

RESEARCH YIELDS A HEALTHY RATE OF RETURN

TEXAS DEPARTMENT OF TRANSPORTATION

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Since 1943 the research undertaken or supported by the Texas Department of Transportation has been reflected in the design, construction, or maintenance of every mile of Texas roads. Each year TxDOT's Research and Technology Transfer Office coordinates about \$20 million dollars' worth of research projects at state-supported universities. Part of the nation's largest cooperative transportation research program, these projects have paid off in substantial cost savings and other benefits, such as increased safety and emissions reductions. Seven research projects and their payoffs are described below, along with the department's recent efforts to restructure its research program to emphasize coordination and implementation.

IMPROVING HYDRAULIC DESIGN TECHNIQUES

The department uses regional flood-prediction equations for the hydraulic design of approximately 90 percent of bridges and culverts on the Texas highway system. Until 1996 these equations were derived on the basis of hydrologic data collected through 1974. Because many parts of the state lacked stream gages at that time, the department's ability to determine the appropriate hydraulic capacity of bridges and culverts was hindered. Indeed, the potential existed for the hydraulic design of structures either grossly undersized and prone to overtopping or oversized, resulting in unnecessary construction costs.

U.S. Geological Survey (USGS) researchers established additional stream gage stations in two Texas regions. These stations' data significantly improved flood prediction equations. The new equations—derived from stream gage data obtained from digitized elevation, slope, and drainage data linked to geographical information systems and from advanced statistical techniques—reduce standard error and accelerate the design process.

Once the department approved new statewide flood-prediction equations, USGS researchers developed software that provides instantaneous regression analysis of stream gage data. The new methodology not only allows the department to determine the appropriate size of structures quickly and accurately but also to evaluate the structures' potential for scour. This methodology is being taught in the department's hydraulic design courses, and the beta version of the program has been released to several districts for pilot testing.

MITIGATING BOTTLENECKS

Freeway bottlenecks delay motorists, waste fuel, increase emissions, and prevent roads from carrying the amount of traffic they are designed to accommodate. Researchers at the Texas Transportation Institute (TTI) proposed improvements, some of which have been implemented in Dallas, Texas, with positive results.

TTI researchers developed a computer model for bottleneck analysis and alleviation. The analysis begins with the definition of the problem. Is a particular bottleneck, for example, caused by an overloaded entrance ramp or by a little-used exit-only lane? The model specifies the data required to answer such a question. Once the cause of the problem is identified, the model suggests possible solutions, which may include restriping, metering, closing entrance ramps, or even adding lanes. Finally, the model estimates the effectiveness of bottleneck removal. Will the proposed solution still leave traffic demand unmet? Will it fix the problem in one area, only to overload another part of the highway? Is there another bottleneck hidden in the congested section? Once these questions have been answered, the optimum solution and its benefits emerge.

As a test, the model was used to suggest a way to alleviate a bottleneck at one of the exits to US 75

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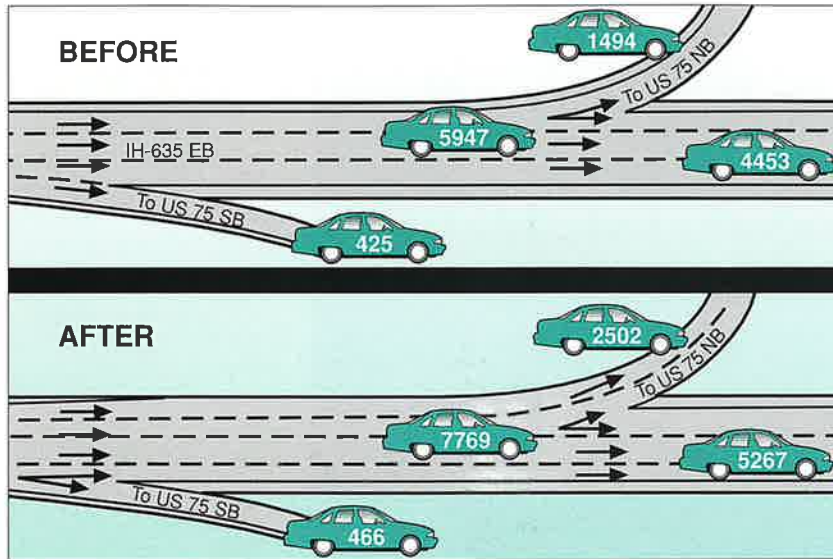


FIGURE 1 By means of a computer model developed by the Texas Transportation Institute, the Texas Department of Transportation was able to alleviate a bottleneck at exit from IH-635 to US 75 during evening peak-hour traffic. Numbers on cars indicate change in traffic volume in each lane as a result of improvements.

from IH-635. The exit-only lane onto northbound US 75 was very busy, but the exit-only lane drop from eastbound IH-635 onto southbound US 75 was receiving relatively little traffic. On the basis of the model's analysis of the problem, TxDOT converted a shoulder section to a driving lane so that the eastbound IH-635 lane drop no longer occurred between the two exits and then added an extra exit lane to US 75 northbound (Figure 1). Lane markings were shifted left to maintain a smooth transition for all four continuing lanes.

The US 75 improvements have worked well. The number of vehicles using the northbound ramp each hour increased 50 percent, and the average speed of vehicles on IH-635 increased. Adjustments to the eastbound side of IH-635 are saving more than \$3.6 million per year. Travel-time reductions from similar adjustments to the westbound side increase the savings to more than \$7.4 million per year. During the next 10 years, the project may save a minimum of \$24.50 for every \$1 of the \$2.45 million invested. Other as yet unquantified benefits, such as improved air quality, reduced energy consumption, and lower vehicle operating costs, increase this already healthy rate of return.

SATISFYING PEAK-PERIOD TRAVEL DEMANDS

As roadways approach their capacity, rising numbers of single-occupancy vehicles lead to increases in travel time, emissions, and fuel use, and reduce productivity. High-occupancy vehicle (HOV) lanes, typically located in the freeway median and

separated from the main lanes, provide a less congested, higher-speed travel alternative for some commuters. HOV lanes can decrease the number of vehicles on the road and increase peak-time highway capacity, resulting in decreased travel time for commuters, better air quality, and reduced fuel consumption.

TxDOT has documented the benefits of HOV lanes implemented in Dallas and Houston with the cooperation of local transit authorities. In these two cities, 72 percent to 180 percent more people per lane are using HOV lanes than general-purpose lanes, and the average number of people per vehicle has increased by more than 15 percent. Travel-time reductions range from 5 to 18 minutes. HOV lanes also increase transit use. The operating speeds of buses have nearly doubled, resulting in faster service to a greater number of people.

Finally, HOV facilities reduce the environmental effects of vehicle use. In a simulation analysis comparing the environmental effects of adding an HOV lane with adding one general-use lane, the Texas Transportation Institute found that the HOV lane produced a 16 percent reduction in fuel consumption and a 31 percent reduction in carbon monoxide emissions. Surveys conducted in Houston in 1994 by TTI indicated that 70 percent of freeway users in that city view local HOV facilities as significant improvements.

IMPROVING PAVEMENT PERFORMANCE

Varying properties of different aggregates affect the strength and cracking characteristics of pavements. Proper aggregate selection is therefore an important element in the design of distress-resistant mixtures.

In a study funded by TxDOT, the Center for Transportation Research and the Texas Transportation Institute jointly investigated two coarse aggregate types, crushed limestone and siliceous river gravel, to determine their effects on pavement mixtures and to develop pavement performance models. Researchers discovered striking differences in the performance of portland cement concrete pavements made with limestone aggregates and that of pavements made with river gravel aggregates. Researchers attributed these differences to early-age bonding characteristics. They also found that the blending of aggregates improved the engineering properties of the concrete mixture made with river gravel. Blending allows engineers to use aggregates that would otherwise be unsuitable under certain paving conditions, such as when daily temperatures vary greatly.

The project team developed the CHEM2 computer program to predict the properties of blended aggregates and to determine optimum blending ratios. They also developed an aggregate classification system to aid engineers in predicting the effect of aggregate types on concrete pavement performance.

Coarse aggregate types used in continuous reinforced concrete (CRC) pavements affect the placement and size of steel reinforcements. River gravel requires less steel reinforcement than limestone. Too large a bar will cause excessive cracking. Tests revealed that different aggregate types have different effects on spalling in CRC. Concrete made with crushed limestone has a strong resistance to spalling, whereas pavements made with siliceous river gravel are more likely to spall. Sawcutting the transverse cracks in river-gravel CRC pavement minimizes spalling. Improved curing practices also reduce spalling at transverse cracks.

Laboratory evaluations of hot-mix asphalt mixtures prepared from different amounts of crushed and uncrushed coarse aggregates revealed a direct correlation between permanent deformation of asphalt concrete and the shape and texture of the aggregates used. In both static and dynamic tests, researchers found less creep, rutting, and permanent deformation with an increased amount of angular coarse aggregates in the mixture. Increasing the percentage of coarse aggregate increased the capability of pavement to recover from compression loading at temperatures of 46°C (115°F) or higher.

The benefits of this work are many. Improved aggregate selection, together with the use of blending ratios, allows pavement engineers to design mixtures for optimum pavement performance. Better designs, along with improved construction procedures developed in field tests and laboratory examinations, result in more durable pavements.

AVOIDING SULFATE-SWELL PAVEMENT DAMAGE

Engineers often stabilize soils at pavement construction sites. Compaction is usually sufficient, but sometimes lime must be added to clay soils to form a stable surface for construction equipment during wet weather. Lime stabilization can double or even quadruple the long-term, load-bearing strength of clay soils, decreasing downtime during rainy periods and allowing quicker construction. Lime stabilization can be a problem, however, when clay soils are high in sulfates because the



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calcium in lime may react with the sulfates to form expandable minerals like ettringite, which can double in volume when exposed to moisture. Such expansion causes heaving, cracking, and buckling of pavements.

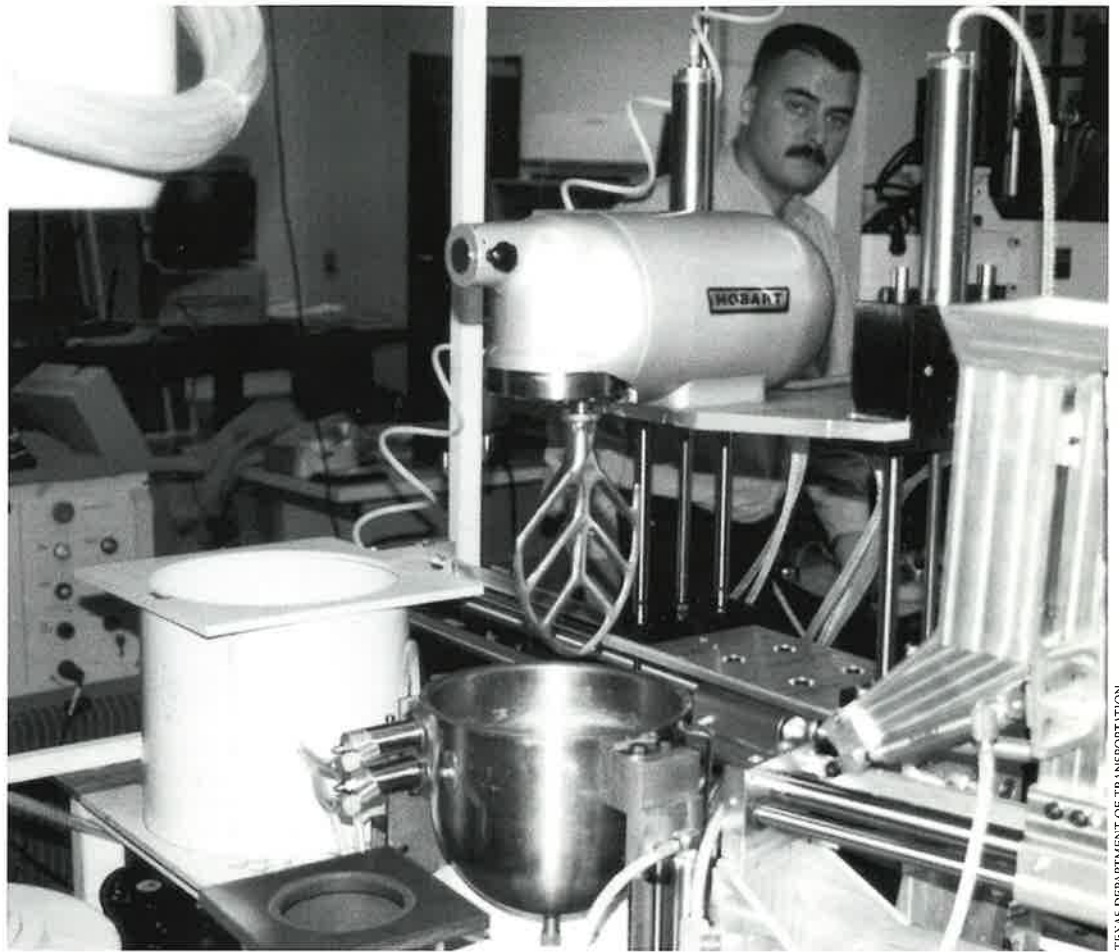
At the request of TxDOT, the Texas Transportation Institute developed a field-testing device and procedures to help identify sites with a high potential for lime/sulfate soil expansion. The field-testing kit consists of a probe, distilled water, and a scale and bowl for mixing and measuring the soil sample (Figure 2). The kit is used to determine the moisture content of the soil sample and to measure electrical conductivity. By graphing electrical conductivity and sulfate content, engineers can estimate the amount of sulfates in the soil and the amount of sulfate-related swell likely to occur before and after lime stabilization. High conductivity usually indicates sulfate-rich soils.

TTI also investigated the substitution of alternative substances for lime to stabilize sulfate-rich soils. Because it is the calcium in lime that reacts with sulfates to form ettringite, researchers recommended the use of low-calcium fly ashes, which are inexpensive and plentiful.

Approximately 42 000 lane kilometers (26,000 lane miles) of Texas roads rest on sulfate-rich soils. The department estimates that use of the soil stabilization test kit and alternative stabilizers could save the state \$23 million a year in repair costs.

FIGURE 2 Use of soil stabilization kit developed by Texas Transportation Institute and alternative stabilizers, such as low-calcium fly ashes, could save Texas as much as \$23 million per year in pavement repair costs.

FIGURE 3 Robotic workcell makes hydraulic cement mortar for testing purposes and is designed to clean its own tools. Automation of manual testing process statewide will save Texas \$31,000 annually.



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AUTOMATING MORTAR TESTING PROCESS

Manual testing of hydraulic cement mortars is tedious and time-consuming. TxDOT asked Texas State Technical College to automate the manual process in accordance with ASTM standards, and to design and program the process to be carried out within a self-contained robotic workcell (Figure 3). Project objectives were to improve safety for technicians; decrease energy costs; improve the precision, accuracy, and repeatability of test results; and improve the consistency of testing procedures.

The testing process for hydraulic cement mortars has been fully automated in the Austin Materials and Tests Division Lab. Once the new process is implemented statewide, cost savings will total \$31,000 annually: \$28,000 in reduced manpower and \$3,000 in reduced energy use. The latter savings result from a decrease in the number of square meters where temperature and humidity must be controlled.

IMPLEMENTING RECYCLING

In 1996 TxDOT proposed an innovative recycling implementation strategy using funds from the Federal Highway Administration's Priority Technology Program (PTP), which is designed to accelerate the use of new technologies. In 1994 the department, FHWA, and the Texas Natural Resources Conservation Commission had sponsored 13 projects involving literature surveys and laboratory testing of waste materials. The projects resulted in the development of draft specifications for those materials with potential applications in transportation construction, but there existed no uniform method for evaluating whether the specifications should be implemented.

In a new PTP-funded project, Texas Tech University is evaluating the specifications on the basis of cost and performance in the context of the department's construction projects. The project encompasses various recycled materials, construction applications, and field test locations through-

out Texas. Objectives include collecting labor and materials costs associated with each project, especially the costs of unique construction practices; assessing markets for recycled materials; and determining the effectiveness of these materials.

Many public and private partners will gain first-hand experience with the recycled materials being evaluated. Information obtained from this experience will make possible the materials' widespread use and, consequently, more environmentally sensitive construction operations. Moreover, large-scale implementation of recycled materials in construction applications will enable the department to deal with shortages of virgin materials.

RESTRUCTURING TXDOT RESEARCH

Responding to a continuous improvement directive, TxDOT recently changed the way it pursues research, restructuring its program to better coordinate studies, streamline and accelerate the investigative process, tailor findings to current and projected needs, and emphasize implementation. The department is achieving these objectives by expanding its areas of research, moving decision-making authority downward, initiating coordinated long-range planning, and creating opportunities for innovative implementation.

To conduct research efficiently, nine research management committees have developed plans that together make up TxDOT's comprehensive Long-Range Research Plan. Objectives and tasks in the Long-Range Research Plan give rise to projects. The plans are reviewed and modified as needed.

Research management committees convene technical advisory panels to provide perspectives on research topics and technical assistance for research projects as well as to stimulate the involvement of universities and state/local govern-

ment entities. Panel members include TxDOT experts, FHWA personnel, university professors and researchers, industry representatives, and local government personnel (county engineers, city planners, MPO officials, and local transit representatives). The members may suggest plan elements for review and acceptance by the research management committees.

TxDOT personnel serving as project directors oversee the technical aspects of research projects and ensure implementation of research products. Project directors promote and monitor the use of project findings for three years after a project ends. Where possible, they quantify the research benefits in terms of economics, safety, emissions reductions, and so on. Project directors also identify barriers to implementation.

Since the department retooled its research program, three important concepts have emerged. First, research plans should be coordinated. Guided by the Long-Range Research Plan, research management committees identify priorities and needs, involve technical advisory panels in decision-making, and formulate programs that address major issues with minimal duplication. Second, project deliverables and their implementation should be discussed when a project begins. The department believes that clearly defining objectives at the outset of projects will help to guarantee the generation of practical and timely final products. Third, research results should be packaged in useful forms. The department is working on supplementing written reports and even replacing them with videos, web sites, data bases, CD-ROMs, or interactive software.

By responding to current challenges, seeking solutions to anticipated problems, and incorporating the needs of diverse constituents into major decisions, the department demonstrates its commitment to continuous improvement.