TECHNICAL QUARTERLY

"AN EXCHANGE OF IDEAS"

TQ 8-4, March 1994 *EDITOR: Kathleen M. Jones*

TXDOT ASSESSES IMPACT OF HIGHWAY OPERATIONS ON WATER QUALITY/QUANTITY

by **Ray Donley**
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In response to concerns regarding highway construction in the Edwards Aquifer recharge zone, the Texas Department of Transportation (TxDOT) has contracted with the Center for Transportation Research to determine the environmental risks posed by the planned construction of the southern extension of Loop 1 in Austin, Texas. Research Study 7-1943, ***Water Quantity and Quality Impacts Assessment of Highway Construction in the Austin, Texas, Area,*** is investigating the potential for contamination of area creeks by highway stormwater runoff. The 5-year study will be coordinated by TxDOT and the Barton Springs/Edwards Aquifer Conservation District.

Headed by Dr. Joseph F. Malina of UT's Center for Research in Water Resources, the project has several objectives: (1) Collect data on the quantity and quality of water in creeks upstream and downstream of highway construction sites; (2) evaluate pollution loads contributed by existing highways near or in the Barton Springs segment of the Edwards Aquifer recharge zone; (3) evaluate the effectiveness of temporary runoff control structures and devices used for the interception and containment of silt during construction; and (4) monitor and evaluate the performance of permanent runoff pollution control systems installed on operating highways.

In their most conspicuous achievement to date, the researchers have designed and successfully installed on Loop 1 (MoPac) a unique rainfall simulator — an enormous water-spraying device that has become a much-publicized fixture on the heavily traveled MoPac Expressway in Austin. The simulator (Fig. 1) allows the re-

FIGURE 1: The rain simulator in action on MoPac.

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information within the transportation community.

searchers to control such parameters as antecedent dry periods, number of vehicles on the highway during a storm, and rainfall intensity and duration.

Using the simulator, the study team has been measuring the runoff flow rate, collecting runoff samples directly, and analyzing the water quality parameters (Fig. 2) These parameters include both field data (measurements of temperature, pH, and specific conductance) and laboratory data (analyses of turbidity, suspended solids, heavy metals, oil and grease, chemical and biochemical oxygen demand, organic carbon, and nutrients).

PRELIMINARY RESULTS

The researchers are also currently evaluating the various types of temporary runoff control devices installed at construction sites. At this point, they have determined that the fabric used in geotextile silt fences — both woven and nonwoven — is generally ineffective in filtering out silt and clay size particles from storm water runoff. But, as CTR Research Engineer Michael Barrett points out, they are "not a waste of time"; that is, many particles are removed through the sedimentation that occurs in the standing water behind the fabric fences. He explained that silt and clay size particles are simply smaller than the weave of the fabric, allowing those particles to escape.

The project team has also begun bench-scale studies to test the effectiveness of various filter media for use in permanent highway runoff control. In these studies, columns are filled with a variety of filter media (medium sand, coarse sand, coal, humic peat, fibric peat, and zeolites). A simulated runoff "cocktail," which includes suspended solids, oil and grease, and four metals (lead, zinc, iron, and copper) is then poured into these columns, after which removal rates are calculated (Fig. 3). Researcher Tom Heathman indicates that the filters have shown "very high initial removal efficiencies."

FIGURE 2: Researcher Huey Miin Wu calibrates a pH meter that will be used to collect highway runoff field data.

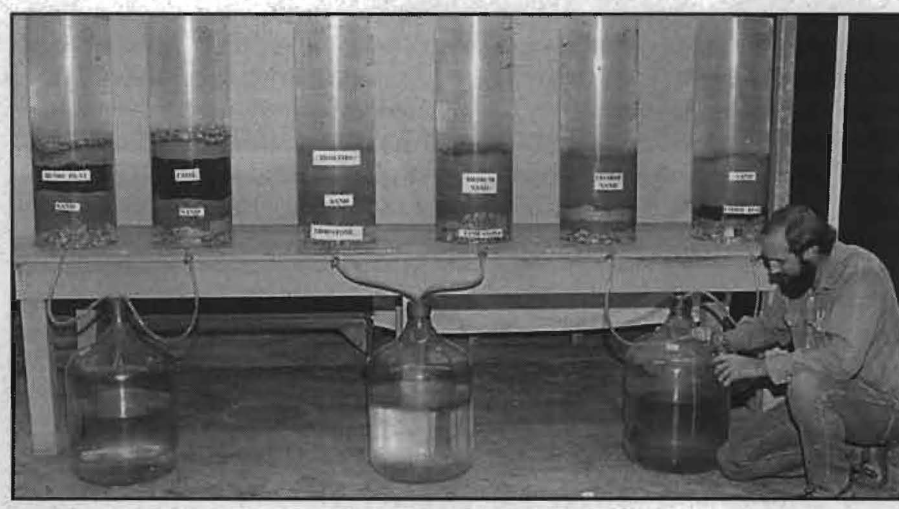

FIGURE 3: Researcher Tom Heathman collects samples from columns containing various filtration media. Simulated stormwater runoff "cocktails" are run through these columns to see which medium best filters out pollutants.

WHERE THE RESEARCH IS HEADING

The researchers will develop a mathematical model that integrates all aspects of the investigation. The model, as contemplated, will predict the effect of highway operation on water quality and quantity in other situations and in other areas. Every phase of project work has been reviewed and analyzed by TxDOT, the Barton Springs/Edwards Aquifer Conservation District, and the Technical Review Committee (composed of three members from the Barton Springs/Edwards Aquifer Conservation District, two members from TxDOT, and two members from The University of Texas Center for Research in Water Resources). Baseline data collected by the project will be a matter of public record for anyone wishing to verify the findings.

The unique technological challenges posed by the study prompted TxDOT's Research and Development Committee to select CTR over other competing agencies. In CTR's favor were (1) a staff of highly regarded, independent scientists; (2) the expertise to fabricate an artificial rainfall simulator (considered necessary for this project); and (3) the exceptional testing facilities at UT's Balcones Research Center, which includes full-scale roadway and river models. A $200,000 prototype runoff treatment system is also planned for construction. This facility will be used to evaluate the performance and effectiveness of vertical and horizontal filter configurations in runoff treatment.

The project, which got underway in February of 1992, is scheduled for completion in mid–1996.

The photographs in this article are courtesy of Michelle Gilson of UT's Center for Research in Water Resources.

FIRE IN THE ROW: RESEARCH RECOMMENDS RISK-REDUCTION PRACTICES

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and
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Research Associate,
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Texas Transportation Institute
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INTRODUCTION

The rash of wildfires during the unusually hot, dry summer months of 1993 did not surprise wildfire experts. Even in normal rainfall years, the northern two-thirds of Texas, the Southern Great Plains, supports an abundance of fine fuel vegetation (such as buffalo grass, blue grama, western wheat grass, and caucasian bluestem) that is susceptible to roadside fires. Dry vegetation and intense heat from the sun create ideal conditions for fire along these Texas roadways. An overheated car pulling off the shoulder and into taller right-of-way (ROW) grass or a tossed cigartte can provide the spark needed for a wildfire that, with a gust of wind, quickly spreads to adjacent property or generates smoke that is hazardous for oncoming traffic.

Bobby Young of the Texas Forest Service estimates that the volunteer fire departments responded to 500 fires per day during the July-August 1993 fire season peak. According to Jean Mitchell of the Texas Commission on Fire Protection (TCFP), "From 1988 to 1991 an average of 3,586 roadside grass fires were reported annually in Texas — that's one fire per 21 centerline miles (33.6 km) of roadway." When the figures are tallied, the 1993 number of roadside fires may double that annual average.

What role can the Texas Department of Transportation (TxDOT) play in presuppression of roadside fires? Work done by Texas Transportation Institute (TTI) scientists Danise Hauser and Dr. Wayne McCully for TxDOT's Roadside Vegetation Management Research Program has assessed the current roadside fire prevention, or *pre-suppression,* techniques and made some recommendations for future policy. The information that follows is taken from TTI Research Report 902-7 [Ref. 1].

TEXAS FIRE PRESUPPRESSION

Current Practice

Since 1950, TxDOT has contributed to presuppression of roadside fires, at the request of property owners, with the "good-neighbor" practice of blading or disking a 12-foot-wide fire guard just inside the boundary between the ROW and adjacent property. The fire guard, a safety-strip of exposed bare soil, removes the fire's fuel, possibly interrupting its spread to adjacent property. Sometimes this practice leaves unmowed fuel between the shoulder and the fire guard.

Concerns and Changes

The Environmental Protection Agency (EPA) has expressed concern regarding the practice of blading or disking fire guards, citing the potential increase of erosion, the introduction of silt into water supplies, and the possibility of damaging endangered species habitats along the boundary of the ROW. Where departments of transportation continue the practice, the EPA may require a NPDES permit, which requires revegetation of newly constructed fire guards.

The Maintenance Environmental Task Force of TxDOT has recommended a review of fire guard policy. An internal TxDOT survey showed that many districts support eliminating bare-earth fire guards; however, some are concerned that total elimination may result in more fires.

Another concern is possible legal questions. TxDOT legal counsel holds that unless the fire was due to negligence by TxDOT personnel, the state is not liable for fire originating on the ROW. However, could discontinuing fire guards be considered prima-facie evidence of TxDOT negligence? No one is sure because this question has not yet come before the courts. [Ref. 2].

RECOMMENDATIONS — RELOCATE, MODIFY, AND EDUCATE

As an alternative to eliminating all TxDOT contribution to a fire presuppression program, this research has identified several courses of action for TxDOT consideration.

Use routine vegetation maintenance activities as a fuel management strategy.

- **Relocate the fire guard from the edge of the ROW to the edge of the pavement, and convert the fire guard from bare ground to a mowed strip.** The U.S. Forest Service recommends moving the location of the fire guard by combining the 8-foot paved shoulder (if present) and a directly adjacent *mowed* 5- to 15-foot safety strip. Figure 1 diagrams both the proposed new location and the old fire guard placement. This strategy would not require permitting from regulatory agencies. Another benefit is that the ROW boundary, an area that is likely to serve as a wildlife habitat, remains undisturbed. With ROW maintenance attention shifting closer to the road, ignition from burning objects or catalytic converters is less likely. Mowing the safety strip, rather than disking it, maintains storm water quality, and the watershed effect of pavement promotes greenstripping with runoff from showers. Grass in the greenstrip will likely contain enough moisture to resist combustion.

- **Use plant cover and mowing strategies that favor fire presuppression.** With almost no extra effort, maintenance or contract personnel can mow the newly located safety strips to certain heights that promote the growth of low ignition, slow-burning grasses, such as Bermuda grass with its lower leaf-to-stem ratio, flat-on-the-ground King Ranch bluestem, and caucasian bluestem. Avoid mowing heights that are so short that they clear the strip completely, that the desired grasses react adversely, or that mower-thrown-objects (MTOs) become airborne. Also, accomplish the initial cycle of mowing before the vegetation becomes too thick and tall: a mat of dried, mowed grass can catch fire more easily than unmowed grass [Ref. 3].

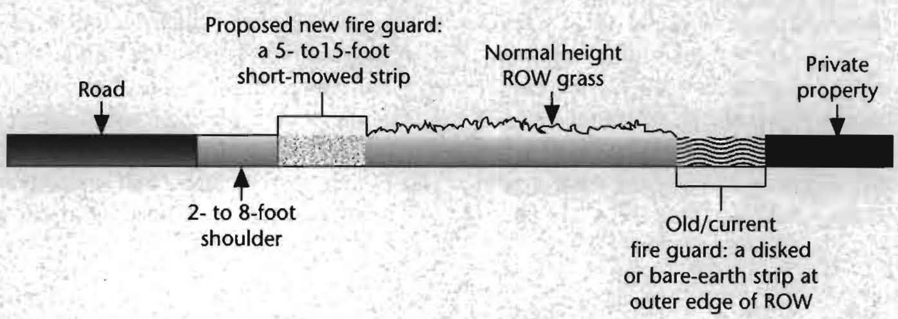

Figure 1: Proposed fire guard position compared to current.

- **Schedule systematic maintenance and cleanup of fuel accumulation areas such as culvert ends and headwalls, turnouts, and armadillo burrows.** Ignited, areas like these are likely to generate firebrands (pieces of burning sticks or limbs that fall into unburned areas and spread the fire) and firewhirls (airborne burning leaves and fibers). Different species of plants are more or less combustible depending on their material make-up and the prevailing weather. For example, experts consider dead juniper, pine, live oak trimmings, and other plants containing oils, waxes, and fats, highly volatile firebrand promoters. On the other hand, they commonly class shinnery oak/grass, sand sagebrush/grass, and running live oak/grass growth as moderately volatile, except in certain wind conditions when this type of cover can spread by firebrand if ignited [Ref. 4, 5]. Reduction of deadfall and selective removal of the most volatile species from ROW reduces risk.

Alter the behavior of those who start roadside fires.

- **Explore** the necessary components of an effective public education and information campaign.
- **Compose** visual and audio materials for television and radio spots and youth education to communicate the risk posed by an overheated car or a thrown cigarette.

- **Establish and cultivate** relationships with the U.S. National Weather Service, the Texas Forest Service, and the Texas Agricultural Extension Service in order to better predict hazardous fire danger weather and further develop signs and/or public service announcements concerning roadside activities that can ignite a fire, as well as dangerously dry periods.

Encourage collection of more detailed data on ROW wildfires for future planning.

- **Estimate** point of fire origin by route and reference marker (using TxDOT's Texas Reference Marker System).
- **Calculate** distance from point of fire origin to pavement edge.
- **Determine** whether or not ROW fire burns onto adjacent property.

Investigate other ROW fire presuppression options.

- **Evaluate** the need for fire retardant chemical use on road sections with a tendency for fire starts.
- **Test different vegetation** (fuels) to determine a relative ignition tendency so volatile grasses can be eliminated and safer ones emphasized in plant mixtures for the active zone.

Ultimately, presuppression of wildfires is a joint effort of TxDOT and its clients who travel the roadways. TxDOT is considering Study 7-902's recommendations including the relocation and change in character of fireguards. Before finalizing any policy the TxDOT Administration will seek input from the Transportation Commission and other sources.

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5. ———. Telephone Interview. May 6, 1993. In Hauser and McCully, *Presuppression.*

TXDOT DATA FROM TNRIS

The Texas Department of Transportation (TxDOT) recently finished digitizing its County/City map series and has made it available for distribution through TNRIS. The County map series is one of the digital layers recommended for statewide use by the Geographic Information System Planning Council (GISPC).

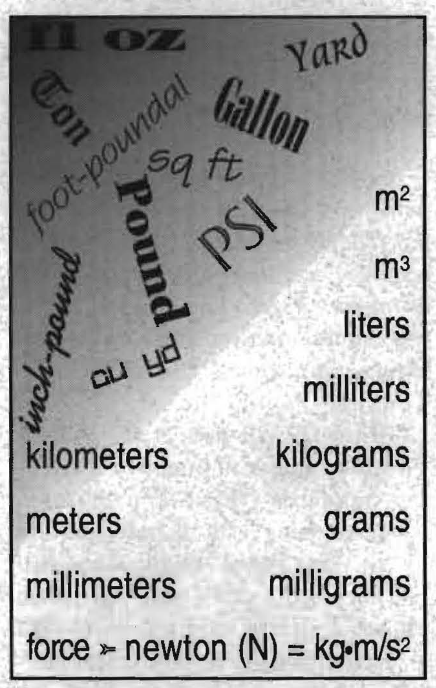
TxDOT developed the County/City map series by digitizing from United States Geological Survey (USGS) 7.5-minute quadrangles (quads). These quads were integrated into a unified data layer, then partitioned according to county boundaries. Updates have been done from 1:24,000 aerial photographs. These files contain all public access roadways (state-, county-, and city-maintained), all state-maintained bridges, all airports, the Gulf Intracoastal Water Way (GIWW), and county and city boundaries. These files do not include contours, fence lines, jeep trails, small creeks, electrical transmission lines, and oil and gas pipelines. Hydrography has been generalized.

TNRIS distributes this data in its role as the state's clearinghouse for natural resource data. TNRIS also indexes and keeps a catalog of public and private geographic files that can be read by mapping and GIS software. This catalog includes the name of the organization providing the database, a description of the graphic and nongraphic data types, a description of the geographic area covered by the database; size of files and format of data storage; availability of files and type of media for transfer; and names and telephone numbers of contact persons. TNRIS system's central telephone number is (512) 463-8337.

*Source: **Texas Natural Resource Information System (TNRIS) Newsletter*** 17(January 1994): 2.

HOW I SWITCHED TO METRIC MEASURE

by **Dave Valentine, P.E.**
County Engineer
County of Haliburton, Ontario
Canada



I was lucky. I got hit with metric measurement when I was working in central Africa, developing curriculum for civil technology students. Being faced with a new system of measurement was just another part of culture shock.

I tried to sidestep it by working in both systems, converting back and forth. I justified this on the basis that graduates would be faced with both systems and would need to understand the engineering calculations in both.

I had worked as a county engineer before taking up teaching, and I remember horror stories of technicians making mistakes in calculating quantities of liquid asphalt products for road surfacing. When a roadway width is measured in feet, its length in miles, and the application rates in gallons per square yard, there's a good chance of getting lost in all of those conversions.

Once I'd started to talk about a roadway width of 7 meters, 17-kilometers long, and an application rate of a liter per square kilometer, the calculation became something you could almost do in your head. So you could recalculate five times to check!

Another problem I ran into there was two lengths of feet; Imperial and Cape. Here, this year's contractor had a brand new distributor —

calibrated in U.S. as opposed to Imperial gallons!

I returned to Canada quite enthused about working metrically. I found my carpentry and home renovations greatly simplified. Soft conversion made my new work look a little different than old, with 16 inches converting to just about 400 mm

I didn't worry about all the fancy names for parts or multiples of meters; millimeters, meters and kilometers served most purposes fine. Decimals of meters are just as useful with a 4-inch lift of gravel equaling 0.1 m.

I volunteered as a guest speaker on metrication and gave talks to service clubs and our local road superintendents' association. One hint they liked was measuring the height of the grader and the width of its blade in meters, as a constant reminder. I also suggested they mark off 1 and 2 meters up the side of the door frame of their machinery shed.

In spite of what you hear, Canada is not operating metrically. The current government made conversion voluntary, so most building supplies and a lot of hardware are still measured in inches and feet.

Our roads department also works in both systems, since we're working off some old land surveys for construction plan control. Any new surveys that we complete are done in meters.

I think that the United States going metric will the boost we need to accelerate our own conversion Will we still be able to buy your quaint penny length nails?

Source: ***Better Roads*** ***63(November 1993):*** 33. Reprinted by permission.

TXDOT'S METRIC PLAN

Why is the Texas Department of Transportation going metric? The short answer is, "Federal mandates." A fuller answer would add that metric is easier to use than the English system and more efficient for scientific and engineering purposes. Also, switching to metric puts us on an event trade footing with the rest of the industrialized and developing nations of the world. Listed below are the federal mandates that most closely affect why and when we make the change.

FEDERAL MANDATES

- Omnibus Trade and Competitiveness Act of 1988 declared the metric system as the preferred system of weights and measures for U.S. trade and commerce and required each federal agency to convert to the metric system.
- U.S. DOT Metric Conversion Planning Guidelines issued in 1990 and amended in 1991 and 1992 requires the nine U.S. DOT agencies to develop plans for conversion to the extent possible.
- Federal Highway Administration (FHWA) developed a conversion plan and a timetable approved in 1991 to lead to complete metric implementation by September 30, 1996.
- Federal Highway Administration (FHWA) complied with requirements in the Omnibus Trade and Competitiveness Act of 1988 by publishing the following policies in the Federal Register on June 11, 1992:
    - After September 30, 1996, FHWA will only authorize funding for projects developed in metric units.
    - The deadline for FHWA reports to be in metric units will be those submitted after September 30, 1994. These reports include the Intermodal Surface Transportation Efficiency Act (ISTEA) Management Systems and Highway Performance Monitoring System (HPMS).

WORKING CRITERIA

TxDOT's metric committee established six working criteria to meet the federal mandates. These criteria mainly affect plans, specifications and estimates (PS&E) and Federal Highway Administration (FHWA) data collecting and reporting. The criteria are:

1. TxDOT will use "soft" conversion, unless national or TxDOT standards ("hard" conversions) have been established and use of these "hard" conversions will not have a significant impact on resources or industry. (In a "soft" conversion, an English system measurement is mathematically converted to its exact [or nearly exact] metric equivalent. With "hard" conversion, a new, rounded, rationalized metric number is created that is convenient to work with and remember.)
2. TxDOT will begin surveying in metric units in February of 1994.
3. All TxDOT projects that are surveyed after February of 1994 and scheduled to be let after September 30, 1996, will be submitted to the FHWA in metric units. Projects surveyed before February of 1994 and scheduled to be let after September 30, 1996, might justify an exception from the FHWA.
4. TxDOT is requesting an extension of the federal FY 95 deadline for data collection and reporting. This extension would allow a reasonable time for conversion once the requirements have been finalized and would allow TxDOT to take full advantage of the opportunity to improve supporting information systems.
5. TxDOT will display English units on documents for public use.
6. TxDOT will allow the following items to remain in English units:
    - supporting documentation
    - **sign legends**
    - data collection (The actual reports to FHWA will be in

metric units, but the data collection is not required in metric units.)

- hardware items designed to meet specific safety requirements and minor exceptions for details of materials (bolt sizes and gauges of steel) in PS&Es let after September 30, 1996.

Note that sign legends are not being changed from miles to kilometers for now. Changing sign distance units must be part of a national effort because it would be very confusing for the driving public if one state reported distances in mileage while another state, whose metric time table and priorities might be different, was already reporting distances on sign legends in kilometers.

The TxDOT Administration has proposed the timeline shown in Table 1. A more detailed explanation of TxDOT's move to metric is available in ***The TxDOT Metrication Guide.*** Call Lois Young, General Services Division, at (512) 465-7326 to order your copy.

TABLE 1: Major milestones in metric conversion plan.

DESCRIPTION	1993 Q4	1994 QI	Q2	Q3	Q4	1995 QI	Q2	Q3	Q4	1996 QI	Q2	Q3	Q4	1997 QI
Acquire Surveying Equipment	♦ Dec 93													
Metric Survey Guide to Districts		♦ Jan 94												
Begin Surveying Metric Projects		♦ Feb 94												
Metric RDS Online		♦ Feb 94												
Revised Design Manual Pts 111 & IV			♦ Apr 94											
Metric IGRDS Online				♦ Jul 94										
Project Id Screens in DCIS				♦ Aug 94										
Draft Addendum to MUTCD Available				♦ Sep 94										
Draft Metric Spec Book Available				♦ Sep 94										
Hydraulic Manuals & Systems Available				♦ Sep 94										
Universal Spec File Revised							♦ Apr 95							
Issue Final Metric Spec Book							♦ May 95							
Standard Sheets Revised							♦ May 95							
Letting System Available								♦ Sep 95						
Target to Start Metric Lettings									♦ Oct 95					
FHWA Deadline for All PS&E in Metric													♦ Oct 96	

SOME CONCEPTS TO HELP YOU THINK METRIC

For civil work, the standard unit is the meter (1.1 yards). The metric unit of an area is the square meter, but large land or water areas are expressed in square kilometers (0.4 square miles). The metric unit for volume is the cubic meter, except for liquids, which are expressed in liters (1.06 quarts).

To think in metric: 1 mm is the thickness of a dime; 10 mm is the diameter of a ball-point pen; 2 m is the height of a door and 100 m is the length of a football field. For design, a 12-foot lane width will be 3.6 m, a design speed of 55 mph will be 90 km/h, and a 6-inch mountable curb will be 150 mm.

BRIDGES AS BAT HABITAT

by **Dr. Merlin Tuttle**
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Bat Conservation International
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WHY HELP BATS

Bats play a key ecological role as the primary predators of insects that fly at night, a category that includes vast numbers of crop and yard pests. Just one little brown bat can catch 600 mosquitoes in an hour. A colony of only 150 big brown bats can catch enough cucumber beetles each summer to protect local farmers from the costly attacks of 18 million of their rootworm larva. And the Mexican free-tailed bat colony living in Austin's Congress Avenue Bridge (Fig. 1) consumes from 10,000 to 30,000 pounds of insects nightly.

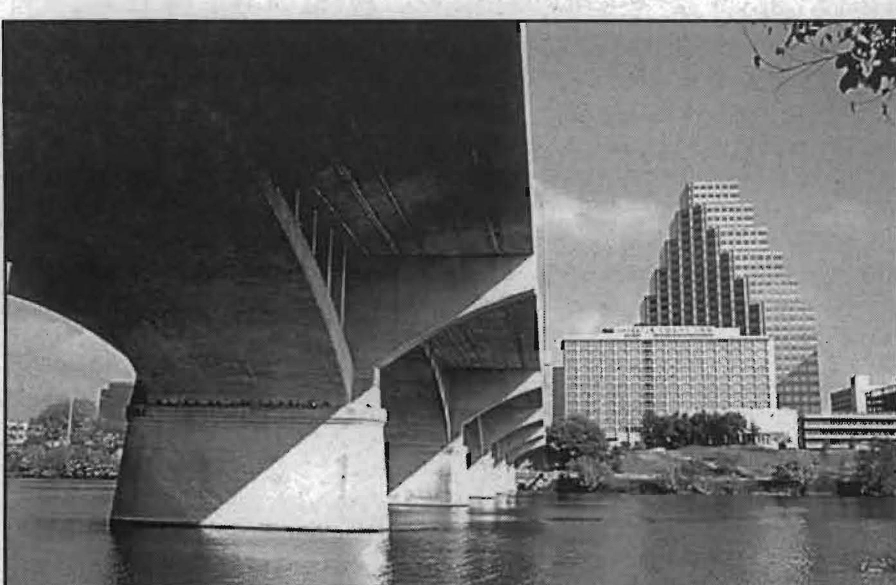

FIG. 1: Congress Avenue Bridge. Bridges that form cave-like chambers within the terminal foundations are especially attractive to endangered big-eared bats.

Texas is home to 33 species of bats, all highly beneficial. However, their numbers are declining, largely due to loss of natural roosting habitat caves. Of the 44 species living in the U.S., nearly 40 percent are now endangered or official candidates.

The most beneficial and abundant species in Texas, the Mexican free-tailed bat, already has declined by more than 30 million in Arizona and by 97 percent at the famous Carlsbad Caverns. It is in trouble nearly everywhere, but like many of America's declining bats, it can be helped significantly by simply using bridge designs that provide critically needed roosting habitat (Fig. 2). To illustrate the importance of helping this species, just those living in the vicinity of San Antonio, Texas, consume approximately 500 tons of insects nightly.

WHAT BATS NEED

The Congress Avenue Bridge bats live in vertical crevices 16 inches deep by 3/4 to 1-1/2 inches wide between Texas Department of Transportation prestressed box beams. The massive concrete structures gather heat by day, radiating it by night, providing incubator-like conditions, usually between 87 and 92° F in summer. These are ideal conditions in which mother bats can rear young. However, even this bridge could have sheltered twice as many bats, at no extra cost, if more space had been left between some beams and less between others.

FIG. 2: Mexican free-tailed bats roosting between beams in Congress Avenue Bridge. Any vertical crevice in concrete, from 3/4 inch to 1-1/2 inches wide by 12 inches or more deep is likely to attract bats. Vertical holes 2 to 6 inches in diameter and 12 to 24 inches deep simply attract different kinds of bats. The deepest holes or crevices are best.

A survey of 200 Texas bridges documents use of 12 percent by bats, though most provide far less shelter than is available under the Congress Avenue Bridge. All bridges surveyed that contained suitable crevices or covered-over drainage holes were occupied by bats, confirming the potential for use of appropriate bridge designs to replace lost habitat for Texas' declining bats.

Locations over rivers are ideal for "bat friendly" bridge designs, both because they offer better protection from human disturbance and because bats prefer to live near rivers and lakes. Bridges even 10 feet above ground are suitable, but those allowing 20 feet or more are best. Any dark cavity in concrete that is out of reach of people and terrestrial predators may provide shelter for bats. Relatively rough surfaces are preferred, but the Congress Avenue Bridge bats are doing fine on prestressed box beams that are quite smooth, and others climb into covered over, rusty drain pipes to roost on concrete plugs at the tops. Metal is not usually suitable for bats to roost on. As an excellent heat conductor, it does not provide stable temperatures.

HOW TO HELP THEM

Some existing bridge designs, such as the one at Congress Avenue, are already suitable for bats if the box beams are properly spaced. However, it is likely that equal or even better habitat could be built into bridges of the future if bats are considered in early planning stages of new designs. What they need is fairly simple. The challenge is to provide it without excessive cost. Experts at Bat Conservation International are always willing to help ([512] 327-9721; P.O. Box 162603, Austin, TX 78716).

In some cases, habitat can be created with minimal expense through retrofitting. Almost any material that can be attached to the surface of concrete support structures under bridges could be used to create protected spaces and habitat. The spaces ideally should form crevices 3/4 to 1-1/2 inches wide. Their depth and length can be anything from one to many feet long and deep.

MEDIA AND PUBLIC RESPONSES

The initial response in Austin was panic and fear that bats were dangerous. However, as people have learned the truth about bats, fear has given way to wide appreciation. Many originally feared that most bats were rabid and would attack, yet even the few that become sick typically bite only in self-defense if handled, and no attacks have occurred. Honeybee stings, dog attacks, auto accidents with deer, and food poisoning at picnics all are vastly more dangerous in terms of human mortality.

The Congress Avenue Bridge bats are now one of Austin's most popular tourist attractions (Fig. 3). In fact, Austin has become nationally famous as a result of highly laudatory articles featuring its bats in ***The New Yorker, The New York Times,*** and numerous other prestigious publications, not to mention national television news coverage on NBC, ABC, CBS, and CNN. We live in a time when far too many people are fighting about the environment instead of working together to find solutions. Creating wildlife habitat as a part of progress has a great deal of appeal, not to mention the documented ecological and economic benefits. "Bat friendly" bridges can be a big winner for everyone.

EDITOR'S NOTE

Dr. Tuttle presented this paper at the recent TxDOT Bridge Designers' Conference. Video tapes of the conference will soon be available from the RTT Library. (See "Bridge Designers' Conference Tackles Significant Questions," page 14.)

FIG. 3: Tourists watch the bats fly from Austin's Congress Avenue Bridge.

RECYCLING CAMPAIGN UNDERWAY AT TXDOT

Who can help improve environmental quality? Who can make a difference? Who can make TxDOT a leader in recycling and in using recycled products? The answer to all these questions is you! TxDOT kicked off its recycling campaign in January, and this effort needs your support.

Landfill space and natural resources, like oil and trees, are decreasing, and air and water pollution are increasing. People in today's world must start recycling and becoming environmentally aware. If society disregards efforts to recycle, quality of life for every creature on the planet will slip.

It's easy to think someone else will help, that one person's actions don't matter. That's a mistake. It doesn't take much effort to make small, positive changes in the environment and, with the help of almost 15,000 cooperating coworkers at TxDOT, small efforts will add up to big improvements in the environment. You can recycle in your office, at your cafeteria, on the roadway, in the maintenance of your fleet, and around the grounds of your office complex. ***The TxDOT Recycling and Recycled Products Manual*** has useful suggestions on how to support recycling in all these areas. Each district and division has a recycling coordinator, and each coordinator has a copy of this manual. (See Tables 1 & 2.)

Why recycle? Six good reasons are to:

- **Aid Conservation** — Recycling and using recycled products saves energy, natural resources, and landfill space.
- **Save Money** — Recycled products are often less expensive than their virgin alternatives. Another sort of example is in-place recycling of asphalt pavement, which not only reduces the need for virgin asphalt and aggregate, but also saves the expense of labor and equipment to haul away milled pavement tailings.
- **Improve Operation Efficiency** — The amount of waste generated by an organization and its operating efficiency correlate: the less waste, the greater the efficiency.
- **Support Department Vision** — Recycling supports the department's vision and compliments the Continuous Improvement philosophy of working smarter.
- **Gain Personal Satisfaction** — People feel good when they realize their actions improve the quality of the environment and the world they leave for future generations.
- **Fulfill Legal Requirements** — State and federal laws, like the Clean Air Act, require types of recycling and environmental protection.

During 1993, Austin TxDOT employees (divisions and Austin District) recycled 231 tons of white office paper. Diverting this paper from landfill saves 762 cubic yards of space (the equivalent of 127 six-yard dump trucks). These savings are a great start. TxDOT kicked off its official recycling campaign in January

Table 1: District recycling coordinators

DISTRICT	NAME	PHONE
Abilene	Allen Morgan	(915) 676-6870
Amarillo	Jimmy Jones	(806) 356-3300
Atlanta	Lowell Revalee	(903) 799-1380
Austin	David McHugh	(512) 832-7043
Beaumont	Vickie Duke	(409) 898-5764
Brownwood	Earla Pallette	(915) 643-0431
Bryan	Lonnie Brothers	(409) 778-9737
Childress	Ross Butler	(817) 937-2571
Corpus Christi	Ella Mason	(512) 808-2276
Dallas	Teresa Maurer	(214) 320-6296
El Paso	Don L. Denham	(915) 774-4206
Fort Worth	Glenn Elliott	(817) 370-6522
Houston	Sherry Randall	(713) 802-5353
Laredo		
Lubbock	Woody Marcy	(806) 748-4423
Lufkin	Hal D. Hubbard	(409) 633-4340
Odessa	Glen W. Larum	(915) 333-9246
Paris	Ed White	(903) 737-9359
Pharr	Danny Espinoza	(210) 702-6126
San Angelo	Michael Decker	(915) 659-0246
San Antonio	Wilbert W. Moore	(210) 615-5957
Tyler	Milton O. Hopson	(903) 510-9238
Waco	Bruce Baker	(817) 867-2850
Wichita Falls	Jim Pierson	(817) 720-7777
Yoakum	Maynard J. Wagner	(512) 293-4350

Table 2: Division recycling coordinators

DIVISION	NAME	PHONE
Audit Office (AUD)	Terri Sullivan	(512) 463-8636
Aviation (AVN)	Susan Page	(512) 476-9262
Budget and Finance (BUD)	Sylvia Antle	(512) 463-8684
Continuous Improvement (CIO)	Kim Vencill	(512) 463-6640
Civil Rights (CIV)	Jean Renner	(512) 475-3116
Construction and Maintenance (CMD)	Don Woods	(512) 416-2541
Central Permit Office (CPO)	Chuck Bennett	(512) 465-1783
Design (DES)	Geneva Bass	(512) 416-2175
Environmental Affairs (EAD)	Don Hill	(512) 416-3009
Gulf Intracoastal Waterway, Office of (GIW)	Joann Riester	(512) 467-3793
General Services (GSD)	Mike McAndrew	(512) 416-2418
Human Resources (HRD)	Ron Petter	(512) 483-3634
Information Resource Manager (IRM)	Birdie Legge	(512) 475-0712
Internal Relations Office (IRO)	Deliah Nuñez	(512) 475-0716
Information Systems (ISD)	Doug Liberty	(512) 465-7546
Legislative Affiars Office (LAO)	Tonia Norman	(512) 463-9957
Materials and Tests (MAT)	Laura Benningfield	(512) 465-7677
Motor Vehicle (MVD)	Crystal Hansen	(512) 476-3618
Occupational Safety (OCC)	Toni Luther	(512) 416-3390
General Counsel, Office of (OGC)	Diane Northam	(512) 463-8630
Public Information Office (PIO)	Jeff Carmack	(512) 463-8612
Public Transportation (PTN)	Todd Hemingson	(512) 483-3653
Right of Way (ROW)	Jimmy Perry	(512) 416-2874
Research and Technology Transfer, Office of (RTT)	Tom Elliott	(512) 465-7908
Motorist Services (MSS)	Lori Crowson	(512) 305-9507
Staff Services (STF)	Ruth M. Frost	(512) 463-8660
Transportation Planning and Programming (TPP)	Ben Dobias	(512) 465-7938
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Travel and Information (TRV)	Valerie Davis	(512) 467-5948
Vehicle Titles and Registration (VTR)	Janet Vorwerk	(512) 465-7641

1994, so let's show a hefty increase in recycling in 1994! Already since the kickoff, TxDOT's General Service Division (GSD) has implemented a white office paper recycling program so that all districts will have an opportunity to recycle. Lubbock, Amarillo, San Angelo, Odessa, Brownwood, Childress, El Paso, Tyler, Paris, Atlanta, Beaumont, Yoakum, and Pharr are participating in GSD's very innovative setup. Other districts with major urban areas may be participating in existing local recycling programs.

Change the environment for the better. Be efficient, responsible, competitive; make a difference — recycle! *If you have questions or ideas regarding recycling, please contact your recycling coordinator.*

The mentioning of brand names is strictly for informational purposes and does not imply endorsement or advertisement of a particular product by the Texas Department of Transportation.

TQ's paper includes 20% post consumer waste in the total fiber content.

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CAN BIOENGINEERING HELP YOU BALANCE YOUR ENGINEERING AND ENVIRONMENTAL NEEDS?

by **Tom Bruechert**
Water Quality Specialist
TxDOT Environmental Affairs Division

In order to provide safe highways and roads, we find ourselves crossing various terrain. Many areas like wetlands, stream crossings, and channel realignments are either regulated or require unique attention and consideration from an environmental standpoint. To this end, federal law and state agency agreements require the Texas Department of Transportation (TxDOT) to avoid, minimize, and/or mitigate for these impacted areas. In an attempt to minimize impacts as much as possible, TxDOT's Environmental Affairs Division (EAD) pursued information relating to bioengineering techniques. In this article, we'll be discussing bioengineering, a field that uses vegetation systems to resolve conflicts between engineering project stabilization needs and environmental requirements.

Bioengineering, as an idea, is not new. Julius Caesar's engineers stabilized earthworks with facines, a type of contour wattling made from bundles of sticks interwoven with vines and placed in shallow contour trenches on a slope. Practiced in the U. S. until around the 1930's, soil bioengineering fell from grace with the evolution of today's standard reinforced concrete and reinforced earth engineering practices. Bioengineering is not a cure all. For instance, it does not use hard mechanical structural elements like concrete walls; therefore, it cannot be used for stabilization deeper than about 5 feet. However, many practical construction solutions may involve a combination of structural and bioengineering techniques.

Bioengineering techniques fall under one or a combination of three main headings:

- seeding
- live transplant (plugs, "live stakes")
- engineered vegetative methods (coconut fiber rolls, willow twig gabions, brush layers, wattling, herbaceous blankets, etc.)

The EAD is looking at bioengineering as an alternative to solid concrete riprap for stream channelization and embankment stabilization in sensitive areas. Also, the EAD hopes to use bioengineering techniques to restore wetlands or mitigate the damage to wetlands done by highway construction.

Figure 1 shows a typical combination of soil bioengineering used to promote wetlands growth. Live willow stakes might be used instead of the wood stakes. The stream bed could be stabilized with an herbaceous blanket, which is like sodding for underwater use. The herbaceous blanket might have to be mowed every two years or so in low volume streams, but concrete channel lining is by no means maintenance-free, either.

Simple bioengineering (only) techniques can be designed in-house for streams with low gradients and a flow velocity of 4 fps maximum. Plant selection and site specific characteristics are critical for any bioengineering design to be successful. Combining the engineering disciplines may provide alternative solutions to more complex stream segments and cross-sections.

The advantages of bioengineering are: low material cost, habitat creation, aesthetic appeal, less site disturbance, a "flexible" solution, and difficult site access. It minimizes slope erosion (Figs. 2 & 3) by:

- directly intercepting rainfall and promoting good infiltration,
- slowing surface water flow and filtering the soil from this runoff,
- binding soil particles in root systems.

Disadvantages include: labor-intensive installation, less control with more risk, increased maintenance and monitoring, and critical timing factor for planting. Despite these disadvantages there is a time and place when and where bioengineering and/or the combination of disciplines can be a very intelligent and practical solution.

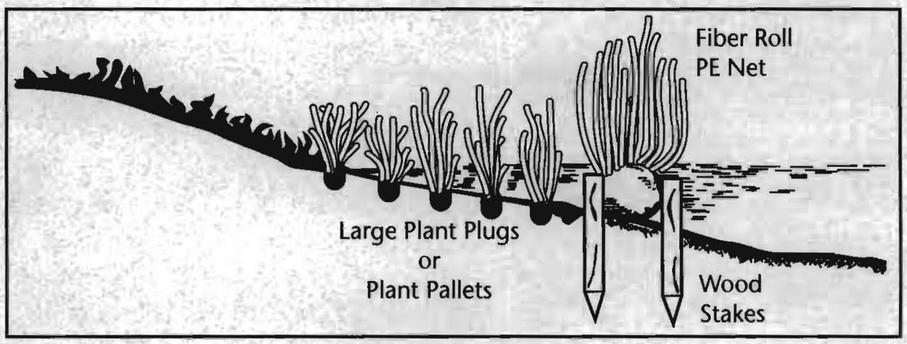


FIG. 1: A bioengineering design for stream velocities of less than 8 feet per second and a bank slope of less than 1:2.

Only through experience can the department realize the potential that bioengineering presents as environmentally friendly, economically feasible, practical solution to various specific areas where habitat and money are critical factors.

EDITOR'S NOTE

This article resulted from a course Tom Bruechert attended at N. J. Cook College. For more information, contact Mr. Bruechert, Water Quality Specialist, EAD, at (512) 416-2735.

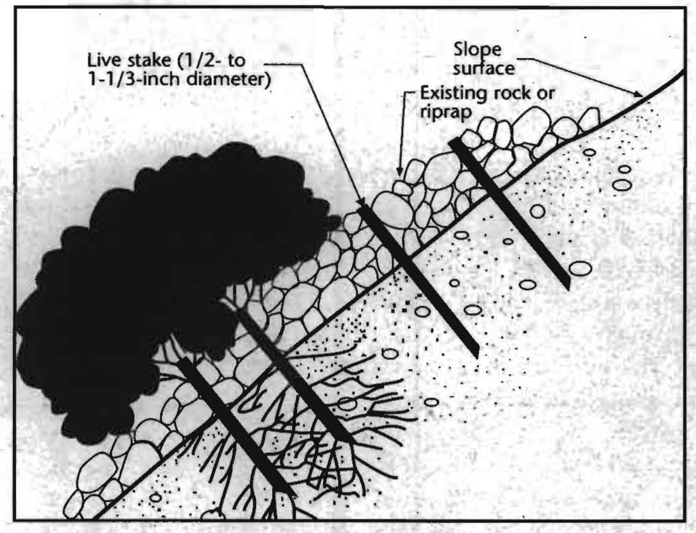


FIG. 3: An upland slope design for erosion protection showing joint planting details. The rooted and leafed condition of the living plant material does not represent conditions at time of installation.

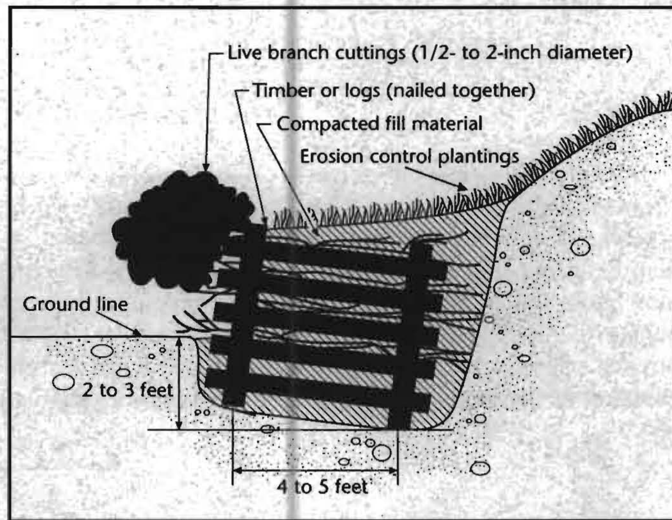


FIG. 4: Live cribwall details for upland slope protection. The rooted and leafed condition of the living plant material does not represent conditions at time of installation.

VINTAGE TROLLEY OPERATIONS

The streetcar has an honorable history in the United States and the world. Forty years ago, the once-common electric cars almost disappeared in America, but trolleys are making a major comeback as "light rapid transit." The new cars, with electronic controls and pantographs instead of trolley poles, bear little resemblance to the trolleys of the past. However, there are vintage trolley operations that celebrate the older form. ***Construction Costs and Operating Characteristics of Vintage Trolleys*** provides information on the old means of transport.

Vintage trolley operations come in several forms, ranging from restored antique trolleys that operate over existing freight or reclaimed streetcar track to trolley replicas running over newly constructed track. Some are regular transit operations. For example, the St. Charles Streetcar line in New Orleans is the oldest continuously operated streetcar line in the world. It offers and maintains vintage trolleys manufactured by Perley A. Thomas in 1923 and 1924. The streetcar tracks were originally laid in 1835 and electrified in 1893. Trolley operations that have acquired and restored genuine old trolley cars include the McKinney Avenue line in Dallas, the Detroit Citizens' Railway, Ft. Collins Municipal Railway, New Orleans Riverfront Streetcar line, the San Jose Transit Mall Vintage Trolley, and the Seattle Waterfront Streetcar. Vintage trolley systems in Denver, Galveston, and Portland operate replicas of turn-of-the-century trolleys. Miner Railcar Services, Inc., of New Castle, Pennsylvania, and Gomaco Trolley Company of Ida Grove, Iowa, manufacture these cars. Vintage car bodies and parts are hard to find. Europe provides a source of relatively complete vintage trolleys, and Melbourne, Australia, which is phasing out a series of cars built in the 1920s in favor of more modern equipment, is also a major source of vintage rolling stock.

The study provides basic information on each of the car lines. Capital costs of the systems vary substantially depending on whether new reproduction cars are purchased at $450,000 to $500,000 per car or restoration of antiques is possible. The refurbishment of the 35 vintage 1923 and 1924 Perley Thomas streetcars in New Orleans will cost approximately $275,000 per car. Construction of new track in the street where none had existed is extremely expensive. Seattle Metro's experience for a 0.4-mile extension of its waterfront streetcar was $15 million per mile. The resurrection of a former route with track in place, as in McKinney Avenue in Dallas, is considerably less expensive than construction of new tracks. Unfortunately, many trolley lines were in poor condition when abandoned, and the condition of the old track and location of the public utility distribution systems above and below the route will determine the cost. Utility relocation is a major cost item associated with both reclaimed and new track projects.

For more information contact Marta Jewell, KPMG Peat Marwick, 8150 Leesburg Pike, Suite 800, Vienna, Virginia 22182 (703-442-0030). The report (DOT-T-92-20) is available through the Technology Sharing Program, U.S. Department of Transportation, Washington, D.C. 20590.

Source: ***TRB Newsline*** 19(May 1993): 2.

BRIDGE DESIGNERS' CONFERENCE TACKLES SIGNIFICANT QUESTIONS

Design innovations, metrication, environmental issues, bats and bridges, project success stories, automated plan detailing, material research — these are a few of the topics covered during the Bridge Designers' Conference. Sponsored by the Design Division of the Texas Department of Transportation (TxDOT), the conference was held 8–10 February 1994. If you missed it, don't despair! The Travel and Information Division (TRV) videotaped the entire conference, and it will be available through the Research and Technology Transfer Office Library (RTT). The conference sessions will be listed in an upcoming Research Digest. Either fill out this request form when you see it or call Dana Herring, RTT Librarian, at (512) 465-7644, to order your loan copy of one or all the sessions. Here are some highlights from the sessions.

All plans must be in metric units in the 1996 lettings. Do you measure up? View *Metrication Issues — Update,* **Alan Matejowsky, P.E., Design Division.**

Texas is developing technology to optimize prestressed concrete design and construction using the new TxDOT U-beam with higher strength concrete and larger strands. For details of the first bridges incorporating economy, aestheics and high-tech materials, view *Extra High Strength Concrete — Louetta Road Overpass Project,* **Dr. Ramon Carrasquillo, P.E., UT at Austin, and Mary Lou Ralls, P.E., Design Division.**

Pondering PONTIS? Review *PONTIS — Prototype Bridge Management Program,* Don Harley, P.E., FHWA.

Worried about what to do with those county bridges in your district? Watch *Off-System Bridge Design Considerations,* **Lloyd Wolf, P.E., Design Division.**

Witness an example of the very latest in bridge design techniques. See *Innovative Segmental Bridge Design: US 183 Elevated in Austin,* **Dean Van Landuyt, P.E., Design Division.**

Want to know how a recent fatigue repair came in at 13 % under cost? Find out in *Current Steel Fatigue Repair, Projects,* **Gregg Freeby, P.E., Design Division.**

Concerned about use of consultants? Watch *Engineering Consultant Issues,* **Robert Wilson, P.E., Director Design Division.**

Why avoid using battered piling under abutment caps? Watch *Retaining Wall Details at Bridges,* **Greg Grusendorf, Design Division.**

Is the mystery of "walking" bearing pads about to be solved? See *Elastomeric Bearing Pads,* **Dr. Joseph Yura, P.E., UT at Austin.**

Learn how "low cost" and "beautiful" can describe the same structure! See *Precast Bridges — Economy and Aesthetics,* **Dr. John Breen, P.E., UT at Austin.**

Curious about the bat colony in the Congress Avenue Bridge? See *Bats and Bridges,* **Dr. Merlin Tuttle, Exec. Director, Bat Conservation International, Austin.** (Also, see *Bridges as Bat Habitats* by Dr. Tuttle in this issue of *TQ*.)

INVESTING IN INFRASTRUCTURE: WILL IT REALLY YIELD A MORE COMPETITIVE NATION?

by **David Gillen**

David Gillen has a joint appointment as Research Economist, ITS Berkeley, and Professor of Economics, Wilfrid Laurier University, Waterloo. He and ITS research Engineer Mark Hansen, an Assistant Professor at UC Berkeley, are attempting to determine what types of public investment are likely to have the greatest impact on growth of the economy.

The belief that public investment in infrastructure will beget economic growth is making a comeback in the United States. The Clinton administration's proposal for a substantial investment in infrastructure appears to enjoy widespread support from the public, despite opposition to the plan within Congress. Proponents of public investment in infrastructure contend it will move the country out of the lingering recession and help turn around the downward slide in productivity growth that began in approximately 1970 — just about the same time investment in public infrastructure also declined. A number of academics also argue that such spending will cure the malaise of the American economy.

This view contrasts sharply with the policy being followed in some other countries. In Canada, for example, the Royal Commission on National Passenger Transportation recently recommended against any large public investment in infrastructure at this time. One reason for the decision was the lack of any clear understanding of how such investment would lead to long-term economic growth and development. Instead, the Commission's recommendation was to first get the pricing of infrastructure right.

There is nothing new in the current clamor for greater public investment. It is an example of what some have termed the "grand transportation mystique": the belief (or hope) that investment in roads, bridges, airports, canals and harbors provides an elixir for economic ills that face a town, city, region or nation.

When community leaders are asked about the value of a proposed new road, airport or harbor, they typically use a standard economic impact study to project numbers of jobs created, tax revenue generated and income to be created. Such projections are said to show what a big contribution public investment makes to the local economy. However, standard economic impact studies usually stress employment and purchases during construction, which undoubtedly represent a "shot in the arm" for the economy in the short term. The typical studies say nothing about long-term assistance to the economy and ignore the alternative investment opportunities that are lost. Often the jobs in transit systems or airports once built are counted as benefits while, in fact, they are costs to be paid and not a measure of the contribution of infrastructure to growth and development.

No one would deny that investment in transportation and other public infrastructure can have some impact on private productivity, costs, profitability and economic growth. However, this has been a conclusion based on an intuitive acceptance rather than any clear or convincing analysis.

STATISTICAL CRUSADE?

Over the last five years, some researchers have been engaged in a "statistical crusade" to establish the relationship between public spending on infrastructure and private sector productivity. The result has been a voluminous literature. However, they simply have not been able to establish the linkage analytically. There certainly seems to be a relationship, but there has yet to be a clear statement of cause and effect.

Meanwhile, any public infrastructure investment strategy is an act of faith founded on the notion, "It has worked before but we do not understand how or why." Therefore, it is not possible to direct investment strategies to yield the highest return per dollar invested. Clearly, decision makers ought to have access to this type of analysis.

Growth in an economy depends upon its ability to be competitive in world markets and to have a rising level of productivity. Researchers have, therefore, made the public investment-productivity link the focus of their investigations. Almost every study has indicated that public capital investment makes a positive contribution to private productivity.

RETURN ON INVESTMENT

The results, however, have a wide variation. The 1988 paper which stimulated this literature claimed that the return on public capital exceeded the return on private capital by a factor of approximately three to four times; each $1 of public capital investment would lead to approximately 60 cents in additional output for the economy. Critics quickly pounced on this figure, claiming it too high. Volumes of paper emerged. Recently, a comprehensive review published by the Federal Highway Administration, which refined the estimate, states that there is a "weak positive effect on private economic *activity...*" (***Assessing the Relationship Between Transportation Infrastructure and Productivity,*** No. 4 in A Policy Discussion Series: U.S. Department of Transportation, 1990.)

Politicians may find it attractive to act on the "knowledge" that public investment in infrastructure will produce some increase in private productivity, however small it may be. But it is important to consider how many other things are changing in the economy.

The labor force is accommodating an increasing proportion of people who have less skill and experience and hence lower productivity. A greater focus upon the environment has diverted capital into pollution abatement, which means that productivity, traditionally measured, will be lower. Increasing public regulation of workplace and safety standards has raised the costs of production. A substantial increase in the proportion of Gross National Product (GNP) which is accounted for by services has led to perceived reductions in output because of erroneous measurement of services in GNP and problems of defining the output from some service industries. Private investment has been declining.

Further, if environmental improvements (achieved through private and public investment) were to be included in total infrastructure expenditure accounts, the sag in infrastructure investment may very well be open to question.

Although empirical studies have established a statistical relationship between private productivity and public investment, this does not provide us with any additional understanding of *how* the transportation infrastructure or other public investment affects private productivity: that is, what the mechanism is.

THE NEXT STEPS

We need to measure and identify the sources of productivity gain. The economic literature has indicated that technical advance is the source of productivity gain. But how does investment in core infrastructure lead to technical advance? There are a number of explanations to be explored. For example, has expansion of the highway system allowed firms to increase capital utilization with their ability to enter new markets or produce more products?

Certainly one of the issues confronting the analyst and policy maker is setting out precisely what "economic development" is. Building a road in some rural part of America, which allows local residents better access to shops, the homes of friends and relatives and to travel in general, is what these people view as economic development; the investment has made them better off than they would have been otherwise. Alternatively, economic development as measured by an increase in per capita income or per capita GNP is a much narrower and more easily measured concept Similarly, input measures must be more carefully defined. Expenditures on highways, for example, must distinguish new capacity from expenditures that fill potholes. The former activity increases the stock of capacity while the latter simply maintains the existing stock. It is also important to distinguish the type of highway invested in; a dollar spent on a two-lane secondary highway is not the same as a dollar spent on an interstate.

Answers to these questions do not lie with estimation of aggregate production functions but rather with a detailed analysis of industries within a given geographic region. If the interest is in how public investment affects a state, for example, the state must be viewed as a multiproduct organization within which public capital may affect different industries in different ways. What is most important is to distinguish between factors over which there is managerial control and those affected by public policy, such as public capital investment schemes. Knowing these things permits one to map productivity impacts from contextual and operational factors and use the results to devise our public investment strategies.

Ultimately the wealth-generating potential of the American economy rests with the productivity of its labor force. We can begin the process of establishing cause and effect by determining the direct and indirect impacts of public investment on the productivity of the labor force.

Currently, Mark Hansen and I are attempting to determine what types of public investment are likely to have the greatest impact on growth of the economy. A central focus in our study is to determine the impact on output if a state moves $1 from private capital spending to public capital spending and to learn what the effect will be of moving $1 from highway spending into some other type of public expenditure such as education. In another study, we are examining how transit planning and transit spending affect the output of an urban area.

Source: ***ITS Review*** 16(May 1993): 2-3.

TQ STARTS NEW SERIES

A new focus on Intelligent Vehicle Highway Systems (IVHS), research for traffic operations and management systems, and one of the four new IVHS Center's of Research established at the Texas Transportation Institute (TTI) makes Texas a U.S. leader in research of advanced technologies for transportation. A new Traffic Management System in San Antonio will rely on sophisticated sensor systems, fiberoptics, video imaging, and advanced software programs to collect real-time traffic data and other important operational information. As a supporter of new research ideas and innovative solutions such as these, the Texas Department of Transportation (TxDOT) has always been instrumental in the technological growth of the transportation industry.

At the same time, as we move into the 21st century, demands on and costs of our infrastucture will continue to rise, and TxDOT can maximize resources by continuing to support advanced automation in other transportation areas, such as the construction, maintenance, and inspection (CMI) of our roads and bridges. Integration and implementation of robotic technology has the potential to facilitate an even safer, more efficient, and more economical environment for CMI employees and the general public. With this in mind, the *Technical Quarterly* begins a 1994 series of articles dealing with the area of automation, also referred to as robotics, for CMI of transportation infrastructure. Specifically, *TQ* will highlight current research, operational and economic issues, available robotics technology and automation solutions identified as potentially beneficial to Texas highway CMI.

ROBOTICS OR AUTOMATION — SO WHAT'S IN A NAME?

by **Kelly West**
Research Associate, TTI Communications
Texas Transportation Institute
Texas A&M University

When people hear the word 'automation,' they usually think first of things like Henry Ford's assembly line, machine-operated mass production, or even the invention of steam shovels, cement mixing trucks, bulldozers, cranes and tractors. In fact, much of this automatic mechanization is largely responsible for the progress of and benefits received from the twentieth-century manufacturing, farming, defense, energy and construction industries, as well as for the completion of the U.S. highway system. However, as computer costs decrease, and electronic sensor systems become more sophisticated, automation of highway construction, maintenance, and inspection tasks is internationally evolving into the area of advanced electronic technology called robotics.

The Robotics Industry Association (RIA) defines the robot as "a reprogrammable multifunctional machine designed to manipulate parts, tools, or specialized devices through variable programmed motion for the performance of a variety of tasks" [Ref. 1]. In its most advanced form, an autonomous robot working in highway CMI may evoke futuristic visions of RoboCop leaning on a shovel or Rosie from The Jetsons waving a flag [Ref. 2]. While multifunctional robots like these do exist and have been used in building construction, firefighting, and underwater inspection, the most immediate potential TxDOT applications of robotics and automation solutions to CMI tasks are advanced single-purpose devices operating from some sort of shared control (teleoperative or remote) with a human [Ref. 1].

For example, instead of sitting on the back of mower in the hot sun, an employee could sit in the shade and monitor a robot lawn-mower with an omnidirectional vision system that steers the mower by detecting the line between cut and uncut grass and uses ultrasonics for obstacle detection [Ref. 1]. Rather than sending four men to drill pavement cores for density testing of concrete during construction, two could operate the Ground Penetrating Radar device and obtain triple the number of readings at half the cost. Instead of sending a man with a shovel into a culvert for clean out, he could operate a remote-control device that crawls through the culvert with a pressure hose and a scoop, 'looking' for debris with its radar/laser vision. Instead of hanging precariously over the back of a pick-up to place cones for a work zone, a worker could simply operate an automatic cone placement and retrieval device from the bed or cab of the truck [Ref. 3].

As automation technology grows, so do the connotations of the word. And as transportation CMI strives toward automation solutions by integrating available robotic techniques, the terms 'automation' and 'robotics' become interchangeable — to mean the use of any new or innovative, electromechanical, reprogrammable technology that offers a savings in construction and maintenance costs, an improvement in productivity and performance, or an increase in safety for the motoring public and TxDOT workers.

CMI AUTOMATION IN TEXAS

Through close coordination with TxDOT personnel and Sandia National Laboratories, Texas Transportation Institute (TTI) Research Engineers Walter Boles and Don Maxwell of the Construction Automation and Robotics Laboratory (CARL) at Texas A & M University developed an implementation process model for robotic applications in TxDOT's construction, maintenance, and inspection (CMI) programs [Ref. 3]. Working through the first two phases in the process model, the researchers then identified five potential "robot friendly" CMI applications that are worthy of conceptual design and economic feasibility studies. Ultimately, the research in Study 0-1440 revealed an exciting variety of currently available and promising new technologies for future automation in CMI problem areas.

The Process Model: How and Why?

The six-phase research and development process works from concept initiation to field implementation:

1. Identify potential application areas and alternative approaches.
2. Screen out operationally unfeasible applications (subjective filters).
3. Screen out uneconomic applications (objective filters).
4. Develop and lab test pathfinder designs.
5. Develop and field test prototype designs.
6. Manufacture, train, and implement the final product in the field.

A systematic strategy that increases successful field implementation of usable hardware involves first deciding which CMI tasks and areas actually present problems that could be solved with robotic technology, and then determining exactly which devices or systems will most likely work and how — all prior to prototype development. The model progressively incorporates this "pre-prototype" research in phases two and four, subjective filters and pathfinders.

Subjective filtering is a process of elimination that operates through input from three important groups — management and design engineers, field personnel and end-users, and technology experts. In brainstorming sessions, working meetings, and interviews, the three groups can build a consensus about which robotic technology could be implemented at a reduced risk and cost. First, management must clearly define problems that are of concern to TxDOT. Design engineers confirm the technical feasibility of a robotic application solving the problem. Field personnel, often as end-users most affected by automation, must address important operational issues such as equipment needs and set-up times, effects of the potential robotic application on other tasks or operations, and possible logistic problems in overall operations. The information from these groups then plays an important role in the assessments conducted by the technology experts as they address the key question — "What exactly is out there that could be adopted, modified, and applied to the specific CMI task ?" If an application passes through all three groups and a relatively feasible automation solution is identified, it then qualifies for the objective filtering phase, which examines the economic feasibility of conceptual designs.

After passing the objective filters, and before prototype development, the model advocates an interim phase — pathfinder development and testing. This involves the detailed design and construction of laboratory test platforms where candidate technologies are compared, different technological options are investigated for incorporation into the prototype, and performance estimates from the economic feasibility phase are adjusted to experimental results.

Why not just approach the implementation process of robotic technology traditionally, with economic feasibility followed by prototype development and field tests? The answer involves the interaction of a multifarious technology and its potential users. According to Dr. Walter Boles, Assistant Professor of Civil Engineering responsible for running CARL at TAMU, and one of the researchers who developed the model, "A wealth of advanced technology is already out there in the defense, energy, manufacturing, and construction industries. In many cases we just need to modify an existing device or integrate robotic characteristics into existing hardware so it's operational in a highway CMI environment."

For example, most commercially available underwater inspection robots that use video for navigation and inspection are not designed for turbulent or black waters precisely the condition in which many roadway structures need to be checked for scour and corrosion [Ref. 3]. As currently built, these robotic divers cannot be used in the very situations that are most dangerous to human bridge inspectors. To increase safety of human divers, possible robotic modifications include incorporating anchors, thrusters, or structure-grabbing devices, and such nondestructive testing techniques as ground penetrating radar, shaker excitation and monitoring, or acoustic response analysis into currently available teleoperated devices. Selecting which combination is most likely to work, from the perspective of both management and field personnel (subjective filters), is an important first step before investment in actual economic feasibility studies. "A pathfinder will allow researchers to actually try different things on a smaller scale in the lab. If we can detect major design or operational problems in a pathfinder, the prototype has a greater chance for a relatively low-cost, error-free field test, and then successful implementation," says Boles.

Another factor in deciding on a technology is user perception brought on by local geography; weather, landscape, and population conditions vary widely across Texas, making the CMI automation possibilities different for each TxDOT district. "It's very difficult to get a consensus of opinion about what robotics could do for specific CMI tasks." says TxDOT Research Engineer Tom Yarbrough, the study's technical chairman. Surveys of TxDOT personnel confirmed this.

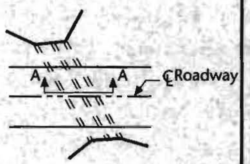
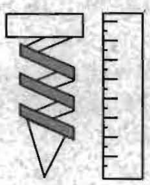
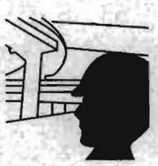
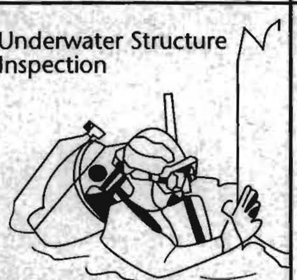
For example, many urbanites were very enthusiastic about the possibility of using the automatic cone-placing device to increase worker safety and save time, whereas some rural districts had no concern about manual cone placement because of low traffic. Culverts in districts with little vegetation have a tendency to fill up with silt, thus requiring more rigorous inspection and clean-out. Personnel from these areas obviously saw more potential benefit in a possible robotic solution than those where vegetation around the culvert opening prevents the clogs [Ref. 3]. The six-phase systematic research and development model, allowing multiple levels of feasibility research through subjective filtering and pathfinder development, makes room for these differing technologies, opinions and needs to all play a part in cost-effective, successful robotic hardware development and implementation in TxDOT's CMI programs.

PROMISING ROBOTIC TECHNOLOGY FOR CMI

According to the most recent published proceedings of the International Symposium on Automation and Robotics in Construction (Vols. 8-10), Japan and Germany are leading hardware development and field testing of robotic construction technology. In fact, over the last three years, the number of U.S. hardware-related studies has actually decreased, while theoretical studies (rarely leading to actual prototype testing) have increased [Ref. 3]. With the systematic process model described above, and the ultimate goal of actual robotic hardware implementation, TTI researchers working on Study 0-1440 have put the U.S. one step closer to catching up.

Several potential robotic applications and available technologies were identified and are highlighted in Table 1 along with other CMI automation technologies that TxDOT is currently investigating. Upcoming articles will focus in detail on TxDOT's current and promising automation research and hardware development efforts toward robotic applications in the transportation CMI environment.

TABLE 1: Potential automation solutions to TxDOT construction, maintenance, and inspection applications.

APPLICATION	AVAILABLE TECHNOLOGY	POTENTIAL BENEFIT
Culvert Clean-out and Inspection 	•Teleoperated pipe crawling robots for tight places. •Moveable robotic arm with a scoop/shovel, water-jet, rotary pipe cleaner, and saw for clean-out. •Laser profiling and ruggedized video systems for optical inspection •Ultrasonics or ground penetrating radar for soil condition inspection.	•Increased safety •Increased accuracy of inspection and ease of clean-out •Reduced cost
Drilled Shaft Inspection and Measurement 	•Video camera and recorder for belled shafts and complete record of inspection. •Scanning laser or ultrasonics for quantitative records of the shaft profile. •Sonar listening sensors with a single pinger for slurry-filled holes.	•Permanent record of inspections •Quantitative maps of the shaft
Nondestructive Pavement Testing and Management 	•Ground Penetrating Radar •Magnetic technology •Vibration and radiological emission techniques •Digital video image processing system for automatic interpretation of pavement distress data •Spectral analysis of surface waves •Automatic crack sealing device	•Increased accuracy and coverage •Increased speed and safety •Decreased labor intesity
Work Zone Safety 	•Commercially available "Cone Wheel" for automatic placement and retrieval of work zone cones. •Robotic line painting and marker placing devices •Automated traffic signals and changeable message signs •IVHS technology that gives drivers in-vehicle warnings of pending work zones.	•Increased worker safety and efficiency.
Underwater Structure Inspection 	•Commercially available underwater inspection robots (remotely operated vehicles: ROV); •Acoustic surface imaging; •Robotic test probe to check foundation soil conditions; •Ground Penetrating Radar, shaker excitation and monitoring, and acoustic response analysis for nondestructive testing of the structure's parts or whole.	•Increased safety for inspectors •More detailed data measurements •Increased accuracy and coverage of the inspections.

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2. Boles, Walter W. Interview with author. December 7, 1993.

3. Boles, Walter W., et al. Applications of Robotics and Other Automated Techniques to the Construction, Maintenance, and Inspection of Highway Systems. TTI Research Report 1440-1F. Texas Transportation Institute, The Texas A&M University System: College Station, TX. November 1993.

TTI DESIGNATED AS CENTER OF EXCELLENCE IN EMERGING FIELD OF IVHS RESEARCH

The Texas Transportation Institute at Texas A&M University has been designated by the Federal Highway Administration as a Research Center of Excellence for Intelligent Vehicle Highway Systems (IVHS). The contract establishing the new center could add at least $6 million to TTI's research program over the next five years.

IVHS — one of the fastest-growing areas of research in the transportation industry — applies state-of-the-art communication and computer technologies to help solve the nation's growing mobility problems. Recent federal legislation called for extensive research in IVHS as part of a mandate to improve the nation's transportation network.

More than $100 billion has been spent developing that network, and the growing cost of maintaining it — coupled with environmental concerns — requires that our existing transportation systems work more efficiently.

"We can't simply build our way out of our current problem," says Raymond Krammes, the Center's director. "IVHS is part of a logical evolution. Once you've got a transportation system in place, the objective should be to use that system to its greatest potential, at the lowest possible societal and environmental cost."

Researchers will pursue that goal through their work in three main areas:

- **Public Transportation Services:** using IVHS technologies to make public transportation services more efficient and cost-effective as well as more convenient, reliable, and safe and, therefore, more attractive to travelers.
- **Traffic Management Services:** developing real-time traffic information systems which combine surveillance, communications, data processing and navigation/guidance technologies.
- **International Border Transportation Services:** developing IVHS systems which will expedite the movement of commercial vehicles along the U.S./Mexico border.

In addition, researchers will focus on institutional and nontechnical issues related to the IVHS movement, as well as technology integration issues such as computer modeling, database management and software design.

The new center will be supported by a federal research contract worth $1 million per year for a minimum of two years and a maximum of five years. The Texas Department of Transportation, the Metropolitan Transit Authority of Harris County, the Dallas Area Rapid Transit Authority, TTI and Condition Monitoring Systems of Long Beach, California, will provide matching funds, bringing the Center's first year budget to a total of $1.95 million.

TTI's application was supported by several transit agencies and the departments of transportation from Oklahoma, Arkansas, Louisiana and New Mexico. Both the Sandia and Los Alamos National Laboratories — as well as more than 20 cities and counties — have given their support to the TTI IVHS Center as well. In addition, nearly a dozen corporations have pledged their support. The complexity and financial expense associated with the nation's transportation problems makes this combination of public and private-sector sponsors necessary, Krammes says, and TTI's ability to bring these groups together helped ensure a successful proposal.

"IVHS is a key element in the future of transportation in the United States," Krammes says, "and our designation as one of three national centers of excellence places TTI and the state of Texas among the leaders who will shape that future."

TTI is the largest university-based transportation research agency in the United States. The Institute is an official research agency of the Texas Department of Transportation, and also performs research for federal agencies, state departments of transportation and a variety of other public and private-sector sponsors.

For more information, call Bernie Fette, TTI Communications, 409-845-2623.

LEADERSHIP IN THE WORK PLACE

by **Thomas R. Elliott, Jr., LTC, (Ret.)**
Research and Technology
Transfer Office
Texas Department of Transportation

Recently, I attended a course at the training center. The instructor was a very experienced and knowledgeable person who had been with the Texas Department of Transportation for almost 30 years. The length of service in itself is not exceptional; his attitude toward change was. He was not afraid of necessary departmental changes. He understood that the department must change if it is to continue to be a model for the remainder of the nation's transportation departments. I was struck by the fact that if a man of this experience was not afraid of change, then the rest of us could learn from his wisdom. Throughout the week, he stressed communication as a key to managing change and to completing a project successfully. As the course progressed, I realized that he believed good communication was the basic ingredient for good management or supervision.

This idea lead me to review some of my own experience as a manager in the military; thoughts that might be useful to TxDOT managers, new or old, who are faced with building new teams of people.

In the military, during war or peace, the ingredient that is always a necessity for a successful operation is good leadership. The civilian work place is no exception to this rule. To manage or supervise is just another name for leadership.

The ability to lead people is easy for some, more difficult for others, but attainable by all. Some personalities are better suited to deal with people. These individuals seem to have the natural ability to lead, but a good leader relies on more than his or her personality. A good leader must understand and use some time-tested basic principles in leadership. Over the years, I have adopted seven rules that I try to incorporate into the leadership process. I will examine these seven rules, discuss their application, and outline the reasons for their application.

KNOW YOUR PEOPLE

To be an effective leader, you must be aware of anything that might disrupt the normal operation of your organization. Therefore, stay attuned to any problems that might be facing your employees. Both in the military and civilian work place, an employee is expected to leave his/her personal problems at home. Everyone knows this is almost impossible. If you, as a leader, are observant and have made the effort to familiarize yourself with your peoples' families and backgrounds, you will know when there is a problem. You must identify the problem early on and help solve it before it creates adverse job performance and/or additional personal problems for the individual. Showing concern and understanding at a critical time can make the difference between a good employee and a bad one. In most cases, when a person has a problem, it will involve his family in some way.

Your responsibility as a leader does not stop with the employee, but includes the welfare of his/her family. Your knowledge of agencies whose functions are designed to assist the individual and his family can be as important as any information you may possess.

AVOID MISUSE OR ABUSE OF PERSONNEL

As a leader you must be sensitive to, and intolerant of, employee misuse or abuse by anyone. Busy work to keep a person occupied is inexcusable and should not be allowed. Misuse of an individual is a sign of poor leadership and lack of organization. Too many important tasks go unaccomplished to allow any senseless misuse of time. Ensure that your employees' time is being efficiently used, accomplishing only those tasks that will fulfill the job requirements or improve the productivity of the person.

The prevention of abuse or harassment of individuals in your organization is a critical responsibility. If it happens, you must stop it and insure that it does not reoccur. Any action taken must be firm, fair, and timely. There will be situations when you must stand up and be counted. These times separate the good leaders from the mediocre. Self-interest has no place in the make-up of a good leader.

SEEK A BETTER WAY

We have all run into the old adages, "We tried that and it didn't work" or "We don't do it that way here." Because something has been done the same way for a long time does not make it the best way automatically. You must be receptive to new ideas and different ways of accomplishing old tasks. To be a successful leader, you must be innovative. A good leader must continually seek a better way. To lack imagination is to become stagnant.

DO NOT BE AFRAID TO FAIL

No one is perfect and a good leader is no exception. If you are afraid to make mistakes, then your subordinates will be afraid. This fear can hinder the learning process of your employees. It will suppress any initiative they may show. People learn from their mistakes, and if you as their leader are afraid of failure, it will reflect in your organization's performance. If a person is afraid to admit his/her own mistakes, that person is not to be trusted. Accepting responsibility for your actions is one of the most important character traits a good leader must possess and one of the most difficult to acquire.

REWARD ALL DESERVING ACTS

A person who does a good job should be rewarded. Do not let the word "reward" mislead you. A simple "pat on the back" at the right time may be more appreciated than any award. Too many people fail to understand that praise of a job well done means much to an individual. A good leader can not be afraid to express feelings of satisfaction. If your employees know that their leader is proud of them, then they in turn will be proud of themselves and their organization.

All deserving acts should be rewarded, but just as important are those acts that need to be corrected. Behavior that is unacceptable will not improve if allowed to continue. Consistent, firm, and fair discipline will encourage a poor employee to stay out of trouble. It will also ease peer pressure on a good employee to do something wrong. When high attainable standards are set by a leader, it creates a positive work environment for all members of the organization.

LEAD BY EXAMPLE

You can manage parts, but you must lead people. To lead people you must be willing to "lead by example," that is, to accept the same privation as your employees. Don't be afraid to get your hands dirty. When time permits, work along side your people, show them you can and will do what they are doing. Always, set the standard and be the example for your employees to emulate.

ENJOY YOUR WORK

If you do not like what you are doing, then it will be apparent to everyone around you. The attitude of an organization is a direct reflection of its leader's attitude. There is no training that can make job satisfaction a reality. It is something that has to come from within, but without true job satisfaction, good leadership will be an unattainable aspiration.

SUMMARY

There is no such thing as an expert on leadership, just as there are no born leaders. The ideas described in this paper have proven helpful to me over the years. They are not my ideas, but the ideas of many who have influenced my growth as a leader. I hope that one point has become obvious, you must care to be a good leader. This caring must be directed at both subordinates and superiors. Without caring, leadership is a hollow word. We can sit and reflect on our many successes and noteworthy theories on leadership; but until we face a decision that could adversely affect not only our people, but ourselves, are we truly going to appreciate how difficult it is to be a good leader.

FHWA EVOLVES AND CONTINUES SHRP ASPHALT LIBRARY

The Federal Highway Administration (FHWA) announces the opening and operation of the Long Term Pavement Performance Materials Reference Library (LTPP-MRL) located in Reno, Nevada. The facility and operation are a continuance and evolution of the SHRP Asphalt Library formally located in Austin, Texas.

The LTPP-MRL exists to obtain and maintain samples of representative aggregate and asphalt materials from throughout North America. Most of these materials are stored in environmentally controlled conditions to minimize possible changes in material properties. SHRP researchers completed extensive study on 33 asphalt materials and 11 aggregates to fully characterize these materials' engineering and chemical properties. The LTPP-MRL stores results of these tests on the MRL Database. Various SHRP reports also discuss these test results. (Most SHRP reports are available on loan from TxDOT's Research and Technology Transfer Library. Call Dana Herring, Librarian, at [512] 465-7644 or order the reports electronically through TTS.) Individuals and/or agencies interested in obtaining materials from the LTPP-MRL should contact the MRL at (702) 358-7574.

SHRP'S NEW WORK ZONE SAFETY DEVICES — THE INTRUSION ALARM

Maintenance workers and supervisors worry about safety continually. And it is no wonder. Sixty highway workers die on the job each year, according to the Federal Highway Administration (FHWA).

Our country's roads and bridges require an ever-increasing amount of maintenance activity and expenditure, and, at the same time, traffic levels continue to escalate. The combination is deadly.

Just how deadly was illustrated by an accident that occurred July 26, 1990, near Sutton, West Virginia. A tractor-trailer collided with two cars stopped for a work zone. The crash killed all eight occupants of the cars. Luckily, no maintenance workers were killed. As a result of the accident, the National Transportation Safety Board (NTSB) recommended that highway agencies provide audible warning devices — such as a horn — in work zones; and encouraged the use of other safety devices, such as rumble strips, to alert oncoming drivers.

These new measures are necessary because, as motorists encounter more and more work zones, they are becoming "numb" to the various warning signs used by highway agencies for so many years, especially when the work is close to home on the routes they drive "automatically" each day. Another problem is the exponential increase in the number of traffic jams caused by highway work, which makes motorists frustrated and angry. All this spells risk for highway workers.

To help make maintenance work safer, the Strategic Highway Research Program (SHRP) conducted a national design competition for new work zone safety devices (Project H-109). Ideas came from private industry, from transportation officials, and, perhaps most importantly, from maintenance worker themselves. Now, after more than 40 months of development and closed-track testing, many devices are ready for use.

INTRUSION ALARM BUYS TIME FOR WORKERS

Of all the new safety devices coming out of SHRP, the Infrared

Intrusion Alarm was rated tops by about 35 maintenance workers surveyed in Iowa, Michigan, and Oregon. The alarm works by sounding a loud (120-decibel) siren whenever a vehicle strays into a work zone, giving maintenance workers four to seven second warning to clear the work area.

Developed by Graham-Migletz Enterprises of Independence, Missouri, the alarm has three components:

- A detector with an infrared "eye;"
- An orange safety cone with a reflective sock; and
- A receiver with a siren.

This mostly solid-state detector weighs in at only 28 pounds. A worker can set it up in seconds. Placed at the edge of the road at the end of the work zone taper, the detector bounces its infrared beam off a reflective strip or sock on an orange safety cone placed on the opposite side of the closed lane. The detector communicates with the siren by radio so no wires are necessary. The siren is placed near maintenance workers. When an errant vehicle enters the closed lane and breaks the beam, the siren sounds. This lifesaving device costs about $4,000.

Source: SHRP's ***Product Alert*** 8(July 1992), as seen in ***The Northwest Technology Transfer Bulletin*** 38(Spring 1993): 1-2.

PATH TEAMS UP WITH IVHS AMERICA TO WIDEN ACCESS TO UNIQUE DATABASE

The California PATH Database — the world's most comprehensive database on Intelligent Vehicle/Highway Systems — is now accessible through IVHS America, the Washington, D.C.-based organization that promotes cooperative IVHS research.

COMPLETE IVHS STORY

The database, created by the library of the UC Institute of Transportation Studies in 1989 as a resource for the California PATH research program, contains more than 4,200 records.

Primarily based on the holdings of the ITS Library, the database covers all components of current IVHS research in the U.S., and also provides a strong historical perspective on the evolution of IVHS research and activity back to the 1930s. There is extensive coverage of European and Japanese IVHS research and demonstrations. Each database entry is fully abstracted and indexed. English-language abstracts are provided for entries from foreign language publications. ITS librarians add about 120 new abstracts each month.

Making the database available through IVHS America's National IVHS Information Clearinghouse should lead to greater use of the resource, according to ITS Head Librarian Michael Kleiber and IVHS America's Krystyna Vostrez, who started the Clearinghouse.

At the request of IVHS America, Kleiber demonstrated the database this spring at the annual meeting in Washington.

"We want to provide the IVHS community members and nonmembers — access to as much information as possible," Vostrez said. "We want to advance knowledge and research in this area."

HOW TO GAIN ACCESS

The PATH Database, copyrighted by the University of California at Berkeley, went on line in March as a separate file that can be called up by users of the IVHS Clearinghouse.

Users will need to obtain a copy of IVHS America "Reach" software and a password at a cost of $50 for nonmembers and $25 for members. They will require a modem to dial in and search the database, and there is an hourly charge for usage.

(PATH researchers and others who, ready have access to the database from the personal computers will not be affected.)

For more information about the IVHS Clearinghouse, write or fax Perry Carter at IVHS America, 1776 Massachusetts Ave., N.W., Suite 510, Washington, D.C. 200361993, Fax: (202) 296-5408.

Making the PATH Database available through other information services is being considered by ITS Berkeley and the California Department of Transportation, the two partners that started the PATH research program seven years ago. One possible approach, is to make the database available on Intern a network which supports a worldwide electronic mail system. Another option might be creating a CD-ROM file that could be distributed in association with the Transportation Research Board's TRIS-on-line service. Talks are still preliminary.

For more information on the PATH Database or connecting by modem or Internet the ITS Library's on-line catalog, write or fax Michael Kleiber at the ITS Library, 412 McLaughlin Hall, University of California, Berkeley, CA 94720, Fax: (510) 642-1246.

Source: ***ITS** (Institute of Transportation Studies) **Review*** 16(May 1993): 6.

TIME MANAGEMENT TIPS

- Ask yourself these three questions: What are my subordinates and I doing that doesn't need to be done? Does anyone really need to do these things? What an I doing that others could do?
- Send agendas before meetings. Attendees won't have to take meeting time to collect their thoughts on topics.
- Use travel time to plan, listen, study, review or write.

Source: *Communication Briefings*, "Time Management Tips," 1991.

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