mix asphalt. This will be referred to as the wet process. The other process blends ground tire rubber and asphalt cement at a remote blending facility. The blend is then transported to a hot mix plant where the modified hot mix asphalt is manufactured. This process will be referred to as the terminal blend method. In addition, a control section was constructed containing a conventional binder. Binders in the two test sections containing ground tire rubber and the control section met the specifications for a PG64-28 asphalt. Each of the three test sections contain approximately 1,000 tons of 2-inch asphalt overlay placed over a cold-milled surface in the eastbound driving lane of US 34 near Greeley. The test and control sections were constructed in the summer of 2009.	TBD. This is an interim project. Research will continue.

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2011-05	2011	n/a	Portland Cement Concrete Pavement Review of QC/QA Data 2000 through 2009	Roberto DeDios	n/a	<p>This report analyzes the Quality Control/Quality Assurance (QC/QA) data for Portland cement concrete pavement (PCCP) projects awarded in the years 2000 through 2009. Analysis of the overall performance of the projects was accomplished by reviewing the Calculated Pay Factor Composite (CPFC) and Incentive/Disincentive Payments (I/DP). Analysis of each of the test elements: thickness, compressive strength, sand equivalent, and flexural strength was also completed. The results of the evaluation are presented in tables, figures, and reports.</p> <p>The overall quality of the PCCP is very high. The quality levels in each of the elements approach the maximum of 100%. The pay factors for the individual elements are also close to their maximums. The material being produced is well above the minimum standards set by the specifications.</p>	NOTE: This is not a Research Project. Courtesy printing for the Materials and Geotechnical Branch, providing a way for publication of their work.
2011-06	2011	34.72	Denver Area Post-World War II Suburbs	Roberto DeDios	YES	Historic Residential Subdivisions of Metropolitan Denver, 1940-1965, documents the development of mid-century suburbs in CDOT Region 6. The report follows the National Register of Historic Places format for multiple property documentation, and is intended as a tool for researchers who need to determine the National Register eligibility for neighborhoods with the potential to be impacted by transportation projects.	This report provides reference material for subdivisions when projects require cultural impact studies. This report will inform transportation projects that may impact subdivisions over 50 years old, by providing the baseline to describe indirect impacts such as noise, or direct impacts such as property acquisition. The first major project it was used for was the US 36 expansion and it is currently being used to evaluate the impact of a project near I-25 and Arapahoe on the Walnut Hill subdivision and potential Section 4f classification.
2011-07	2011	34.11	Colorado Statewide Historic Bridge Inventory	Bryan Roeder	YES	The purpose of the Colorado statewide historic bridge inventory was to document and evaluate the National Register of Historic Places eligibility all on-system highway bridges and grade separation structures built in Colorado between 1959 and 1968. The results of this study were to be documented in a searchable database, in individual historic bridge site forms, and in Multiple Property Documentation Form (MPDF), a report that includes a historic context and provides guidance for evaluating historic properties. The project scope also included an update to information about the listed, eligible, or possibly eligible bridges identified in CDOT's previous bridge inventories from 1983, 1987, and 2000. The project was not completed during the contract period, so all of the data is in draft form and there are no results to report.	The inventory is being used by the history staff at CDOT headquarters and Regions 4 and 6 in coordinating compliance with Section 106 of the National Historic Preservation Act for projects involving bridge replacement and repair. It was distributed to each of the CDOT Regions for use in project planning. The survey has been used by the Colorado Office of Archaeology and Historic Preservation (OAHP) and local historical societies, preservation groups, certified local governments, and other organizations interested in historic bridges.

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2011-08	2011	34.23	Investigation of Best Options for Using Scrap Tires in Highway Noise Barriers	Roberto DeDios	YES	In Colorado, approximately 60 million scrap tires have been stockpiled and approximately 4.5 million scrap tires are generated annually. CDOT has goals and policies to promote sustainability/recycling and receives requests for more traffic noise barriers than can be funded. CDOT identified an opportunity to combine these two topics by investigating new ways to incorporate scrap tires into highway noise barriers. This research project reviewed potential noise barrier materials made from scrap tires, selected a material for field testing, designed and built a test barrier at the designated site using the material, and monitored barrier performance for one year. The material selected was a railroad tie barrier replacement made from scrap tire treads. These railroad ties were found to be effective as a noise barrier material. The ties provided a substantial noise reduction, consumed a number of scrap tires, had significant internal strength that is a plus as a building material, and were easily assembled in a post-and-panel barrier design. The barrier performed well over its first year. Identified challenges included: the ties were not a low-cost alternative (see reasons in the report); the finish stain method may need adjusting for a better long-term appearance; rust will appear on the steel components; and a few minor construction/finish improvements were identified.	CDOT will informally monitor the cost and availability of Tire-Ties™ and similar types of potential noise barrier materials. A separate process for inclusion in CDOT's Approved Product List, maintained and managed by the Staff Materials and Geotechnical Branch, may be pursued by the manufacturer at their discretion. The material and the wall design are recommended for consideration by CDOT on other projects to provide innovation in sustainable design through materials re-use. Also, this implementation lessens the quantity of waste that would otherwise enter landfills.
2011-09	2011	90.73	Safety Performance Functions for Ramp Terminals at Diamond Interchanges	David Reeves	YES	CDOT's research and safety engineers are in the forefront of national efforts to develop methods that use Safety Performance Functions (SPFs) to screen large networks to find sites with a potential for safety improvement. CDOT has previously developed SPFs to identify freeway, rural roadway segments, and ten categories of intersections that have the potential for accident reduction. This report documents two further efforts to support CDOT in the area of SPF development. The first effort involved the data collection and development of SPFs for ramp terminals at diamond interchanges. The second effort involved estimating the overdispersion parameters for a number of existing SPFs already in use by CDOT for various roadway segment categories. The development of SPFs for the five categories of ramp terminals was successful. Separate SPFs were developed for total and for injury (fatal+injury) accidents. These SPFs compare favorably to those developed for another North American highway agency. The calibration of overdispersion parameters for the existing neural network SPFs was also successful.	The developed safety performance functions are being used by CDOT for road safety management activities, including screening the network to identify diamond interchange ramp terminals with a potential for safety improvement, diagnosing safety issues at specific ramp terminals, and evaluating the safety effectiveness of implemented countermeasures. The overdispersion parameters developed for roadway segments will facilitate the application of the empirical Bayes methodology for safety management activities for these site types.

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2011-10	2011	12.69	Investigating Crack Sealant Performance and Causes of Bumps in New Hot Mix Asphalt Overlays Over Crack Sealants	Roberto DeDios	NO	This final report provides information on the performance of crack sealants supplied and installed by three manufacturers for experimental use in a three-year evaluation of in-service pavements on three Colorado highways. Preliminary conclusions were developed regarding the propensity of these sealants to contribute to bumps in new overlay hot mix asphalt. Results indicate that the crack sealants failed at a surprising rate after only one winter, but subsequent performance surveys after an additional 24 months indicate a tendency for the sealants to heal. Routing the cracks prior to filling appears to provide the best performance when the filler is overbanded, and filling the cracks to within ¼ inch of the surface instead of flush with the surface or overbanding produced the poorest performance.	Results are inconclusive.
2011-11	2011	80.50	CDOT Strategic Plan for Data Collection and Evaluation of Grade 50-H-Piles into Bedrock	Aziz Khan	YES	This report presents Phase I of CDOT's effort to address the issues associated with Colorado-specific resistance factors for driven pile designs. As proven during the process of this research, resistance factors vary with geomaterial types and geological locations. Procedures for the driven piles performance data collection for the evaluation of resistance factors for Grade 50 Steel H-piles penetrating into bedrocks are recommended. The data collection of driven pile performance is planned to continue in Phase II and the benefits of Grade 50 steel piles beyond those of Grade 36 steel piles will be investigated. The research will be expanded to investigate the benefit of using steel driven H-piles with sizes larger than the sizes currently adopted by CDOT, including 18-inch and 24-inch steel H-piles. The benefits in terms of capacity enhancement, pile number reduction in pile group for bridge support, and the associated time and cost savings will be assessed. Different methods for nominal capacity assessment will be used to evaluate the nominal capacities of 18-inch and 24-inch piles. Pile performances will be monitored using the pile driving analyzer (PDA), and, if budget permits, load tests will be performed to check the pile capacity calculation.	The research shows that Grade 50 steel piles can provide significantly higher capacities (strength) than Grade 36 piles, because they can be driven deeper without exceeding their yield stress. The high yield strength also allows the use of a heavier hammer to facilitate pile driving. This means potential cost savings for a bridge project with less required piles.

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2011-12	2011	20.60	Evaluation of Longitudinal Joint Tie Bar System	Roberto DeDios	YES	An adequate longitudinal joint tie bar system is essential in the overall performance of concrete pavement. Excessive longitudinal joint openings are believed to be caused by either inadequate tie bar size or spacing or improper tie bar installation. If designed and installed properly, tie bars prevent the joints from opening and consequently improve load transfer efficiency between slabs and between slabs and shoulders, resulting in increased load carrying capacity. This study evaluated the longitudinal joint tie bar system currently used by CDOT, examining the criteria for proper use of tie bars and determining the maximum number of lanes that can be tied together without negatively impacting the concrete pavement structure. An improved mechanistic-empirical tie bar design method was developed. Tie bar design tables with recommended bar size and spacing were provided for each combination of pavement base types, CDOT concrete mixes, and weather stations. Field studies were conducted to investigate longitudinal joint performance and further evaluate the impact of factors related to design and construction practices. The experimental plan for this round of testing included the evaluation of tie bar alignment, measurement of joint load transfer, and measurement of relative slab movement at the joints.	CDOT adopted the mechanistic-empirical tie bar design procedure developed in this study. This resulted in a construction specification change.
2011-13	2011	33.10	Evaluation of Environmental Commitment Tracking Systems for Use at CDOT	Roberto DeDios	YES	The purpose of this study is to review existing Environmental Tracking Systems (ETS) used by other, select state Departments of Transportation (DOTs), as well as the existing Environmental Commitment Tracking System (ECTS) currently in use by Colorado Department of Transportation (CDOT) in an effort to determine which system would be the most beneficial for long-term implementation at CDOT.	The recommendations resulted in an update of CDOT's Environmental Commitment Tracking System.

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2011-14	2011	98.20	Encouraging Innovation by CDOT Workers	Rich Sarchet	YES	In the course of their work, Colorado DOT employees have been known to create devices that improve the safety, efficiency, and quality of their work. The purpose of this study was to identify recent devices that were created by CDOT employees and to document them. In response to a request for innovations, CDOT employees submitted 34 candidate innovations. An Inventing and Patenting workshop was developed and delivered to these and other CDOT employees. A series of documents were developed for 23 of the 34 devices, namely: (1) Device Costs and Benefits, (2) User Manual, (3) Mechanical Drawing Package, and (4) Preliminary Patentability Assessment. The intent of this effort was to help disseminate, if appropriate, innovative devices throughout CDOT and other DOTs, and to provide input on patentability to the device developers.	The purpose of this study was to identify recent devices that were created by CDOT employees and to document them. Ideas for encouraging innovation within CDOT were developed as was a process to gather device information in the future. Four documents were developed for each submitted device: Device Cost and Benefits; User Manual; Mechanical Drawing Package; and Preliminary Patentability Assessment. The Device Costs and Benefits document provides information essential for deciding whether to replicate a device. The User Manual describes the installation and use of the device. The Mechanical Drawing Package is a set of part and assembly drawings required to replicate the device. The Preliminary Patentability Assessment presents the findings based on a prior device search regarding patentability addressing the three criteria: novelty, non-obviousness, and usefulness.
2012-01	2012	n/a	Cost-Benefit Evaluation of Short-Term Warranties for Hot Mix Asphalt Pavements	Roberto DeDios	n/a	The purpose of this report was to provide the reader with the ten-year analysis for the cost-benefit of hot mix asphalt projects constructed using the three and five-year warranty specifications developed by CDOT. There were eight projects evaluated using the three-year warranty specifications and two projects evaluated using the five-year warranty specifications. Each warranty project was evaluated with a comparable non-warranty (control) project. Overall, 214.6 lane-miles of warranty projects were constructed and compared to 276.6 lane-miles of control projects.	NOTE: This is not a research project. Courtesy Printing.

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2012-02	2012	32.42	The Reliability and Effectiveness of An Electromagnetic Animal Detection and Driver Warning System	Rich Sarchet	NO	This report contains data on the reliability and effectiveness of an animal detection system project along US Hwy 160 between Durango and Bayfield, Colorado. The system that was first installed was a Perimitrax [®] system from Senstar Corporation. In the fall of 2010 this system was replaced by an OmniTrax [®] system, manufactured by the same company, Senstar Corporation. The Perimitrax [®] system was also installed at a controlled access facility near Lewistown, Montana. Here more detailed investigations were conducted into the reliability of the system using horses, llamas and sheep as a model for wild ungulates.	The number of reported large mammal carcasses was highly variable between years for the different road segments both before and after the detection system. The high variability of the data combined with the limited number of years with available data do not show clear results of the potential effectiveness of the different treatments. The average number of large mammal carcasses per year in the years before installation of the animal detection system (mile reference posts 95-96) was 9.0 whereas it was 15.0 after installation. The relatively low number of large mammal carcasses in 2011 did not only apply to the treatment segments (including the segment with the animal detection system), but also in the control and extended control segments. This suggests that the low numbers in 2011 were unlikely to be related to the treatments, but they may be a reflection of changes in the population size of the large ungulates, or reduced search and reporting efforts by road maintenance crews.
2012-03	2012	105.81	Hydraulic Efficiency of Grate and Curb-Opening Inlets Under Clogging Effect	Aziz Khan	YES	The goal of this project was to investigate the hydraulic efficiencies of Type 13 (bar inlets), Type 16 (vane inlets), and Type R (curb-opening inlets) for street and roadway drainage. Although these inlets have been widely used in many metropolitan areas, the design empirical formulas and coefficients have not been verified. In this study, a flume was constructed in the laboratory to simulate street gutter flows ranging from 6 to 18 inches of flow depths. Type 13, 16, and curb-opening inlet models were built using a 1/3 scale to investigate the depth-flow relations under both on-grade and in-sump conditions. It was found that the flow interception capacity for a sump inlet is determined by either weir or orifice hydraulics, whichever is less for the given flow depth. Two new splash-velocity curves were developed to model the street gutter flow around a Type 13 or 16 inlet on a grade. In this study, a decay-based clogging factor was developed and recommended for the design of a series of inlets. The clogging effect shall be applied to the effective wetted length for an inlet that operates like a weir, or to the effective opening area for an inlet that operates like an orifice in a sump.	A new chapter of Inlet and Sewer Designs was introduced to the CDOT Hydraulic Design Manual. This design procedure has been coded into the design tool: UDINLET (MS Spread Sheet Model). Visit WWW.UDFCD.org to download.

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2012-04	2012	87.60	Deterioration and Cost Information for Bridge Management	Aziz Khan	YES	This study applied contract bid tabulations and element-level condition records to develop element-level actions, costs for actions, transition probabilities for models of deterioration of bridge elements, and transition probabilities for improvements to elements due to actions. The information on actions, costs, and transition probabilities was input to a Pontis BMS bridge database. The study used transition probabilities for element deterioration to compute the number of years to possible loss of safety in bridges, and to compute the number of years for inspection intervals. It examined variations in costs of actions and deterioration of elements among CDOT regions. A set of software applications was developed to handle bid tabulations, compute costs of actions, compute transition probabilities, and mediate the steps needed for movement of data into and out of Pontis BMS.	The Pontis Bridge database has been merged with CDOT's OnSys bridge database. Also, procedures were developed for element-level tracking of repair and rehabilitation work on in-service bridges, and finally, tools outside of Pontis were developed for decision support for bridge projects.
2012-05	2012	35.00	Tire-Pavement and Environmental Traffic Noise Research Study	Roberto DeDios	YES	In response to an interest in traffic noise, particularly tire-pavement noise, CDOT elected to conduct tire-pavement noise research. Following a rigid set of testing protocols, data was collected on highway traffic noise characteristics along with safety and durability aspects of the associated pavements. This report completes a comprehensive, long-term study to determine if particular pavement surface types and/or textures can be used as quieter pavements, and possibly be used to help satisfy FHWA noise mitigation requirements. The study addressed: <ul style="list-style-type: none"> - The noise generation/reduction characteristics of pavements as functions of pavement type, pavement texture, age, time, traffic loading, and distance away from the pavement; - Correlations between source measurements using on-board sound intensity (OBSI) and wayside measurements including both statistical pass-by (SPB) and time-averaged measurements; and - The collection of data that can be used for validation and verification of the accuracy of the FHWA Traffic Noise Model (TNM) to use on future Colorado highway projects. 	This study supplemented two other research projects. There are new requirements and recommendations for the texturing of new concrete pavements. Noise was not the sole reason that study was undertaken, but it did become a factor in the determination of how the new pavements needed to be surfaced so as to perform optimally and still be safe over the long term. It is very well documented how rubberized asphalt is being used in several areas around the country to help with the noise generated by the pavement as well as trying to get waste tires out of landfills.

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2012-06	2012	92.12	Adaptive Signal Timing Comparison between the InSync and QuicTrac Adaptive Signal Systems Installed in Colorado	David Reeves	YES	The FHWA's Every Day Counts (EDC) initiative identifies adaptive signal control as a tool for local agencies to deploy innovation. In an effort to achieve the goals of the EDC initiative, the traffic sections of CDOT in Region 2 and 4 and the City of Greeley implemented adaptive traffic signal control systems on 10th Street in Greeley and US 24 in Woodland Park. This new technology uses real-time data collected by system detectors to optimize signal timing for each intersection in the corridor. The use of real-time data means that signal timing along the corridor changes to accommodate the traffic patterns at any given time of the day. There are many different adaptive traffic signal control systems, of which two, InSync and QuicTrac, were selected for implementation in Colorado. The evaluation of the performance of these systems on their distinct corridors was documented in separate reports and provided to the agencies and stakeholders. This report focuses on a more direct comparison between the two systems including costs for installation, maintenance, and expected benefits on a per intersection basis.	The implementation of new traffic signal systems had an impact to the overall safety of the corridor through a decrease in the number of accidents that occur at the signalized locations. The improved progression for the mainline approaches to the intersections helps reduce the frequency of some accident types, primarily rear end. CDOT traffic safety engineers conducted a multi-year crash study on the corridor over the next 3-5 years to compare accident rates to the before-implementation conditions. During the period of time that both systems have been operational, there has been a decrease in accidents along the corridors.
2012-07	2012	107.00	Modeling Ballasted Tracks for Pollutants	Aziz Khan	YES	In this study, the Regional Transportation District's (RTD's) light rail operations were examined for pollutant production and runoff. A rainfall-runoff physical model of the light rail system was constructed at the Colorado State University Hydraulics Laboratory to study the effectiveness of the as-built ballasted tracks in the railroad environment. A rainfall simulator was designed to vary rainfall duration and intensity. The model had the capability of capturing all of the runoff for volumetric measurement of the quantity and quality of the runoff. Potential sources of pollutants from a light rail system are: metal introduced from track abrasion; metal from wheel abrasion; material from disk brakes; and material from overhead power lines. These quantities were computed using RTD's maintenance records for wheel truing, brake rotor maintenance, track replacement, copper power line replacement, and field sampling of light rail tracks. The measured iron and aluminum concentrations were introduced into the laboratory ballasted-track model and were subjected to various rainfall events. Runoff water and soil samples collected during and after different frequency events were analyzed to trace the effectiveness of ballasted tracks for capturing pollutants.	The majority of runoff from the ballasted tracks is retained for the initial 0.5 inch of rainfall within the body of the tracks. The ballasted tracks do not produce more runoff than the predevelopment, and therefore do not require a BMP. This discovery reduces the environmental cost since BMPs are not required. Since ballasted tracks form only a portion of the light rail system, the embankments, light rail bridges, construction sites, drainageways, etc. forming the rest of the rail system should be subject to CDOT inspections and recommended BMP treatments as any other highway project.

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2012-08	2012	107.00	Modeling Ballasted Tracks for Runoff Coefficient C	Aziz Khan	YES	In this study, the Regional Transportation District (RTD)'s light rail tracks were modeled to determine the Rational Method runoff coefficient C, values corresponding to ballasted tracks. To accomplish this, a laboratory study utilizing a rainfall-runoff facility was conducted at Colorado State University's Hydraulics Laboratory. The input to this model was provided by using RTD's design criteria, data from existing installations, and a field study to sample surface materials along ballasted tracks. For frequency of 2-year, 5-year, and 10-year events, the average C value is approximately 0.55. For the 25-year, 50-year, and 100-year return frequency rainfall events, the C value is in excess of 0.55 and is expressed in terms of multiplication factors of this average value. The runoff coefficient for ballasted tracks was significantly larger than the previously tabulated values for railroad yards. The higher runoff coefficient reflects the design of ballasted tracks to drain rainfall as quickly as possible. As a part of the research, detention times in the ballasted tracks were also determined. The detention time is a function of antecedent soil moisture content and rainfall intensity. In general terms, for dry antecedent conditions the initial 0.3 inch-0.4 inch of rainfall was detained in the ballasted tracks. The initial 0.5 inch of rainfall produced only a small amount of runoff. For 25-year, 50-year, and 100-year events, the runoff started 9 minutes, 7 minutes, and 6 minutes after the start of the event.	The study answers the question of how much runoff is generated from the railroad right-of-way for a given event. This information is necessary in designing drainage facilities along the light rail installations. CDOT is now using the newly determined C values in the CDOT Drainage Design Manual.
2012-09	2012	92.11	Developing an Active Traffic Management System for I-70 in Colorado	David Reeves	NO	CDOT is at the forefront of developing an Active Traffic Management (ATM) system that not only considers operation aspects, but also integrates safety measures. In this research, data collected from Automatic Vehicle Identification (AVI), Remote Traffic Microwave Sensors (RTMS) and Real-Time weather data were utilized to incorporate safety within the ATM system. The results from the research study suggest that there is a clear demand to incorporate real-time weather conditions and roadway geometric characteristics within the development of the ATM system.	This study was not implemented. The method was overly complicated. However it led to other implementable studies.

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2012-10	2012	21.80	Assessment of Concrete Pavement Texturing Methodologies in Colorado	Roberto DeDios	YES	This report presented information and data produced by the Colorado Department of Transportation's long-term study of Portland cement concrete pavement (PCCP) textures used within the state. The information included vehicle accident, friction, and texture data. This information was used as the basis for a review of proposed revisions to the CDOT texture measurement method, CP-77, and a specification for PCCP texturing found in Sections 106 and 412 of the Standard Specifications.	As a result of this study, it can be concluded that: 1. An average texture depth (ATD) of 0.05 inches or greater is an adequate texture; and 2. Artificial turf drag texture is an adequate PCCP texture. With respect to turf drag texture, not only does its use comply with FHWA safety and durability requirements, but another positive impact is reduced tire pavement noise, which was demonstrated through a complementary CDOT study that was recently completed (study number 35.00). This study resulted in a construction specification change.
2012-11	2012	25.00	Application of Roller Compacted Concrete in Colorado's Roadways	Roberto DeDios	NO	Roller Compacted Concrete (RCC) is a no-slump concrete mixture that is transported, placed, and compacted with the same construction equipment as asphalt pavement. RCCs were used to construct three sections of pavement in Weld County Road 28 (WCR 28), eastbound of State Highway (EB 66), and westbound of State Highway (WB 66). Three sets of field inspections were conducted: 1) during construction; 2) nine months after construction; and 3) two years after construction. Strength and durability behaviors of the RCCs were tested right after construction, and some of the material properties of the RCCs were further tested nine months after construction. The test results obtained after the construction indicated that the chloride permeabilities are in the low to very low ranges, the drying shrinkages are in the normal range, and freeze-thaw resistance is fine. The compressive strength, splitting tensile strength, and flexural strength are also in the normal range similar to that of conventional concrete. The test results obtained nine months after the construction indicated that deteriorations occurred in the RCC concretes.	More research is needed.

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2013-01	2013	87.40	Self-Consolidating Concrete Repairs on Interstate 25 Bridge Abutments North of Mead	Aziz Khan	YES	CDOT performed maintenance on Interstate 25 bridges D-17-DA and DB on I-25 north of Mead, CO. The maintenance was performed using self-consolidating concrete (SCC). The concrete abutments at the Mead Bridges on I-25 deteriorated in recent years due to unexpected freeway embankment movements. In many places the concrete had spalled off and exposed the steel reinforcement. This movement forced the abutment against the steel girders, and progressed to the point where the abutment cover was crushed and the girders came in direct contact with the abutment reinforcement. It also resulted in buckling of the concrete deck, which was lifted off of the girders, resulting in a gap between the deck and the girders. To mitigate the problems described above, CDOT decided to "lock" the girders to the abutments with the use of SCC. The intent to use SCC was based on the need to have a flowable, yet stable concrete that could encapsulate the ends of the steel girders and the space in between them, without leaving voids at the interface of the new concrete and the existing deck slab. To achieve these goals, a high flowability concrete was designed with the intent of placing it through a number of holes at the deck within the encased area.	The application of the SCC and normal concrete successfully encased the ends of the steel girders. There is no evidence of concrete cracking due to girder deflection under typical service loading. Therefore, this method has been implemented in other bridges that suffered similar problems.
2013-02	2013	74.95	Sustainable Stabilization of Sulfate-Bearing Soils with Expansive Soil-Rubber Technology	Aziz Khan	NO	The beneficial use of scrap tire rubber mixed with expansive soils is of interest to civil engineering applications since the swell percent and the swell pressure can be potentially reduced with no deleterious effect to the shear strength of the mixture. The two main objectives of this research were (1) to propose a new subgrade soil stabilization protocol to allow CDOT to rely upon an alternative stabilization method that is not subject to the typical problems associated with calcium-based stabilization of sulfate-rich soils, and (2) to develop a new database of MEPDG parameters for local soil samples obtained from CDOT and to provide advanced testing and analysis of the stiffness degradation of these materials.	Tires have not been used anywhere to address expansive soils on Colorado roadways. This study may be tried on a project; however, it will be up the Region to decide if it will be done or not. The Soils & Geotechnical Program is an internal consultant to the Regions. They only make recommendations, but the Regions make the final decisions on how to design and construct their roadways.

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2013-03	2013	61.22	Alternatives to the Public Funding and Operation of Colorado's Rest Areas	David Reeves	n/a	This report was completed in 2012. Due to budget challenges, Colorado is looking for alternative funding sources for the operation and maintenance of its interstate safety rest areas (SRAs). Federal Code 23 U.S.C. § 111 prohibits commercialization of rest areas. Based on this law, the majority of SRAs in the U.S. have been developed to provide motorists with access to restrooms, picnic tables, and vending machines, but no other commercial services. In FY 2012, the cost of operating and maintaining twenty-seven rest areas in Colorado was over \$3.5 million; planned and emergency projects in 2012 cost CDOT an additional \$251,233 for a total cost of approximately \$3.75 million. The maintenance budget has not grown fast enough to finance their operation and maintenance. The closure of five SRAs in 2012 has been estimated to save the department \$300,000 annually. CDOT also closed two SRAs in 2009 for financial and other reasons.	N/A. This study was informational only. It cannot be implemented without changing the law.
2013-04	2013	n/a	Implementation of the AASHTO Mechanistic-Empirical Pavement Design Guide for Colorado	Jay Goldbaum	YES	The objective of this project was to integrate the American Association of State Highway and Transportation Officials (AASHTO) Mechanistic-Empirical Pavement Design Guide, Interim Edition: A Manual of Practice and its accompanying software into the daily pavement design, evaluation, rehabilitation, management, and forensic analysis practices and operations of the Colorado Department of Transportation (CDOT). The Pavement ME Design software (formerly DARWin-ME) is a state-of-the-practice analysis tool for evaluating new, reconstructed, and rehabilitated flexible, rigid, and semi-rigid pavement structures based on mechanistic-empirical principles. Using project specific traffic, climate, and materials data, Pavement ME Design estimates and accumulates pavement damage and other forms of deterioration over a specified design/analysis period and then applied transfer functions to transform damage/deterioration into distress and smoothness. The pavement designer then determines the adequacy of a desired pavement section by evaluating predicted distress and smoothness at a given reliability level at the end of the design period. As a forensic analysis tool, Pavement ME Design can be used to model a pavement structure, simulate the combined effect of application of traffic load and climate cycles, and determine the performance (or lack of) for a specified time period.	This were accomplished using data from Long Term Pavement Performance (LTPP) projects located in Colorado and CDOT pavement management system sections. Default key data inputs were also developed, as was guidance for using the Pavement ME Design procedure for pavement design in Colorado.

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2013-05	2013	10.15	Optimum Use of CDOT French and Hamburg Data (French and Hamburg Tests)	Roberto DeDios	YES	The Colorado Department of Transportation (CDOT) has been collecting data from the Hamburg Rutter and the French Rutter for over 20 years. No specifications have been written in that time for either the Hamburg Rutter or the French Rutter. This report looks at the state of practice within other states that own similar equipment. It addresses mixes being produced to pass the Hamburg Rutter being designed too dry. Tests that could be run along with the Hamburg Rutter are examined from a review of literature to determine if there is a suitable companion test for the Hamburg Rutter that would work to keep asphalt levels in the mix high enough to prevent cracking and fatigue.	Currently, A CDOT representative is on an AASHTO committee that is working on the Hamburg Rutter procedure. The new companion test is the Disk-Shaped compact Tension Test (ASTM D7313) This is a fracture energy test. CDOT is moving forward with testing on every mix.
2013-06	2013	61.12	Construction Cost Forecast Model – Model Documentation and Technical Notes	David Reeves	YES	Construction cost indices are generally estimated with Laspeyres, Paasche, or Fisher indices that allow changes in the quantities of construction bid items, as well as changes in price to change the cost indices of those items. These cost indices, while useful in forecasting the near-term costs of construction contracts for projects that have been designed and are about to be let, are not good indicators of price inflation in highway construction. This report contains the documentation and supporting technical notes for a statistical model that estimates changes in the price components of the Colorado Construction Cost Index. The model contains two specifications. In the first, the composite construction index is a function of the producer prices of inputs: oil, concrete, steel, labor and equipment. In the second, the composite construction index is a function of the price of oil, wages and nationwide demand for construction services.	The model has been transferred to CDOT's economist, who will maintain and operate it to forecast price inflation in construction costs over a thirty-year period, in support of statewide planning and programming.
2013-07	2013	12.72	Performance of Chip Seals Using Local and Minimally Processed Aggregates for Preservation of Low Traffic Volume Roadways	Roberto DeDios	YES	This report documents the performance of two low traffic volume experimental chip seals constructed using locally available, minimally processed sand and gravel aggregates after four winters of service. The projects were constructed by CDOT maintenance personnel during the summer of 2009 using two sources of aggregate. These aggregates consisted of locally available products representing 1) materials routinely utilized and 2) materials that were marginal with respect to aggregate gradation and crushing requirements. An objective of this work was to evaluate the feasibility and cost/benefit of using aggregates in chip seals of lower quality than normally used with respect to gradation on low volume roadways. Because the cost of transporting high quality aggregates from front range sand and gravel and quarry locations to the eastern regions of Colorado is high and much of the pavement preservation activities in eastern Colorado are on low volume roadways, utilizing locally available aggregates would provide economic benefits if acceptable performance were demonstrated.	Based on this research, recommendations are provided regarding chip seal materials, design, and construction methods to be used for low traffic volume pavements. Locally available, minimally processed aggregates has been successfully applied as chip seal aggregate on low volume roadways.

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2013-08	2013	30.70	Helicopter Avalanche Control	David Reeves	YES	The Colorado Department of Transportation (CDOT) performs a large number of helicopter based avalanche control missions annually. Due to the high cost of helicopter-based control work and the safety issues inherent to using helicopters at high altitude in poor weather conditions, this study was commissioned to look at ways to maximize the efficiency of helicopter-based control work. This document reports the results of surveys and experimental testing and the conclusions that can be drawn from those results to fulfill this goal.	This research led to a change in maintenance practices.
2013-09	2013	22.50	Developing Criteria for Performance-Based Concrete Specifications	Roberto DeDios	Yes	For more than 50 years now, concrete technology has advanced, but CDOT specifications for durability have remained mostly unchanged. The minimum cement content for a given strength is derived from mix design guidelines that were developed before water reducing admixtures were widely used and accepted. The minimum cement content generally controls the mix design process, with many mix designs exceeding the minimum strength requirements by 500 to 1,000 psi. Ready mix suppliers that supply to non-CDOT projects have developed mix designs that use less cement and more fly ash than CDOT mix designs and exceeded their strengths. They are able to accomplish this improvement through gradation optimization and admixture combinations. The proposed study tested current CDOT standard mix designs to determine minimum required performance criteria that will be used to develop performance-based concrete mix design criteria.	CDOT has developed a performance based specifications for concrete mixtures.
2013-10	2013	22.65	Recycled Tires as Coarse Aggregate in Concrete Pavement Mixtures	Roberto DeDios	NO	The reuse potential of tire chips as coarse aggregates in pavement concrete was examined in this research by investigating the effects of low- and high-volume tire chips on fresh and hardened concrete properties. The fresh concrete properties, compressive strength, flexural strength, splitting strength, permeability, and freeze/thaw durability were tested in the lab to evaluate the potential of including tire chips in concrete paving mixes. The testing results indicate tire chips can be used to replace coarse aggregate in concrete pavement mixtures. The rubberized mixtures investigated in this study sustained a much higher deformation than the control mixture when subjected to compressive, flexural, and splitting loadings.	Additional testing will need to be done to evaluate mix optimization and alternate sources of material and/or combinations of materials.

Research Implementation Report

Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2013-11	2013	34.28	Investigation into Effective Traffic Noise Abatement Design Solutions for Mountain Corridors	Bryan Roeder	YES	Traffic noise abatement in mountain corridors can be difficult because traditional roadside barriers may be ineffective due to topography or may not fit the setting. This study examined current best practices from around the world to gather concepts for mitigating traffic noise in mountain corridors in Colorado. A literature review of prospective noise abatement actions found that noise barriers are the most effective direct noise abatement measure, although quieter pavements could have an important supporting role. Several noise barriers were evaluated through modeling at two areas along the I-70 corridor using the Nord2000 Road prediction method. Each of the barriers was found to be effective in some or many situations; the largest, most imposing barrier (galleries) showed the most potential for reducing traffic noise at locations above the elevation of the highway. Continued use of noise barriers as a primary abatement mechanism was recommended. Consideration of quieter default pavement types was recommended to lower general traffic noise levels in support of environmental stewardship goals.	CDOT is considering the implementation of different wall concepts and materials that may be needed to overcome noise abatement difficulties in the mountain corridors where precast concrete panels may not be the ideal barrier choice. CDOT continues to monitor and explore new developments in best noise abatement practices.
2013-12	2013	90.75	Safety Performance Functions for Freeway Merge Zones	David Reeves	YES	This report documents the results of a research project to support CDOT in the area of Safety Performance Function (SPF) development. The project involved collecting data and developing SPFs for ramp-freeway merge zones categorized as isolated, non-isolated and weave. For each of these three categories, data for the period 2007 to 2011 were collected at sites selected to ensure statewide geographical representation and coverage of the range of traffic volume and other variables in each category. The development of SPFs for the three categories of ramp-freeway merge zones was successful. Separate SPFs were developed for Total, fatal+injury (FI) and Property Damage Only (PDO) crashes.	CDOT uses the developed SPFs to apply state-of-the-art methodologies for road safety management activities. CDOT applies the SPFs developed to screen network applications, diagnose crash problems at specific sites and conduct before-after evaluations of implemented treatments.
2013-13	2013	85.11	Long-Term Monitoring of Mechanical Properties of FRP Repair Materials	Aziz Khan	NO	Fiber-reinforced polymer composites (FRP) are an attractive repair option for existing concrete structures. CDOT has used this material on some projects, in particular the repair of the Castlewood Canyon Bridge in 2003. This project evaluated the condition of the FRP on the Castlewood Canyon Bridge through onsite inspection and pull-off tests, and by bringing FRP back to the labs at CSU to test the tensile strength. Conclusions about the FRP condition are limited by the lack of baseline data, but there does appear to be some deterioration over time.	The conclusions drawn from the field assessment of the FRP on the Castlewood Canyon Bridge are limited by the lack of initial data, and the fact that no intermediate testing was conducted between the repair in 2003 and this research project in 2011. The FRP seems to be holding up reasonably well, but the performance is difficult to quantify.

Research Implementation Report

Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2013-14	2013	30.02	Evaluation of Soil Resources for Sustained Vegetative Cover of Cut-Slopes Along I-70 near Straight Creek	Bryan Roeder	YES	Revegetation of high elevation decomposed granite cut-slopes often requires repeated applications of soil amendments to attain sustained vegetative cover. Plant transects from slopes west of the Eisenhower Tunnel from 2007 to 2012 showed that cover was generally stable during this period. Soil fertility tests indicated that nutrients are generally low but still comparable to disturbed-but-revegetated reference plots. Soil organic matter and slow-release forms of nitrogen (N) may be a potential limiting factor. The N release rates of several common CDOT soil amendments were evaluated in a multi-year, field incubation experiment. Test results indicate a wide range of N release availability from nearly immediate to fairly slow release rates. Of the slow-release materials, about 74 % of total N content was released the first growing season, another 7 % in the following two years, while 19 % was still retained in a more stable organic matter form at the end of the experiment. The study suggests that after several applications of slow-release amendments, vegetative cover on these cut-slopes is stabilizing.	This study led to a construction specification change. The study improved the process of soil amendment use for revegetation cut slopes. Thus reducing maintenance costs.
2013-15	2013	80.30	Evaluation of Seismic Testing for Quality Assurance of Lime-Stabilized Soil	Aziz Khan	NO	This study sought to determine the technical feasibility of using seismic techniques to measure the laboratory and field seismic modulus of lime-stabilized soils (LSS), and to compare/correlate test results from bench-top (free-free resonance) seismic testing on LSS cylinders to in-situ (surface seismic) testing performed on field-constructed LSS. The study supports the recommendations of the CDOT specification for LSS (Section 307).	In the event that simultaneous acceptance via unconfined compressive strength (UCS) testing is desired, a correlation between seismic modulus and UCS is recommended. Attempts to core field-constructed LSS for UCS testing were not successful, and this approach is not recommended.
2013-16	2013	30.51	Colorado Mileage-Based User Fee Study	David Reeves	YES	The Transportation Research Board, Government Accountability Office, and Colorado Transportation Finance and Implementation Panel (CTFIP) suggested that Colorado pursue fees based on actual travel as an alternative to the fuel tax and possible mechanism to improve funding for transportation. Revenues from mileage-based user fees (MBUF) would not vary based on fleet fuel consumption and would instead return revenue in proportion to use of the roadway network. The final report documents: 1) state of the practice in MBUF; 2) stakeholder and public perceptions of MBUF in Colorado; 3) operations guidance; and 4) recommendations for next steps. This yielded the primary conclusion: although a mileage-based user fee system can be created in Colorado so that all Colorado drivers pay their proportional share of roadway system costs, significant issues remain from technical, policy, and public acceptance perspectives.	This study led CDOT to participate in WRUCC pooled fund. Also, there is a study being advertised to continue with the next phase.

Research Implementation Report

Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2013-17	2013	92.20	Evaluation of Guardrail Embedded Lighting System in Trinidad, Colorado	Skip Outcalt	YES	This report provided information on the design considerations of the embedded highway lighting design on Interstate-25 in Trinidad, Colorado, in terms of visibility. The information was based on visibility characterizations of small targets using luminance, illuminance, and contrast calculations as well as participant input on the detectability of small targets. Experimental conditions included two different aim angles of the lighting design (forward and cross) as well as two small target colors (red and blue). When compared to the small target detection distances produced by conventional overhead lighting systems in previous studies, the research determined that the small target visibility distances of the embedded lighting design to be shorter by approximately 50%. Adjustments to the spacing, aim, and breadth of the lighting design are recommended for future research considerations.	The results of this research indicate the lighting design is an alternative; however, additional considerations to the beam angle, beam width, beam height, and spacing has been improved in the implementation of the system.
2013-18	2013	8.41	Development of Estimation Methodology for Bicycle and Pedestrian Volumes	David Reeves	YES	CDOT adopted the Bicycle and Pedestrian Policy directive in 2009 stating that "...the needs of bicyclists and pedestrians shall be included in the planning, design, and operation of transportation facilities, as a matter of routine..." This requires accurate estimates of bicycle and pedestrian volumes on CDOT facilities, which will enable CDOT to answer whether or not these road users are being adequately accommodated. CDOT developed Colorado-specific methodologies to collect count data throughout its system to calculate annual bicycle/pedestrian use from short-term counts. CDOT's methodology will facilitate improved use of its existing investments in collecting data and enable CDOT to better understand the needs of bicyclists and pedestrians as well as best allocate limited resources in order to properly meet those needs.	CDOT is the first DOT to create such factors. For this reason, the research team has presented parts of this work at national conferences and has publish relevant sections of this report.
2013-19	2013	12.92	In-Place Voids Monitoring of Hot Mix Asphalt Pavements: Follow-Up	Rich Griffin	YES	In order to validate the policy of allowing the adjustment of the asphalt cement to reduce the laboratory air voids up to one percent, cores were taken over a period of four years on 19 paving projects and tested for air voids. After being compacted by traffic over several years, the average air voids in these pavements were 3.8%. Since the design air voids are required to be between 3.5% and 4.5%, the monitoring validates the effectiveness of the policy. However, there was significant scatter in the data with most of the in-place voids falling out of this design range.	This project was undertaken to validate the AC adjustment policy and since the average in-place voids was found to be close to the center of the design range, no change to the policy was recommended.

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Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2014-01	2014	74.90	Design of Mechanically Stabilized Earth Wall Connections and End of Walls Subjected to Seismic Loads	Aziz Khan	YES	The 4th Edition of the AASHTO LRFD Bridge Design Specifications requires all states to design for a 1,000-year return period earthquake, as opposed to earlier editions' 500-year return period. In response, CDOT examined the impact that these more stringent design requirements have upon connection details in mechanically stabilized earth (MSE) walls. The objective of this study was to perform displacement-based dynamic finite element analyses of MSE walls to examine the response of selected internal components when subjected to seismic excitations such as those expected in Colorado. Details of particular interest were the upper block connections in modular block walls; the dynamic displacements of the ends of walls; and the relative displacements and motions between the wall facings, soil reinforcement, and soil.	The results of this study show that MSE walls performed well when subjected to seismic loadings that reflect the updated 1,000-year return period earthquakes in Colorado. The mode shapes were dominated by shear behavior, which causes swaying in and out at different locations along the wall. The maximum overall displacements were all less than 0.5 in under seismic loading. No yield stresses were exceeded for the concrete facing units, the geogrid reinforcement, or the geogrid to facing unit connectors. None of the specific examined connection details such as corner joints and reinforcement connections were found to suffer from any detrimental issues.
2014-02	2014	84.14	Performance of Thin Bonded Epoxy Overlays on Asphalt and Concrete Bridge Deck Surfaces	Aziz Khan	YES	This study is the evaluation of two thin bonded epoxy overlays: SafeLane (marketed by Cargill), and Flexogrid (developed by PolyCarb). SafeLane is an anti-skid/anti-icing overlay that stores deicing chemicals for release during winter events. Flexogrid is an anti-skid overlay. These two products were compared on the basis of physical properties, including mean texture depth, surface friction, bond strength, ability to stop chloride intrusion, and anti-icing properties, as well as traffic safety and cost. Both overlays worked as intended when they were initially applied on the bridge decks. They both provide a durable wearing surface with good traction. All the SafeLane bond tests exceeded 250 psi (1.72 MPa). Flexogrid had initial high bond strengths, but had varied failure modes.	CDOT developed construction specifications for thin bonded overlays.
2014-03	2014	22.60	Internal Curing of High Performance Concrete Using Lightweight Aggregates and Other Techniques	Roberto DeDios	NO	Internally cured concrete has been rapidly emerging over the last decade as an effective way to improve the performance of concrete. Internal curing (IC) holds promise for producing concrete with an increased resistance to early-age cracking and enhanced durability (Bentz and Weiss, 2011). This report specifically examined the freeze-thaw resistance of internally cured concrete. It showed that internally cured concrete, using the recommended mixture proportions (i.e., pre-wetted fine LWAs to replace only the water lost due to chemical shrinkage) is freeze-thaw resistant.	This recommendation has not been tried yet at CDOT.

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Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2014-04	2014	62.60	Development of Risk-Based Decision Methodology for Facility Design	David Reeves	YES	This report developed a methodology for CDOT to use in the risk analysis of various types of facilities and provides illustrative examples for the use of the proposed framework. An overview of the current practices and applications to illustrate the context from which the proposed methodology has been developed is presented first. Next, the report introduced the proposed methodology for CDOT. In order to understand how the framework operates in practice, two illustrative examples were presented. The first example demonstrated the framework through the context of allocating resources for the operation and maintenance of a portfolio of signalized mast arms. Two risk assessment methods were introduced through the first example, and it was shown that mast arms could benefit from varied inspection frequencies based on current structural defects present. The second illustrative example used the framework in the context of making design decisions with regard to seismic hazard in Colorado. A quantitative risk assessment method was introduced, and the illustration suggested that seismic hazard was not a controlling hazard in Colorado.	This research led to a planning process change. Low-risk mast arms are inspected less frequently than the previous inspection routine.
2014-05	2014	40.04	CDOT Thermal Mapping Report	David Reeves	YES	Thermal Mapping surveys were carried out on approximately 1000 miles of the Colorado Department of Transportation's (CDOT's) roads. The purpose of these surveys was to identify road surface variations across the network to determine whether forecast Thermal Maps or the data from the surveys would be useful to decision-makers in the CDOT regions. The distribution of road surface temperatures across the network and identifying Climatic Domains for the regions enabled Vaisala to look at current weather station locations and whether there were any gaps in coverage.	The maintenance practices have changed to include this recommendations.
2014-06	2014	80.11	Evaluation of Bridge Deck Sealers	Aziz Khan	YES	This study focused on the evaluation of bridge deck sealers commonly used on highway bridge decks and their relative performance. Four sealer products that could potentially be used by CDOT were selected for evaluation. High molecular weight methacrylate (HMWM), two epoxies, and a silane were assessed for their skid resistance and ability to block or slow down moisture and chloride ion penetration into concrete bridge decks. Skid resistance, temperature variation, moisture fluctuation, and chloride concentration profiles in concrete were selected as the four experimental parameters for evaluating the performance of the four sealers. Eighteen integrated sensors were installed in the bridge decks in the five testing sections and at different depths for monitoring the internal temperature and relative humidity distributions in concrete. From the analysis and comparisons of the test data, the performances of the four sealers were ranked in terms of the four experimental parameters.	The need for a sealer system on a bridge deck is selected based on the above characterization methods.

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Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2014-07	2014	90.10	Full Closure Strategic Analysis	David Reeves	YES	The full closure strategic analysis was conducted to create a decision process whereby full roadway closures for construction and maintenance activities can be evaluated and approved or denied by CDOT Traffic personnel. The study reviewed current full closure practices in Colorado and throughout the country, gathered stakeholder input, and employed an iterative development process to reach a systematic decision tool that can be applied to judging the merits of full closure scenarios. A number of case studies were created to more fully understand the methodology and adjust the tool to best match real-world scenarios. Project deliverables include a technical report and a series of electronic forms that can be used by CDOT to work through the process.	This study led to the creation of a lane closure strategy (A congestion Management Initiative), which is now being used at CDOT.
2014-08	2014		Accelerated Bridge Construction Utilizing Precast Pier Caps on State Highway 69 over Turkey Creek, Huerfano County, CO	Aziz Khan	YES	The purpose of this report is to document Accelerated Bridge Construction (ABC) techniques on IBRD (Innovative Bridge Research and Development) project 102470 for the construction of Bridge N-16-Q on State Highway 69 over Turkey Creek. The project demonstrated faster pier erection by utilizing precast pier caps to eliminate concrete cure time from the critical path in the construction schedule.	CDOT uses this technique when appropriate.
2014-09	2014	50.00	CDOT Rapid Debris Removal Research Report	David Reeves	NO	Highway debris represents a traffic safety problem that requires a prompt response from state or local transportation agencies. The most common practice for debris removal currently is for agency personnel to leave their vehicles and remove the debris by hand. This includes sweeping traveled lanes, shoulders, or intersections of debris in the case of crashes, mechanical failure, or embankment erosion. This exposes agency workers to safety risks. Innovative equipment has been introduced to the market which allows for high-speed debris removal, such as the Gator Getter®, which is very effective for collecting tire treads on smooth (asphalt) pavements where operating speeds can be maintained above 45 MPH. But, the Gator Getter should not be used on segmented pavements, bridge decks, or railroad tracks, and should not be used to collect rocks, concrete fragments, or metal objects.	The Gator Getter is not being used in clearing tire debris. There exist reluctance from maintenance to change current practices.

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Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2014-10	2014	n/a	Years to First Rehabilitation of Superpave Hot Mix Asphalt	Jay Goldbaum	TBD	CDOT spends more than 30% of its annual construction and maintenance budget on pavements. Pavements need to be properly designed in the early phases using an analytical process with accurate design inputs to estimate and establish the project cost. The performance life of the initial pavement design and associated rehabilitations greatly impact the life cycle cost analysis (LCCA) used to determine the most cost-effective final pavement design. This study evaluated the performance of four roadway functional classes utilized by CDOT: interstates, principal arterials, minor arterials, and major collectors. Performance was evaluated with respect to smoothness, permanent deformation, fatigue cracking, transverse cracking, and longitudinal cracking to develop a reliable forecasting model and an accurate LCCA.	TBD NOTE: This is not a research study, just a courtesy printing.
2014-11	2014	42.50	Benefit-Cost Analysis of CDOT Fixed Automated Spray Technology (FAST) Systems	David Reeves	YES	The Western Transportation Institute (WTI) conducted research on behalf of the Colorado Department of Transportation (CDOT) to study the cost effectiveness of existing CDOT FAST systems. Both the national survey and the CDOT survey confirm the need for significant maintenance activities to ensure successful operation of FAST systems. Safety analysis of CDOT FAST system reveals a reduction in the number of annual crashes on multilane rural highways by 2 percent, urban interstates by 16 to 70 percent, rural interstates by 31 to 57 percent and interchange ramps between interstates by 19 to 40 percent. Overall, CDOT FAST systems included in the analysis have reduced crash severities at many sites resulting in potential safety benefits of \$196,428 per winter season during the "after deployment" study period. Further, a benefit-cost excel sheet was developed based on the estimated crash reductions observed for each of the different roadway types.	The safety analysis of CDOT's FAST system revealed an estimated reduction in the number of annual crashes on multilane rural highways by 2 percent, urban interstates by 16 to 70 percent, rural interstates by 31 to 57 percent and interchange ramps between interstates by 19 to 40 percent. CDOT FAST systems have reduced crash severities at many sites, resulting in potential safety benefits of \$196,428 per winter season. FAST has been applied on higher traffic roads to prevent and reduce crashes.
2014-12	2014	34.24	Use of Waste Tires (Crumb Rubber) On Colorado Highways	Aziz Khan	TBD	The objective of this study was to determine the feasibility of using waste tires (crumb rubber) in the construction of asphalt pavements in Colorado. Two pilot test sections and one control section were constructed and observed over a five-year period to meet this objective. One section used the Wet Process that involved ground tire rubber (GTR) blended with hot asphalt cement at the asphalt plant to form the hot mix asphalt. The other process, Terminal Blend, blended GTR and asphalt cement at a remote blending facility that was then transported to the hot mix plant to produce the hot mix asphalt. The control section contained a conventional binder. Binders in the two test sections containing GTR and the control section met the specifications for PG 64-28 asphalt. Each of the three test sections contained approximately 1,000 tons of 2-inch asphalt overlay placed over a cold-milled surface in the eastbound driving lane of US 34 Bypass near Greeley, CO.	TBD. CDOT will continue to perform annual pavement condition surveys for a maximum of five years to obtain results and final analysis and implementation.

Research Implementation Report

Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2014-13	2014	11.40	Hot Mix Asphalt Crack Sealing and Filling Best Practices Guidelines	David Reeves	YES	Crack sealing and filling on hot mix asphalt (HMA) pavements are cost-effective pavement preservation techniques that improve pavement performance and extend the life of existing pavements. The draft Guidelines included in this report reflect CDOT experience, current state-of-the-practice, and the most recent research findings, and address where and when to perform crack sealing and filling, material selection, installation methods, construction inspection, and follow-up evaluation.	CDOT has developed guidance on project selection to include identification of appropriate windows of opportunity to seal non-load related cracking. Where feasible, maintenance differentiates between crack sealing and crack filling operations. CDOT Maintenance adopted self-inspection procedures in which crack conditions are verified, and sealant is placed in clean and dry pavements.
2015-01	2015	47-10	Assessment and Placement of Living Snow Fences to Reduce Highway Maintenance Costs and Improve Safety	Bryan Roeder	YES	Living snow fences (LSF) are designed plantings of trees and/or shrubs and native grasses along highways, roads and ditches that create a vegetative buffer that traps and controls blowing and drifting snow. These strategically placed fences have been shown to be cost effective in reducing highway maintenance associated with blowing and drifting snow conditions. The objective of the study was to equip CDOT with the tools and knowledge to expand the use of living snow fences.	The Colorado State Forest Service (CSFS) conducted an informal survey of existing LSFs along Colorado state highways. The inventory identified approximately 177 existing LSFs along state highways. Training sessions were held for CDOT staff in each of the five CDOT Regional Offices. A notebook entitled "Colorado Living Snow Fence Guidelines and Short Course" was prepared and provided to attendees at these sessions.
2015-02	2015	42.00	Assessment of CDOT Revegetation Practices for Highway Construction Sites	Bryan Roeder	YES	The revegetation of previously disturbed areas from highway construction activities is a critical component to overall site stormwater management strategy. Poor revegetation actions during and after construction can lead to difficulty in deactivating stormwater construction permits (SCPs), which can result in higher non-project costs for erosion control, revegetation rework and maintenance, and regulatory compliance monitoring and documentation. Open SCPs can increase the potential for regulatory inspections and fines. Unexpected rework and liability costs can be experienced by CDOT Maintenance staff, who are responsible for SCP compliance. This research study developed five hypotheses that looked at active construction projects' revegetation practices using a quality control approach. An informational survey was conducted to assess construction engineering staff's understanding of the CDOT revegetation process.	CDOT has prioritized and implemented several of the recommendations.

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Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2015-03	2015	n/a	Life Cycle Cost Analysis Rehabilitation Costs	Roberto DeDios	n/a	This study evaluates data from CDOT's Cost Data books and Pavement Management Program. Cost indices were used to normalize project data to year 2014. Data analyzed in the study was obtained from the CDOT's Cost Data books and the Pavement Management Program. The results were obtained for heater remixing (process mat, rejuvenating agent, and furnish hot-mix asphalt), heater scarifying and its rejuvenating agent, cold in-place recycling process (rejuvenating agent and hydrated lime), and full-depth reclamation. The purpose of this study is to evaluate the cost of rehabilitation techniques used on interstates, state highways, and principal arterials dating back to 2009 for use in LCCAs.	NOTE: Not a Research Study. Courtesy Printing.
2015-04	2015	12.75	Best Practices for Full-Depth Reclamation Using Asphalt Emulsions	Roberto DeDios	YES	Full depth reclamation of asphalt pavements using asphalt emulsions (AEFDR) is a process that recycles and rejuvenates the existing asphalt pavement surface, base, and, sometimes, the subgrade, providing an improved underlying structure for the new asphalt pavement. This report provides design guidance, standardized plans and specifications, construction inspection best practices, materials testing procedures and frequencies, a performance evaluation process, and quality assurance and quality control protocols when constructing FDR projects.	A best practices manual was created to provide design guidance, standardized plans and specifications, construction inspection best practices, materials testing procedures and frequencies, a performance evaluation process, and quality assurance and quality control protocols to use when considering rehabilitating asphalt pavements using the AEFDR process.
2015-05	2015	32.47	Monitoring Wildlife-Vehicle Collisions: Analysis and Cost-Benefit of Escape Ramps for Deer and Elk on U.S. Highway 550	Bryan Roeder	YES	Wildlife fencing along highways can lower wildlife-vehicle collision rates by excluding animals from the road right-of-way. Still, animals can breach fencing and end up trapped within the fencing along the highway right-of-way, exposing wildlife and motorists to the risk of collision. Wildlife escape ramps are designed to allow trapped animals safe passage out of the right-of-way. The investigation included the usage levels, escape success, wildlife-vehicle collisions, and design of 11 escape ramps and two escape jumps along an eight-mile stretch of U.S. Highway 550 near Ridgway, Colorado. The goal was to relate usage levels and escape success to ER structure design and its surrounding environmental characteristics, describe the animal use of ER in the study area, conduct a cost-benefit analysis for escape ramp construction and provide recommendations regarding ER design and WVC based on data collected.	Escape ramps were used by mule deer, elk, bear, mountain lion, coyote, red fox, bobcat, raccoon, striped skunk, wild turkey, rodents, raptors, and passerines. Mule deer visited escape ramps more than any other species, with a total of 1,333 successful mule deer escapes. Elk in the study area used escape ramps far less than mule deer, with a total of 25 successful escapes.. Mule deer were able to use escape ramps to enter the highway right-of-way. Wildlife-vehicle collision rates were measured as animal collisions per mile per year. Before construction of escape ramps, this rate was 1.94 for mule deer. After construction of escape ramps in the study area, the mule deer collision rate dropped to 1.12. Elk collision rate prior to escape ramps construction was 0.58 collisions per mile per year. After eight more ER were constructed, the rate dropped to 0.03. Prior to construction of ER, wildlife-vehicle collisions in the study area cost society \$172,839 per year. Following construction society's cost was reduced to \$66,766 (\$62,353 for mule deer, \$4,413 for elk).

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Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2015-06	2015	214.01	Feasibility Study of Developing and Creating a Standardized Subset of Bridge Plans	Aziz Khan	TBD	This study investigated sizes and geometry of existing bridges in Colorado and investigated standard bridge systems used by other entities. The study proposed standard bridge types advancing the goals of SHRP 2 R19A & B, the rapidest ABC construction, and encompassing a wide range of span and structure lengths and widths, with the capability of a wide range of skews while preserving, to the extent possible, simplicity, low construction cost and a competitive contracting environment, in order to achieve the largest practical benefit to Colorado's bridges over the coming decades. For Colorado these are pre-decked simple made continuous precast girders, and shaft and precast cap substructures, all made integral with details emulative of CIP construction. These are made practical by an effort to control camber and camber variations by design and by monostrand post-tensioning camber adjustment.	TBD This report is at the Bridge Engineer's desk for his recommendation. After that it will need upper management support.
2015-07	2015	414.02	Evaluating The Effects of Concrete Pavement Curling and Warping on Ride Quality	Rich Griffin	No	Construction of a jointed concrete pavement on US 34 near Greeley, Colorado in 2012 led to an investigation of slab curling and warping that appeared to be contributing to undesirable levels of pavement roughness. Specifically, the westbound lanes that were constructed in July appeared to exhibit significantly higher roughness than the eastbound lanes that were constructed in September. Furthermore, smoothness testing by the contractor at three different times of the day on one of the westbound lanes revealed significant differences in roughness values depending on the time of day. In response, CDOT initiated the investigation under this study to determine the effects of slab curling and warping on ride quality for the US 34 project with the expectation that the findings from this study can also be applied to jointed concrete pavement projects in general. The outcomes of this study are recommendations for improvements in construction practices to help minimize the effects of curling and warping on jointed concrete pavement ride quality as well as recommendations for the collection of ride quality data for acceptance.	Further evaluation is required.

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Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2015-08	2015	32.08	Potential Impacts of Solar Arrays on Highway Environment, Safety and Operations	Bryan Roeder	YES	The advent of solar energy use in highway infrastructure around the country has been increasing in recent years. Rights-of-way (ROWS) have several advantages for energy development such as the existing electrical infrastructure aligned with the major highways, a secured boundary, and easy maintenance access. It has been identified by various Departments of Transportation (DOTs) and the Federal Highway Administration (FHWA) that solar array deployment along the ROW is possible after adequate site evaluation and impact study. With higher solar insolation available, CDOT can generate electricity from solar arrays on its ROWs across much of the State of Colorado. Political climate, public cooperation with energy providers, commitment of utility companies and potential impacts are some of the major concerns in successful solar array deployment. The potential impact of photo voltaic (PV) arrays on driver safety, highway operation and maintenance, and the environment are the focus of this research study.	A guidance manual has been provided to CDOT regions with the basic considerations and requirements to address the expectations of CDOT environmental, safety, and operation and maintenance programs.
2015-09	2015	312.01	Oil and Gas Impacts on Transportation	David Reeves	TBD	This study was completed in 2015. This research study aims to answer the following questions: What are other states with similar levels of oil and gas activity doing to recoup the costs of the industry's impacts to roads?; How do the trip generation characteristics of oil and gas development differ based on variables such as: well organization (number of wells per pad), drilling technology (horizontal vs. vertical), fracking activity, pipeline infrastructure, and development phase (construction, drilling, completion, production)?; What are the truck typologies and duration for various phases of development and what are the corresponding impacts (ESAL)?; What are the industry's impacts (in terms of reduction of drivability life and costs to offset the impacts) on a per-mile basis?; What variables affect the level of industry impacts (current drivability life, seasonality of activity, freeze/thaw cycle, duration of activity compounded with environmental impacts, etc.); How do the bridges on the State Highway system with weight and/or height restrictions affect the industry (rerouting requirements, bridge replacements for improved access)? What areas of the state are currently most affected by the oil and gas industry and what might future scenarios of oil and gas activity in Colorado look like? What is the magnitude of the oil and gas industry's impacts on the State Highway System? (How much truck activity on the state highway system is related to the industry? What portion of the loads on the state highway system is related to the industry? What are the estimated costs to offset the industry impacts?); What State Highways are generally most susceptible to industry impacts, given the current road conditions, current oil and gas activity and future development scenarios?	TBD

Research Implementation Report

Report No	Year	Study ID	Report Title	Research PM	Implemented?	Report Summary	Implementation
2015-10	2015	11.50	Effectiveness of Two Reflection Crack Attenuation Techniques	Richard Griffin	TBD	Asphalt overlays are one of the most common tools for rehabilitating existing asphalt and concrete pavements. However, the performance of new overlays is often jeopardized by the cracking distress in the existing pavement. This existing cracking propagates, or reflects, through the new overlay to the surface of the new overlay. The rate at which this reflection cracking propagates to the surface is a function of overlay thickness, crack severity, traffic loading and subgrade or subbase support. Once reflection cracks appear on the surface of the new pavement, water and debris can enter the subbase and subgrade which can affect pavement strength and reduce the life of the overlay. Therefore, reducing the rate at which these reflection cracks propagate to the surface of the pavement is desirable in order to lengthen the time between rehabilitation projects or crack sealing operations. Various methods have been used in past decades in an attempt to reduce the rate of reflection crack propagation. These include geosynthetic membranes and asphalt stress absorbing interlayers. This study compared performance of a grid reinforcing system, a polymer-modified asphalt-rich interlayer system, and control pavement test sections. The study presents the differences in performance after five years' service for the two reflection crack attenuation systems and the comparable control pavement test sections.	Still being considered by the MAC for future implementation.
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