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TECHNICAL QUARTERLY

AN EXCHANGE OF IDEAS
Editor:
Kathleen M. Jones

D-10 IMPLEMENTS THE TECHNOLOGY TRANSFER SYSTEM (TTS)

By Cindy King
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Today's technology is introducing and producing information, concepts and products at a rate far exceeding the highway industry's capacity to evaluate and to disseminate these innovations. The demand for more and better highways accompanied by spiralling costs, by ecological constraints, and by depletion of currently available resources makes the use of new products and concepts imperative.

Numerous new products and techniques are evaluated by Departmental personnel every year. However, there has been no organized method for recording and cataloging either the work done or the results obtained. The same effort is frequently duplicated, or the ideas remain localized instead of being made available for statewide use.

The Technology Transfer group has developed a variety of methods to serve as a link between the creators of ideas and techniques and the users. The most progressive is the recently released Technology Transfer System (TTS). TTS is an automated storage and retrieval system that allows keyword searching, on a personal computer or CRT terminal, of all of the materials contained in the Technology Transfer library. It provides the department with an organized method for monitoring, recording, cataloging, analyzing and disseminating technical information in a timely manner.

TTS was a pilot project for DISOSS, an IBM software program under evaluation by D-19. The T² group designed an easy-to-use format, and the automation division conducted extensive programming to produce the system. The result is an uncomplicated system that is

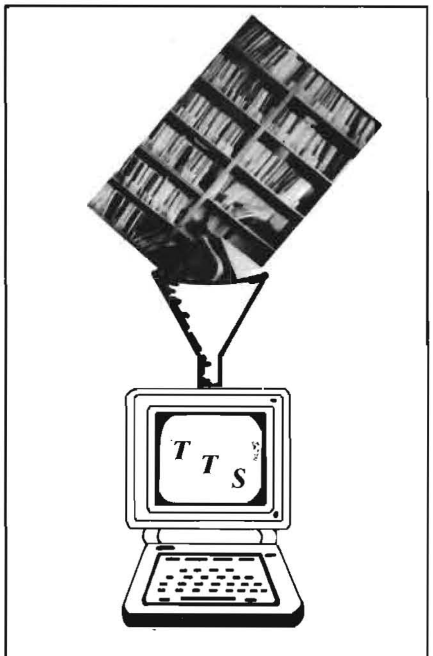

FIG.1: TTS automates the library.

INSIDE...

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suitable for everyone in the Department to use.

The TTS data base is divided into six classes of information:

1. *Reports* — Includes research reports, periodicals, proceedings, etc. from such sources as Center for Transportation Research (CTR), Texas Transportation Institute (TTI), SDHPT, other state DOTs, other countries, Transportation Research Board (TRB), Federal Highways Administration (FHWA), AASHTO, National Cooperative Highway Research Program (NCHRP), etc.

2. *FHWA Experimental Features* — Contains information on the location, date, and the nature of various experimental features being tested in the Districts under FHWA's Experimental Projects Program.

3. *Texas Research Studies* — Contains information on studies emanating from the Department's research program.

4. *Product/Equipment Evaluations* — Includes information on products and equipment which have been, or are being, evaluated by the Department's Product Evaluation Committee.

5. *Field Trials and Innovations* — Includes innovations developed in the districts, divisions or other states.

6. *Videotapes* — Includes over 300 technical videotapes which are contained in the Technology Transfer audio/visual library.

Each week the library receives between 100-150 items of technical information. Most of these documents are made available each week through the ***Research Digest***, an annotated bibliography. This technical information is available to the Department immediately because the information is input daily into TTS.

The system now contains 30,000 entries. Over the next 2 years it is estimated that the number will reach 50,000.

Departmentwide use of the system should provide some major benefits including:

- Elimination of duplicate field experimentation efforts.
- More effective use of technical information.
- More effective use of available manpower through wider use of innovations.
- Widespread, timely access to technical information.

For TTS to be successful as the Department's central source for technical information, input will be needed from the districts and divisions. For example, if all of the districts and divisions report all of their experiments, as well as the results obtained, to the system, much duplication of effort could be avoided. This would still allow the districts and divisions to retain their current freedom to experiment, while allowing them the opportunity to consider previous experience prior to any new work. With these new results available to the entire Department, the next experiment can be carried even further. To illustrate how the system can assist the Department's operations, the product LIGNOSITE was entered as a key word. The record indicated the following:

PRODUCT NAME: *LIGNOSITE*

MANUFACTURER'S NAME: *Georgia-Pacific Corp.*

PE#: *PE-233*

CONTACT: *D-10 Research*

BRIEF DESCRIPTION OF PRODUCT: Lignin, calcium lignosulfonate roadbinder, 50% solids. The product's primary use is for dust control on dirt or gravel roads; can also be used for soil stabilization prior to application of asphalt. Manufacturer claims product to be environmentally safe. Contact D-10R for Material Safety Data Sheet.

ABSTRACT: (from 17 Feb. 1987 letter from Sam Cox, District 21, to Wayne White, D-18): "About two years ago we began experimenting with Lignin Sulfite liquor to stabilize unpaved shoulders in all soil

TTS contains abstracts from each article of the following publications: **

**** Also contains various newsletters and incomplete sets of magazines.**

FIGURE 2: Magazine articles have individual abstracts.

types existing in the Lower Valley area. Results were good, but not lasting, since the glue [water-soluble tree sugar] leached out as rain occurred and sooner or later we were back where we started. We then blended lignin with MS-1 in equal volumes and enhanced the stabilization process as we waterproofed the treated material. Results have been excellent and long lasting, with some areas having performed very well for over a year. Prior to stabilizing we had to 'pull shoulders' on six week intervals and still had (at times) unsatisfactory pavement edge conditions."

TTS can be accessed through CICS. After log-on, simply type TTS and press "enter" to begin. Provided with help screen functions, the user is then guided through the steps of a search. The search generates a list of available documents from which the user may choose to view abstracts, to print abstracts, or to order associated material from the library.

Reports ordered on-line will normally be mailed within 48 hours of the request.

Following an initial introduction of the system to the Research and Development Committee, Districts 11, 14, 20 and 24 received "pilot" demonstrations. Approximately 90% of the participants have accessed the system.

There are plans to demonstrate the system in each district and many divisions over the next six months. However, immediate access to TTS can be gained through the use of a CICS key. To order a TTS videotape and/or handbook, contact Debbie Hall at 465-7684 or TEX-AN 241-7684.

UNWANTED PLASTIC COULD LOWER COST OF ROAD REPAIRS

Plastic soft drink bottles, a bane to landfills everywhere, might become a Texas money-maker, according to two University of Texas scientists. David Fowler and Don Paul want to recycle the bottles to make polymer concrete, a repair material for highways. Although polymer concrete has been used for almost 20 years, its many advantages have been obscured by its astronomical cost. Fowler, a civil engineer, and Paul, a chemical engineer, think the bottles could be cheap inspiration for a fledgling industry. They want to use the bottles to make the plastic resins that bind sand and gravel in polymer concrete. The bottles are accumulating because they are not biodegradable and, increasingly, are rejected by landfills. The UT-Austin engineers recently received $216,500 for three years of research into the recycling idea from the Texas Higher Education Coordinating Board.

Austin American-Statesman, *July 18, 1988.*

BRYAN DISTRICT'S FLOOD GAUGE

A flood gauge is a good supplement to the warning signs, "Water Crossing" (W8-13) and "Watch for Water on Road" (W8-15) at low water crossings and at low bridges where wet weather conditions often result in temporary ponding or flowing water on the roadway. Flood gauges give the motorist immediate information on how much water is actually on the road, so the motorist can decide if it is safe to cross. The "Flood Gauge" sign (D26), according to ***Texas 1980 Manual on Uniform Traffic Control Devices,*** should be 18 by 12 inches. The letters and border of the sign are black, and the background is white reflective material. Dimensions for the gauge itself are not described.

Bryan (District 17) is using their own design for a flood gauge (Fig. 1). The District's design calls for 4- by 8-foot plywood sheets which come with white engineer-grade reflectorized sheeting adhered to one side. Three 8-foot by 16-inch gauges can be made from one sheet of reflectorized plywood. Red lines are used to denote full-foot increments, blue lines for half-foot. The nighttime visibility of this type of gauge is excellent. By slightly modifying the "Flood Gauge" sign dimensions from 18 by 12 inches to 16 by 12 inches, the sign can be made as part of the top of the gauge.

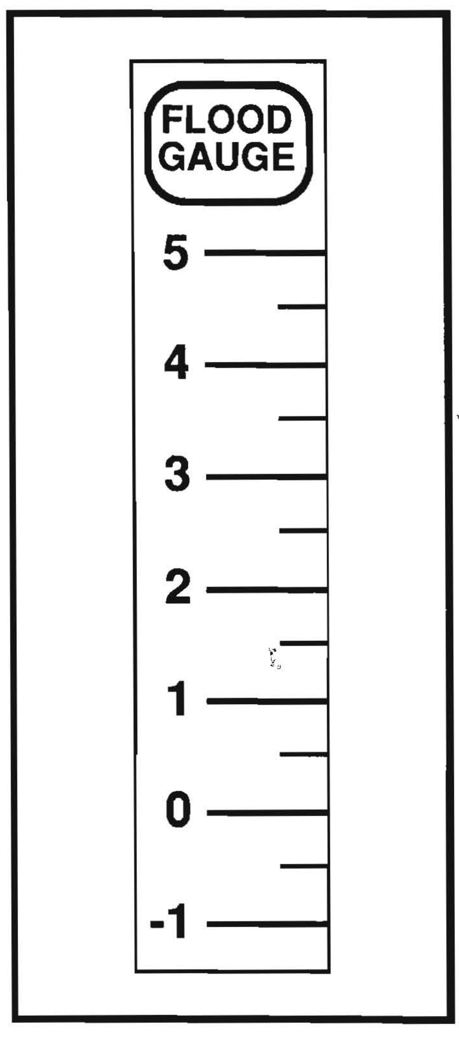

FIG. 1: Dst. 17's flood gauge.

VOIDS IN THE MINERAL AGGREGATE

Developing specifications that directly relate to pavement performance for asphalt concrete pavement quality control is an ongoing, difficult process. The percentage of voids in the mineral aggregate (VMA) is a compositional characteristic of asphalt mixtures which relates to pavement performance. Minimum VMA requirements for Texas mix types are being considered for inclusion in the 1990 ***Standard Specifications.***

WHAT IS VMA?

Voids in the mineral aggregate are the spaces that exist between the aggregate particles in a compacted asphalt/aggregate mixture. This volume includes both the spaces filled with asphalt and the actual air voids in the compacted mixture (Fig. 1). VMA represents the space that is available to accommodate the effective volume of asphalt, i.e., all of the asphalt, except the portion lost by absorption into the aggregate, and all of the volume of air voids necessary in the compacted mixture.

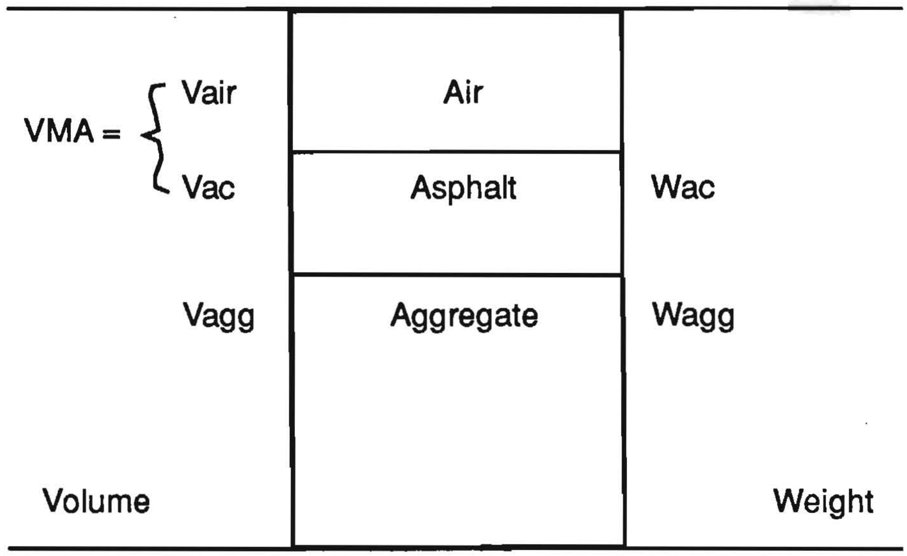

FIGURE 1: Relationship of VMA to total volume of compacted sample.

WHAT ARE THE BENEFITS OF SPECIFYING VMA?

The percentage of voids in the mineral aggregate relates directly to pavement durability. The greater the VMA in the dry aggregate, the greater space which is available for asphalt to coat the aggregate particles, while still leaving room for the optimum percentage of air voids. The thicker the asphalt film (up to the point where film thickness begins to interfere with stability by reducing the internal friction of aggregate interlock) the more protected the mix is from water damage. The primary advantage, though, is that thicker asphalt films mean slower oxidative aging of mixtures.

Specific minimum requirements for VMA are recommended and specified as a function of the aggregate size. Mixture types with larger aggregates have lower minimum VMA requirements. VMA values should be adhered to so that a durable asphalt film thickness can be achieved. Increasing the density of the gradation of the aggregate to a point where below minimum VMA values are obtained leads to thin films of asphalt and a dry-looking, low-durability mix. These mixtures will fatigue crack sooner than mixtures with thicker asphalt films. Therefore, economizing in asphalt content by lowering VMA can be counterproductive and can harm pavement quality.

HOW IS VMA CALCULATED?

VMA is the percentage by volume of air voids and asphalt cement in laboratory compacted mixtures. In mixtures containing absorptive aggregates, the volume of absorbed asphalt cement is not considered. The following formula is recommended until a VMA formula is officially included in Test Method Tex-207-F:

$$VMA = 100 - \frac{Ga \times W}{G}$$

where:

Ga = Average actual bulk specific gravity of three specimens compacted in accordance with Test Method Tex-206-F;

W = Percent by weight of aggregate in the compacted specimens;

G = Average bulk specific gravity (and apparent specific gravity for the aggregate finer than the No. 80 sieve) of the combined aggregate determined in accordance with Test Method Tex-201-F.

For more information, call Paul Krugler (D-9), (512) 465-7603, TEX-AN 241-7603.

PRODUCTION TESTING OF ASPHALTIC CONCRETE MIXTURES

by Paul E. Krugler, P.E.
Materials and Tests
Bituminous Engineer

Production testing of fresh hot-mix asphaltic concrete has a twofold purpose. The tests must reliably indicate the quality of the pavement being constructed; a quality control function. The tests must also indicate to the engineer when adjustments to the design are necessary; a production control function. The two functions are closely interrelated, and each is very important.

The quality and production control functions can be fulfilled only to the extent that the tests accurately measure mixture characteristics important to pavement performance. The ideal production testing program would include a separate test to directly measure each desired mixture characteristic. This is, of course, an impossibility. Mixture properties are interdependent, and current technology does not include many tests which directly measure desired asphaltic concrete properties. Therefore, it is our objective to select a group of production tests which, together, either directly or indirectly measure as many desired mixture characteristics as possible.

Production tests can be divided into two groups, qualitative and compositional. Qualitative tests are those designed to measure specific material characteristics necessary for the pavement structure to perform the design function.

Compositional tests, on the other hand, only determine the proportions of asphalt cement and aggregate size fractions in the mixture. Compositional test results are not measures of quality in themselves, but good quality is assumed when they closely match the mixture design. If qualitative tests could consistently and accurately measure all necessary characteristics for excellent pavement performance, perhaps compositional testing would not be needed. As this is not the case, a good production control testing program must include both qualitative and compositional tests. Our program includes laboratory density, Hveem stability, and pavement air voids testing as the predominant quality measurements. The extraction test is our primary compositional test procedure.

The following commentaries are offered on the mixture design and on mixture tests included in our Texas quality control program. These comments are to help less-experienced inspectors understand the values and limitations of the mixture design and the production tests, and how these tests relate to making plant adjustments.

Mixture Design: HMAC quality control begins with the mixture design. The laboratory work establishes both quality and physical characteristics of the individual aggregates. The laboratory mixes also estimate the mixture characteristics to be expected from plant-mixed materials.

FIG. 1: Aggregate sample for mix design.

Value of Mixture Design:

It determines if the proposed materials can be combined in a way to meet all specification requirements prior to plant start-up.

It establishes the "design," or job-mix-formula, for plant start-up.

It determines the adequacy of internal aggregate frictional characteristics of the proposed aggregate combination. This is determined at a range of asphalt contents so that sensitivity to asphalt content is seen.

It establishes individual aggregate and mixture specific gravities.

Limitations of the Mixture Design:

Not all quality characteristics can be measured because of technology limitations.

Gradations used in the design will not be completely representative of plant stockpile gradations.

Mixture temperature, mixing action, and aggregate moisture conditions differ between the plant and the laboratory. These differences explain the frequent need to adjust asphalt content after initial plant production. In fact, many make this adjustment prior to initial production, based on experience.

Laboratory Density: We rely on this test to indicate if the amount of asphalt cement in the mixture is correct for the proper ultimate pavement density. The gyratory compactor was designed to compact a mixture to the density that traffic will ultimately achieve on the road. Our optimum density of 96 percent (by Rice) or 97 percent (by our other methods) states our intent that our pavements never compact under traffic to less than about 4 percent air voids.

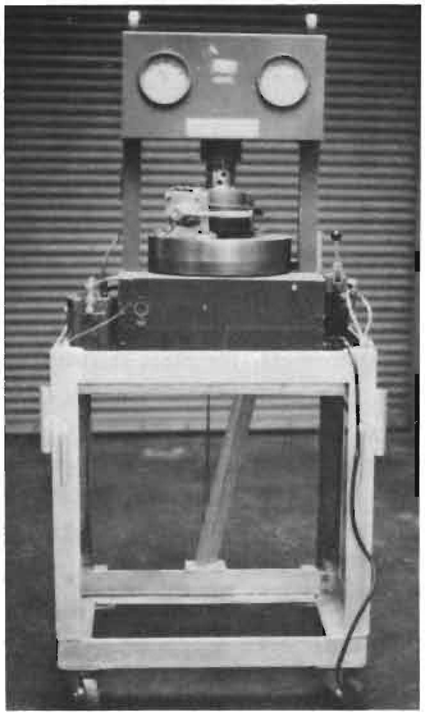

FIG. 2: Gyratory compactor.

Value of Laboratory Density Testing:

It determines the mixture's tendency to flush or rut in the future, regardless of the reason for this tendency. Whether a mix is overasphalted because of a change in gradation which affected the voids in the mineral aggregate or because of overshooting the design asphalt content, the need to make design adjustments to allow proper ultimate pavement air voids will be indicated.

The value of the laboratory density determination increases with the use of Tex-227-F (Rice) because the accuracy of the determination is improved.

Limitations of Laboratory Density Testing:

The drying and curing procedures prior to compacting can only approximate the moisture and asphalt absorption conditions of the mixture after hauling and going through the paver. As some mixtures are quite sensitive to asphalt absorption and to small amounts of moisture, the laboratory density may not correlate as well to ultimate pavement density in these cases.

While our gyratory compactor is gaining national recognition as an excellent laboratory compaction device, it can only estimate ultimate pavement density in a general sense for all pavement situations. The traffic level and environmental circumstances of a given project can also be significant factors.

The gyratory compaction procedure was developed when traffic loadings were somewhat lighter, and the density obtained by gyratory compaction has not been correlated to traffic-obtained compaction in recent years. Therefore, the degree of correlation may not be as accurate as it was originally.

The laboratory density can be in considerable error and go undetected if changes in individual or effective specific gravities have occurred and gone undetected.

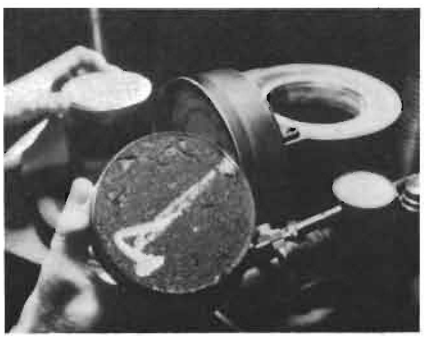

Fig. 3: Compacted sample for Hveem Stability test.

Hveem Stability: This test is the only measurement pertaining to load-carrying capability in our quality control program. This most important characteristic can be detrimentally affected by changes in asphalt content, asphalt absorption, moisture in the aggregate stockpiles, minus No. 200 content, aggregate surface texture (microtexture), and aggregate shape. Obviously, load-carrying capability results from the cumulative effects of each of these in a given mixture. Since it is not possible to monitor all of these characteristics individually during production, and since it is really the cumulative effect of these factors that we are interested in, the Hveem stability is extremely significant.

Value of Hveem Stability Testing:

Hveem stability is a physical (load application) test. A physical test is required to provide a measure of assurance that the pavement will withstand moving and stationary traffic loadings.

Hveem stability is considered an excellent measure of internal aggregate friction, which is the predominant load-carrying mechanism of asphaltic concrete. The test is close to a direct measurement of the desired property and is sensitive to most of the production and mixture variables which can detrimentally affect the load-carrying capability of asphaltic concrete.

Limitations of Hveem Stability Testing:

Hveem stability is determined on a laboratory-compacted specimen which is not representative of pavement density immediately after compaction. Since the density affects interparticle contact, it also affects interparticle friction. While this difference in density makes the test less representative of the initial pavement, it correlates better with the pavement condition after a full summer or two of traffic. Since significant rutting usually occurs ater the failing pavement layer has reached ultimate density, the selection of ultimate pavement density for the test is believed to be the best choice.

The test specimen is of a standard height, regardless of pavement placement depth. As the depth of HMAC placement increases, the actual rutting resistance of a given mixture decreases. A standard two-inch specimen height is used because shorter specimen heights make the stability determination less precise (repeatable), and in considerably thinner specimens, less accurate. However, placements thicker than two inches may not possess the desired frictional characteristics, even though so indicated by the two-inch specimen test.

Hveem stability does not measure cohesive mixture properties. (Asphalt binder strength is believed to be a factor in rutting only in extreme cases.) An example is the high stability which can be obtained from compacting rapid cure patch mixture prior to curing out the volatiles. While found to have high stability in the confined condition of the stabilometer, the specimens can be deformed by hand. The mixture would shove if placed in a large pothole in warm weather.

Pavement Air Voids: We desire that most pavement densification occur at the time of construction, while viscosity of the asphalt is reduced. The determination of pavement air voids is an indication of the thoroughness of construction compaction.

Value of Pavement Air Void Testing:

Proper construction compaction is necessary for desired initial pavement performance. The pavement will be less permeable to water and oxygen from the outset, thereby slowing oxidation (asphalt aging). Proper initial compaction will also minimize wheel path consolidation, a minor cause of rutting.

Cores and Test Method Tex-227-F (Rice) give an accurate measure of air voids, provided proper care is taken in obtaining the cores and in following test procedures.

Limitations of Pavement Air Void Testing:

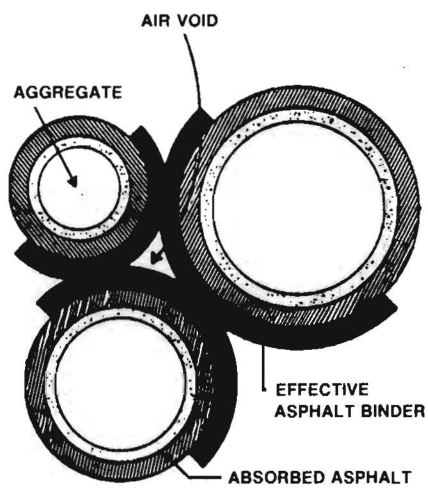

FIG. 4: Schematic of air voids.

A proper air void content after construction compaction does not offer any assurance that traffic will not over-densify the pavement. We rely on the laboratory compacted density for this assurance.

Validity of the test results on thin and fragile cores is a concern. Certainly, any damage to a core will result in a higher than actual air void determination.

Accuracy of nuclear density determinations are totally reliant on the validity of correlative work with core test data.

Extraction: The compositional test which we use is the extraction test. This test measures how well the contractor has performed in producing the mixture which we designed or approved.

Value of the Extraction Test:

It is necessary to know the daily composition of the produced mixture so that causes of poor quality test results can be identified and corrected.

Since the extraction test is performed on the final product, the resulting gradation data is preferred to that from belt or stockpile sample sieve analyses.

Limitations of the Extraction Test:

Extraction test methods cannot differentiate between moisture and asphalt cement. Any moisture remaining in the sample at the time of extraction will be counted as asphalt cement. This is also true of nuclear asphalt content testing equipment.

Asphalt content is not directly measured. It is determined by a process of elimination. After the asphalt cement is washed from the aggregate, the procedure is to account for all other materials, leaving unaccounted for material assumed to be asphalt content. Therefore, any aggregate lost during the test would be counted as asphalt cement.

Extraction procedures cannot always remove all absorbed asphalt cement. This seems to be particularly true if a sample is allowed to cool prior to testing. Reheating does not completely return the sample to the original, fresh-mixed condition.

Perhaps the most difficult aspect of asphaltic concrete inspection is knowing what plant adjustments should be made when the pavement quality becomes questionable. Better decisions can be made when one understands the values and limitations of the testing procedures which we rely on to indicate quality. It is hoped that some of these thoughts will provide less-experienced inspection and engineering personnel some additional insight as we head into another asphalt season. Good luck on your upcoming projects.

BRIDGE DIVISION'S NEW CHALLENGE: UNDERWATER INSPECTION

by Kathleen M. Jones
Technology Transfer
Transportation Planning Division

FIGURE 1: Engineer/diver inspecting underwater structure.

BACKGROUND

Bridges must be inspected below waterline level at least once every 5 years to comply with National Bridge Inspection Standards (NBIS). This underwater inspection is necessary because surface inspections cannot adequately predict underwater structural conditions and channel scouring. This kind of inspection requires an experienced salvage-type diver who is skilled bridge inspector, either an engineer or technician supervised on the surface by an engineer. Unfortunately, the combination of bridge inspector/experienced diver is a rare one.

Up until June 1988, the Texas State Department of Highways and Public Transportation (SDHPT) contracted underwater inspection to consultants, usually engineering firms with engineers (or inspectors) who were licensed divers or who sublet part of the contract to commercial divers under the supervision of engineers. The average cost for one bridge underwater inspection by consultants is $10,000. Texas has approximately 200 bridges on-system that require underwater inspections in the next two years. The total number of bridges on system is approximately 31,000. The number of off-system bridges is about 15,000.

In June 1988, SDHPT formed an in-house diving team made up of registered engineers, engineering graduates, and experienced technicians. They are aiming ultimately toward doing all underwater and fracture critical inspections. The same people who do underwater inspection during warm months will do fracture critical inspections during cold weather. The in-house team will inspect on-system bridges, for the most part, with the exception being a few high traffic, urban off-system bridges. Because of the work load, inspection of off-system will continue to be done by consultants

THE DIVE TEAM

Presently, the team consists of Brian Barnett, Paul Ysaguirre, P.E., Dan Stacks, Reynaldo Cantu, Randy Cox, P.E., and Martin Button, P.E., all of Bridge Division. Barnett, Ysaguirre, Stacks, and Cantu are BRINSAP (**BR**idge **INS**pection and **AP**praisal) staff concerned mainly with maintenance. Cox is more concerned with construction. Button, the nondiving engineer, is in charge of communications, technical support, and diver safety. The most experienced diver on the team is Barnett, who heads the team. He had already accumulated about nine years experience sport diving when the Department sent him to commercial dive school. The other team members had not had previous diving experience, but have received training and are now certified by the National Association of Scuba Divers (NASDS). Training and certification is extremely important: Inspection diving is more rigorous and often much more hazardous than sport diving since there are frequently strong currents, turbulence, and murky water around structures. Team members are also trained in first aid and in CPR.

After developing specifications for equipment, bids were let 17 February 1989. Full-face scuba gear, rather than hard hat deep diving gear, was selected because most dives will be in water not deeper than 30 feet, and scuba gear allows the diver more freedom of movement around footings and piers. With hard hat gear, there is a risk of entangling or of abrading the surface air supply line on the structures being inspected. A full-face scuba mask, rather than face mask and separate air regulator, allows verbal communication with the surface (like hard hat gear) and provides protection to bridge inspectors diving in polluted water.

Scuba dry suits for use in polluted waters, as well as the more common wet suits, have been ordered. Also, SDHPT may be working with the Health Department to minimize health risks to the engineer/divers when they are working in heavily contaminated waters.

The initial investment in full-face scuba gear, underwater 35mm camera, metal boat, and communications apparatus is expected to run about $60,000. In other words since no new personnel were hired, after only six dives the in-house program will represent less cost per inspection than hiring a consultant. Not only does the program reduce costs, but also it provides a more hands-on approach for the Department; a more flexible underwater inspection schedule (available on shorter notice than consultants for flood damage and ship collision emergency inspections); and a service the districts don't have to take out of their maintenance budget.

UNDERWATER INSPECTION

Lake Palestine bridge is the first inspection the team will perform. This bridge is under construction, and the team will be looking at pour problems in some of the underwater columns before SDHPT decides on final acceptance of the bridge. Starting with the coastal areas, districts are sending D-5 information to prioritize the 200 bridges that need underwater inspection. To make best use of time, the team will schedule two or three bridges in one area and stay a whole week. If there is a causeway to be inspected, however, no other bridges will be scheduled because causeways can take up to a week by themselves. The findings of inspections will be carefully documented and much of the data incorporated directly into BRINSAP.

Many of the 200 bridges slated for the next 2-1/2 years require baseline underwater inspections. For baseline inspections, initially, the inspector does a 5- to 10-minute "swim-by." Obvious damage and amount and types of debris associated with the structure are noted by recording the diver's narrative over the communications net. The inspector concentrates on the mud line of the structure, as well as the mean low water line and one or more intermediate depths. Scour depth measurements are plotted to chart the bottom profile so adherence to construction plans and changes in succeeding years can be measured. (Severe scour is one of the few "Close the bridge now!" types of distress.)

Depending on the visual inspection and environment, the inspector may clean a 1- to 2-foot patch on a vertical face of the structure to assess deterioration. Done with picks and scrapers, cleaning is time consuming and is kept to a minimum. Larger areas are cleaned if the severity uncovered warrants the time investment. Photographs are taken for documentation. In zero-visibllity water, photographs are made possible by displacing dirty water with clean water sealed in a freezer bag. The freezer bag of clean water is pressed against the section to be photographed. The wide angle camera lens is pressed against the other side of the bag. A powerful strobe flash is used as the light source.

Inspectors generally use simple tools such as calipers, graduated picks, and rulers to estimate damage or deterioration in the cleaned sample areas of 1- to 2 feet.

FIGURE 2: Full-face scuba mask.

FIG. 3: Barnett in scuba dry suit.

Amount of corrosion is noted by estimating section loss percentage on steel structures. On concrete, cracks are counted and their lengths and widths measured. Types of distress are sketched. The structure is evaluated for general maintenance needs. Advanced nondestructive testing techniques such as ultrasound may be used to detect hidden flaws or damage. Some minimally destructive sampling such as coring of wood or in situ hardness testing of concrete may be done.

SUMMARY

The addition of an underwater inspection unit rounds out the Department's bridge inspection capabilities, giving the State a comprehensive in-house program. Therefore, the program will give more uniform evaluations from bridge to bridge and from inspection cycle to inspection cycle. The dive team members have detailed knowledge of BRINSAP requirements and Departmental bridge policy and will be able to collect the right data and document it using methods that are most suited to in-house requirements. The in-house team can also do quality control preacceptance inspections of new structures. They can be mobilized quickly for priority or emergency inspections. Also, in-house underwater inspection is a cost effective way to assess Texas' 31,000 on-system bridges to ensure the safety of the traveling public.

D-9 LABS RECEIVE AASHTO ACCREDITATION

The AASHTO Material Reference Laboratory (AMRL) began a program this past year of accreditation of laboratories in the areas of asphalt, asphalt concrete, portland cement concrete, soils and aggregate testing. Materials and Tests Division received accreditation in these areas 1 May 1989. D-9 is among the first in the country to receive accreditation from AMRL.

For a number of years, the D-9 laboratory has participated voluntarily in AMRL periodic inspections. Every 15 to 18 months, an inspector from AMRL arrives to check out equipment for calibration and for being within test specifications, as well as to observe technicians performing the various AASHTO or ASTM tests. The inspectors give a preliminary report on what equipment is out of "spec" or out of calibration and inform technicians of procedural errors immediately. A follow-up formal report is submitted to the Materials and Tests Engineer. In addition to these inspections, AMRL sends out reference samples, and a list of which tests, to run to laboratories throughout the country for round-robin testing. AMRL analyzes all the test results from the laboratories and sends back the averages, standard deviations, and individual lab standings.

Although the AMRL testing and inspection standards are very strict, prior to the accreditation program, all of the results were merely for individual labs' information: nothing had to be done about procedural problems uncovered by inspection or testing if a lab did not feel it was necessary.

The accreditation program adds to the usual inspection and reference sample program by requiring conformance to a minimum frequency of equipment calibration, and by requiring more information on training of technicians, handling of samples and reporting of data.

Under the accreditation program, if significant variations in equipment or procedures are found during an AMRL inspection, to maintain accreditation, a lab must explain how the problem will be corrected, e.g., what equipment modifications will be made or what supplemental training will be given. If a lab is more than two standard deviations off of the nationwide average on a reference sample, a report on the sources of testing error must be made. This is most easily done if a portion of the original reference sample is retained and can be retested. The accreditation program gives laboratories around the country the incentive to standardize their equipment and procedures to produce results that are uniform from one lab to the next.

Programs like the AASHTO Materials Reference Laboratory's accreditation improve quality of testing. Within the Department, several districts, like Fort Worth and Paris, have evaluation programs for field labs. Reference samples are sent by D-9 to all district labs for round-robin testing, similar to the way D-9 participates in round-robin testing at a national level. D-9 is encouraging the development of programs by the districts to ensure the quality of our work involved in material testing and control.

CONCERNING EXPERT SYSTEMS

Broadly speaking, the regulation, operation, and maintenance of modern transportation systems break down into a hierarchy of interdependent but nonetheless discrete functions. Equipment and systems controls are built on a modular basis. Modern hardware and software permit each module to be controlled by its own microprocessor with human intervention required on an exceptional rather than a continuous basis. This permits greater equipment and system productivity and safety; it also permits greater human productivity. This latter impact has been perceived as a threat. On the contrary, it creates time for operators to enrich their working experience. It does mean, however, that for the foreseeable future strategies for the introduction of advanced computer-based technologies must recognize

- The attainment of specific objectives for increased safety and productivity and
- The psychological impediments to introduction of the powerful new technologies and, the other side of the coin, the need to define strategies to enrich the jobs of the users of these technologies.

In this context, and as noted in the introduction, expert systems are one of the first commercially applicable derivatives of some 30 years of research in artificial intelligence (AI). Other emerging product areas include natural language software, computer-aided learning, and voice recognition. There are many aspects to AI research; however, it may be characterized as

- The part of computer science concerned with designing intelligent computer systems (i.e., systems that exhibit characteristics that humans consider intelligent);
- A branch of computer science the objective of which is to endow a machine with reasoning and perceptual capabilities; and
- The area of computer science that deals with problems that are incomplete in nature or that have indefinite solutions.

These definitions of AI reflect the academic nature of the work and mark the tremendous interest, matched by commitment of enormous sums of money, that has arisen in the field. The Japanese plan to develop a fifth-generation computing system with an architecture heavily dependent on a variety of technologies embodying concepts usually termed AI. For both military and civilian purposes the United States and countries in Western Europe have mounted similar projects.

Aside from the long-term military and civilian objectives that are being pursued under these programs, two applications of AI are now in the marketplace. The first is marked by the development and introduction of robots and computer-aided design/ computer-aided manufacturing (CAD/CAM) that have revolutionized manufacturing processes, notably in the automobile industry. The second derives from advances in knowledge representation and expert systems that are reflected in the variety of medical and other diagnostic systems that have recently entered the marketplace.

An expert system (ES) is a computer program that uses knowledge and inference procedures to solve problems that are so complex as to require significant human expertise for their solution. The knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners in the field.

There are three categories of clients for an expert system:

- Clients who require answers to problems. These are the operators who will require answers in time frames dictated by the nature of the problem. They may range from a dispatcher who is controlling a demand-responsive system, to a scheduler, a maintenance mechanic, a maintenance manager, or a planner. Response time may vary from a requirement for a real-time solution to hours for complex problems.
- Clients who are attempting to improve the quality of the system, to increase its knowledge, or to refine and hone their own expertise. A variant of this would be to use the system as a research assistant.
- Clients who are students taking advantage of the system to upgrade their knowledge and skills.

In summary, an expert system may be used as a decision aid, to transfer knowledge or expertise, to improve the efficiency of an expert's use of time, to improve the quality of an expert, or as a training tool.

From R. T. Lewis and W. F. Johnson, "Application of Expert Systems to Transportation: A Strategy for Safety and Productivity Gains." ***Expert Systems for Transportation Applications, Transportation Research Record 1145*** (1987):1-8

APPLICATIONS OF EXPERT SYSTEMS IN TRAFFIC OPERATIONS

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INTRODUCTION

One of the exciting fields in transportation engineering involves the application of computerized models for traffic operation analysis. Significant developments have been made in recent years for applying computer tools to assist engineers in evaluating urban traffic improvements *(1)*. Today, the traditional barrier between theoretical model development and field implementation has been reduced due to the increasing availability of microcomputers and interactive programming techniques.

Artificial Intelligence Technology (AI) has been introduced in many disciplines. "Knowledge-based Expert Systems" (KBES) or "Smart Systems" are a collection of design procedures and computer programming techniques that enable computer systems to assist people in analyzing specialized problems *(2,3)*. Expert systems, as part of the AI/KBES technology, are computer programs that incorporate the knowledge and thinking processes of experts to provide other people the insights gained from years of experience. In other words, an expert system is a computerized decision-making system.

Expert systems differ from conventional data-processing programs. The latter rely on defining logical algorithms for a program. Expert systems rely on expert performance, symbolic reasoning, depth of knowledge representation, and self-knowledge for logical operation. Traditional programs are developed by explicitly stating all of the applicable rules and execution sequences. Usually, algorithmic programming states only the action part of the rules. A KBES, on the other hand, uses the same action rules as algorithmic programs, but specifies independently all of the heuristic parts of the decision-making process. The rules can be programmed in symbolic relationships and treated as the knowledge base. *(3)*

Expert system (ES) application has a strong potential to provide spontaneous responses and decision-making support. It is possible to apply ES applications to implementing successful control strategies to alleviate urban freeway corridor congestion problems.

This paper summarizes the research being conducted at TTI to investigate the potential applications of knowledge-based expert systems (KBES) for traffic analysis in the IBM PC/XT/AT microcomputer environment. Several prototype signal control systems and freeway incident management systems are being investigated. They are being designed to simulate the reasoning process of experienced engineers assisting other users in efficiently selecting alternative control strategies. These decision analyses and expert advice systems can later be implemented in real-time as if a group of experienced traffic engineers were constantly available to automate the selections of traffic control strategies for arterial streets and freeway corridors.

STUDY BACKGROUND

In the United States, more than half of all vehicular trips take place in urbanized areas. Most metropolitan areas are encountering growing urban traffic management problems, such as providing intersection control and congestion management for oversaturated highway networks. These problems result from general traffic increases as well as the need to reconstruct major urban freeways. There is an immediate need to improve existing arterial traffic operations in addition to the reconstruction of major urban freeway systems. Urban traffic control strategies often need to be evaluated through experienced engineering decision-making. The optimal control process can be determined through efficient alternative control strategy analysis. Today, urban congestion problems are no longer restricted to single transportation facilities, such as isolated intersections, arterial streets, and the street networks in central business districts. Instead, the traffic engineer is faced with complicated urban traffic problems on parallel street systems and freeway corridor networks. Often there are insufficient funds for allowing the evaluation of all the traffic control alternatives, such as adding new highway facilities or reconstructing entire street systems, through traditional problem-solving techniques.

Existing traffic management techniques used by practicing engineers can be better implemented through the application of computer models. Recently, a large number of computerized program packages have been developed for providing consistent operational analysis. With the increasing availability of mainframe computers and microcomputers, numerous applications are available for detailed engineering evaluations. Without having to conduct full-sized field traffic control experiments, traffic engineers at virtually any location can analyze traffic operation problems efficiently, thereby allowing more quality engineering time for alternative design and evaluation. "Expert Advice Systems" or "Smart Systems" design may be employed for effective engineering analysis and decision-making support. This design concept demonstrates a feasible approach for incorporating both the human decision-making process and computerized operational analyses to assist practicing traffic engineers in managing growing traffic problems, especially in overcongested urban areas *(3)*.

COMPUTER TRAFFIC MODELS

Traffic engineers have used different techniques to assist in transportation improvement evaluation *(1)*. Traffic engineering approaches are usually implemented through easily understood graphic representation techniques. Both analog and symbolic models have been implemented through either manual methods or computer programs to evaluate the effects of implementing different traffic control strategies. The most widely used models are those applied for capacity analysis, traffic signal timing, and traffic assignment. Most manual techniques available to increase the capacity of existing facilities have been exhausted in the last twenty years. Generally, two approaches have been used to model transportation engineering problems. The first applies the experimental, or empirical, approach to engineering questions through actual measurement. The second uses the mathematical modeling approach. Both approaches have been applied successfully in many traffic engineering areas. For example, the time-space diagram approach has been used in optimizing traffic signal timing plans. Today, traffic engineers have found that computerized techniques can provide tools to efficiently study complex urban transportation problems. Potential methods for analyzing traffic improvements may range from traditional manual techniques to more extensive traffic management solutions. These applications result in improvements such as better signal timing and phasing, interconnection of signals, turn prohibition, parking prohibition, exclusive turn lanes, and additional through lanes.

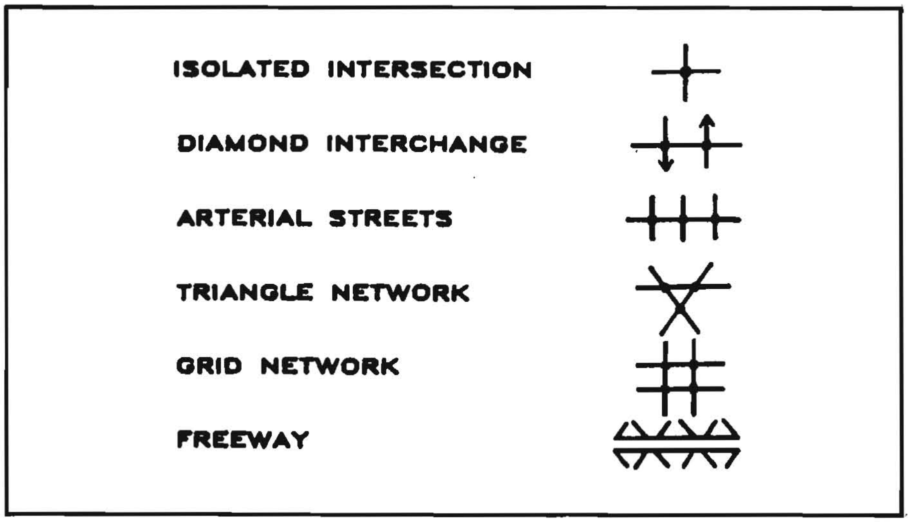

FIG. 1: Applicable areas of computerized traffic analysis models (Ref. 1).

Traffic engineering problems are characteristically resolved by applying one of three methods: algorithmic calculations, decision-making processes, or empirical experience. Recent traffic computer modeling developments allow traffic engineers the added opportunities to evaluate alternative control strategies with the basic information required for using manual methods. For example, the traffic-carrying capacity of a roadway can be addressed experimentally to determine the effects of roadway width and roadside parking interference as described in the ***Highway Capacity Manual (HCM).*** Using computer models, a more interactive evaluation of incremental benefits from different engineered solutions may be obtained by using the same procedure. However, the practicing engineer must have detailed familiarity with the computerized traffic models to apply these techniques effectively. Users must also have a clear understanding of the modeling process and of the applications of computer models for evaluating traffic system improvements efficiently to solve daily operation problems.

FUNCTIONAL APPLICATIONS

Applications of computer modeling require the adequate real-world representation of the system being analyzed. It is necessary to clearly identify the feasible areas for computerized analysis. The simulation techniques may supplement conventional solutions by realistically producing random variations as in field conditions. Combining traffic analysis with simulation study complicates the applicable approaches considerably, and strengthens the potential for using computer models as problem solving tools. Many computerized traffic models have been successfully implemented for analyzing different transportation facilities and control strategies. Three types of computer programs have been developed to deal with urban traffic control strategies *(1)*. They include the computerized traffic models developed to assist in the analysis of intersection operations, arterial street and signal network operations, and freeway corridor network operations.

Figure 1 illustrates the typical urban traffic problems faced by traffic engineers in different urban metropolitan areas. The suitable application areas of computerized traffic model configurations include: "Isolated Intersections," "Arterial Streets," "Arterial Networks," "Freeway Mainlanes," and "Transportation Corridors." These computer programs can provide the evaluation of certain performance measurements. The typical measures of effectiveness may include delay, stops, speeds, fuel consumption, progression efficiency, and the overall transportation system performance. Graphic-type outputs are often produced to compare operational scenarios of traffic control alternatives.

EXPERT SYSTEMS DESIGN

Since World War II, scientists have developed Artificial Intelligence technology (AI) to simulate human behavior and decision-making processes in robotics design, natural language processing, problem-solving techniques, and expert systems. Among them, the expert systems have the most promising applicability to engineering problems *(3)*. Artificial Intelligence (AI), Knowledge-Based Systems (KBES) and Expert Systems Design (ES) are the results of the AI development. A Knowledge-Based Expert System (KBES) is a collection of AI techniques and analysis processes that enables a computer to emulate human experts in analyzing specialized problems. AI/KBES applications for traffic operations require specific knowledge which permits engineers to interact with the following three components: characteristic traffic data, theoretical or simulation results, and specific hypotheses for measuring the effects of traffic control measures. Since the explicit algorithms for traffic analysis do not usually exist and traditional programs may provide only restricted problem solving and limited analysis, the structured guidelines of most traffic engineering analyses are highly suitable for KBES applications *(3)*.

COMPONENTS IN EXPERT SYSTEMS DESIGN

There are five major elements of AI applications involved in ES designs.They are the:

- expert system
- domain expert
- knowledge engineer
- expert-systems-building tool
- end user *(2)*.

Figure 2 demonstrates these AI/ES components and their corresponding relationships to each other. The domain or area expert is an articulate, knowledgeable person who produces successful solutions to problems in a particular field. The knowledge engineer is usually a person with the computer science background and AI technology needed to build expert systems. The knowledge engineer interviews the domain experts, organizes the knowledge, decides how it should be represented, and assists in the program development. The expert-systems-building tool is the programming environment and language used by the knowledge engineer or computer programmer to build the expert system. The end user is the person for whom the expert system is developed. The user may be a traffic engineer debugging the expert-systems-building tool or AI language, a knowledge engineer refining the existing knowledge, a domain expert adding new knowledge to the system, the end-user relying on the system for advice, or a clerical person adding information to the knowledge engineering data base. A knowledge engineer converts a domain expert's decision-making process and rule-of-thumb guidelines for the specific problems into sets of IF-AND-THEN-ELSE rules, and ultimately implements and translates the expert system into primitive machine instructions.

EXPERT SYSTEMS PROGRAMMING

Recent AI/ES evolution has led to more application-oriented development. AI/ES development is directed into three areas: expert systems, natural language queries, and AI languages. Many pre-identified factors and rules are required to determine the choices among different intersection control design alternatives. The typical traffic signal phase design includes:

- algorithmic methods

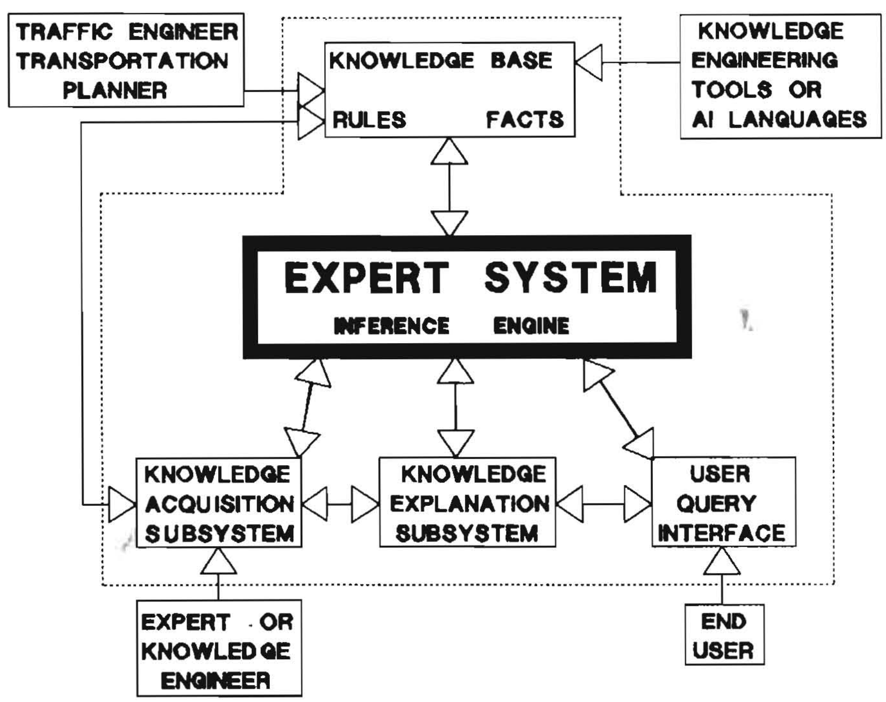

FIGURE 2: Expert system design, main components (Ref. 3).

- knowledge inference capabilities
- the knowledge base of a traffic engineer

In analyzing a signal phase design, first the critical volume cross-product is calculated algorithmically from the input traffic. Then the inference mechanism, forward-chaining deductive reasoning, derives new facts from rules and facts existing in the knowlege base. Forward chaining checks to determine whether goals or subgoals fit the input and evaluates the dependencies among decision-making activities in the human reasoning process. The reasoning for inference process optimizes design objectives by starting from known information. In the third decision-making process, the domain knowledge is written in IF-AND-THEN-ELSE rules to resemble the human decision-making process. For example, the existence of sight distance restrictions and severe left turn accidents may justify the provision of protected left turn signal treatments, which might also be recommended by an experienced traffic engineer under similar conditions.

These reasoning processes as documented in decision rules are very useful for developing problem-solving in instances which may not be covered by established design guidelines. The construction of specialized expert systems based on established guidelines can provide users with added reasoning knowledge similar to that which would be provided by a constantly available human expert *(3)*. The expert system can generate solutions resembling those used by engineers for determining appropriate measures. Since only a few heuristics are being evaluated each time, the system operation is very efficient. Most traffic engineering problems have similar characteristics. Therefore, traffic engineering expert systems are especially useful for assisting users to solve repeatedly occurring problems, sharing common working experience for mutual learning, and providing better understanding of design alternatives in the future. By correctly constructing the knowledge based expert system, traffic engineers can further refine the decision-making rules to reflect the incremental experience obtained from the previous design processes.

KNOWLEDGE ENGINEERING TOOLS

Most conventional programming is made in high-level computer languages, such as BASIC, COBOL, FORTRAN, PASCAL, LISP or C. AI languages are used in ES designs for processing user input to derive conclusions and recommendations. Problem-solving AI languages such as LISP and PROLOG are often used in expert systems development *(2)*. LISP, which stands for **LIS**t **P**rocessing, is suited to symbolic and numeric processing in decision analysis. LISP is suitable for manipulating lists of symbols, i.e., strings of numbers and/or words. For years, LISP has been preferred by AI engineers in the United States. On the other hand, PROLOG, representing **PRO**gramming in **LOG**ic, is preferred in Europe and Japan. PROLOG contains structures more suitable for writing programs that evaluate logical expressions, whereas LISP contains operators that facilitate programs that manipulate lists for representing specific expert knowledge.

Knowledge engineering (KE) tools or shells allow quick programming for specialized applications. KE tools are often used to build expert systems. These tools provide the environment for applying knowledge systems through natural language interface in a user-friendly manner. They also provide features needed in an expert system, such as help functions, windowing capabilities, graphics support and other functions, to help the knowledge engineer add information from the domain expert. The knowledge shell usually includes an explanation subsystem that describes the steps needed to reach a conclusion. The natural language interface can further help explain these programming development steps in ordinary English to enhance understanding of the decision support process.

Using the expertise programmed, the KBES tools can evaluate the viability of a path or a chain of production rules depending on the probability of occurrence. Today, many KE tools are available commercially for program development. The advantages of using KE tools are their easily understood programming structure, well-equipped program support functions, and user-friendly environment. Since the system will seek to optimize execution, the order of the constraints in the production rules is not very important in the input. The constraints within the production rule will be executed in the expert system for matching the goals and subgoals. Just as developing a knowledge base is simple, using the knowledge engineering tool is also an easy task. The items which need to be defined are the specific constraints required to determine application goals and study objectives.

POTENTIAL APPLICATIONS

For years, transportation professionals have used computers to assist them in operation analysis, transportation planning, traffic signal timing, and evaluation of alternative strategies. The development of desk-top microcomputer systems has dramatically increased the engineer's productivity and reduced the time that transportation professionals must allocate for optimizing traffic operations and control strategies. These microcomputer tools can allow more opportunities for innovative analysis. The expert systems design concept can be successfully pursued in at least three traffic operation areas:

- Traffic signal system design and maintenance activities
- Traffic control strategy evaluation and analysis
- Traffic engineering education and personnel training.

The ES design concept has the potential for helping field transportation engineers apply optimal solutions in simulated or proposed traffic conditions *(3)*. Control strategies can then be effectively determined as if a group of experienced traffic engineers were constantly available to select the alternative intersection management strategies. Spontaneous response and decision-making support can be used to evaluate the effects of alternative traffic control strategies for a signalized intersection, linear-type arterials, and street networks. The AI/ES approach has a dual function. On one hand, it can computerize the expert decision-making process. On the other hand, the design process can also help field experts to systematically review their expertise through different knowledge representation techniques, as well as allow other users to understand the analysis process for other applications.

An expert system is best suited for applications in which the subject is highly detailed, but tightly defined, as in the traffic engineering field. Computerized traffic operation analysis is related to several areas of expertise. Using these computer models can be improved as technology advances in the theories of traffic control strategy and in control hardware and software. Texas Transportation Institute (TTI) researchers are developing computer software using AI/ES techniques to assist the potential user in optimizing traffic management strategies. The current investigation focuses on knowledge acquisition, knowledge representation, system programming, and future traffic operation applications. One result of this investigation is that a traffic engineer knowledge-based signal design system has been developed in the PASSER II-87 system to assist users in preparing input data, optimizing timing plans, selecting alternatives, evaluating solutions, and recommending actions for arterials or open-type networks *(4)*. Effective analysis using the 1985 ***HCM*** analysis procedure has been added in the input pre-processor and output post-processor to ease the implementation of timing plans on solid-state, pre-timed and actuated signal controllers. The traffic analysis system also can be used to assist users as an experienced traffic engineer for implementing arterial signal timing plans for both fixed-time and actuated equipment. This tool can drastically reduce the time that transportation professionals must allocate to optimize signal control strategies, thus allowing more time for innovative analysis. This type of system can assist officials in solving growing traffic congestion management problems by ensuring the proper use of these computerized techniques, clarifying the traffic modeling process, assisting the traffic engineering community to solve daily operational problems, and assisting users to evaluate traffic improvement alternatives.

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