Overview of Smooth- and Treaded-Tire Friction Testing by Illinois Department of Transportation

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The Illinois Department of Transportation (IDOT) has been involved in pavement friction testing with locked-wheel equipment since 1968. In 1980 IDOT started testing with a smooth (blank) tire in addition to the treaded (ribbed) tire. Since 1985 IDOT has routinely tested with both smooth and treaded tires and has accumulated a multitude of test data. In 1987, IDOT developed tentative guidelines for evaluating both smooth- and treaded-tire data in analyzing high wet accident sites. The history of friction testing equipment development in Illinois and the upgrading process used for constructing IDOT's current friction testers are described. A summary of various distributions of smooth- and treaded-tire friction test data collected since 1985 on IDOT's highway network is presented.

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This paper describes the history of friction testing equipment development in Illinois and describes the upgrading process used for constructing IDOT's current friction testers. It also presents a summary of various distributions of smooth- and treaded-tire friction test data since 1985 on the highway network.

STATUS OF FRICTION TESTERS IN 1983

IDOT bought its first friction tester in 1968 and its second system in 1978. System maintenance was difficult because parts from the systems were not interchangeable, complicating repairs and lengthening downtime. IDOT investigated upgrading or replacing its two friction testing systems in the fall of 1983. At that time, IDOT had two complete friction testing systems and an extra trailer designed and built in-house.

The condition of IDOT's friction testers in 1983 necessitated immediate action to improve friction testing operations. The average downtime for IDOT's two friction testers was averaging 2 days a week. Minor repairs often stretched into days or weeks because parts were unavailable. The two friction testers were completely incompatible, further complicating repairs. Neither friction tow vehicle could tow the other's trailer or interface to the control equipment.

Hand processing of data often resulted in substantial delays in evaluating and reporting test results. The results of previous tests were difficult or impossible to reference because of manual recordkeeping.

A major problem with both of IDOT's existing systems was that they relied on too many different parts from nonstandard sources. Many of the subassemblies were custom-designed, and when one component failed the parts to reconstruct it were no longer available. These conditions hurt the effectiveness and efficiency of IDOT's friction testing programs.

CRITERIA FOR FRICTION TESTER UPGRADE

Although several friction testing systems were available commercially, retrofitting IDOT's existing equipment was determined most advantageous, economically and operationally. IDOT already owned the basic components for two complete friction testers plus the extra trailer frame. IDOT decided to retrofit the existing systems in stages over 3 years. This was done to replace obsolete mechanical components, improve the mounting design of electrical and mechanical subsystems, and replace the control system with a state-of-the-art microcomputer that would record test data on magnetic storage media.

There were several advantages to doing the work in-house. First, the implementation time frame met budget constraints. Second, redesigning the systems in-house allowed complete control over the selection of components. Third, IDOT personnel would develop the background necessary to repair or modify the systems as necessary. Be redesigning the systems in-house, IDOT could make timely repairs and incorporate future upgrades as necessary.

The goal of the upgrade was to design and build a system composed of standard components with off-the-shelf availability. This was not an easy task because a friction tester is a custom device. Top priorities were locating and purchasing interchangeable components and building a system that allowed in-house modification of equipment and software. The system was to meet or exceed the following requirements:

1. All electronics are interchangeable between systems.
2. Parts are readily available.
3. Calibration techniques are compatible and efficient.

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4. Test cycle can be controlled and modified using software developed in-house.
5. Calibration is accurate within 1 percent.
6. Data are recorded on magnetic media.
7. Operation is menu-driven.
8. Either test wheel can be tested.
9. Water flow is monitored during tests.
10. Design and installation are modular.
11. Equipment is reliable.

The planning and researching manufacturers took about 3 months. IDOT wanted equipment and mounting techniques that made it relatively simple to remove and reinstall equipment in either tow vehicle when necessary. Commercial products were selected for as many components as possible to eliminate the necessity for in-house construction of circuit boards or manufacturing of special parts. It was necessary to have some circuit boards modified to provide the necessary functions and also to do some custom machining of parts. This was kept to an absolute minimum. IDOT also eliminated as much interfacing as possible between the computer system and the electrical subassemblies.

The friction tester upgrade project was a cooperative effort between the University of Illinois Civil Engineering Department and IDOT's Bureau of Materials and Physical Research. By spring 1984, upon evaluation of different upgrade methodologies, the major components were selected and detailed design criteria were approved.

It was determined feasible to design, build, and operate a friction tester with a commercially available microcomputer. Several microcomputer systems were available that could control the friction test cycle, write test data to a magnetic media, provide a hard-copy printout, and visually display current tests for the operator. A system that had all or most of these capabilities built into a single unit was desired, because complexity was reduced by minimizing external cabling and interfaces. A single unit also provided the capability to modularize design components to allow easier access of mounting and removal. Under this arrangement, a backup unit is required for each module of the system in case of malfunction.

In addition to data collection, various methods of managing and reporting the collected data were also evaluated. A microcomputer data base was designed to interact with the data collection activities and provide automated data management of various testing programs. The Pavement Technology Information Base (PTIB) was designed to document the location of test sites, provide historical test information regarding specific sites, and provide traffic and test information for use by field crews. Reporting procedures developed on the PTIB issue a field sheet for the field crews. The field sheet provides the field crews with information to determine the location of test sites, the type of pavement, how much traffic to expect and the results of previous tests. To do this, information from several sources is combined into one data base.

The upgrade of all of the systems took several years and was completed in 1986.

FRICTION TESTER SYSTEM OVERVIEW

A Hewlett-Packard Integral Personal Computer (HP-IPC) running AT&T System V UNIX and an HP-3497A Data Acquisition Controller were chosen to be the heart of the system. The HP-IPC came with a IEEE 488 equipment bus that interfaces directly with the HP-3497A data acquisition controller. The HP-IPC has a built-in flat-screen VDT, a built-in ThinkJet printer, and a built-in 3.5-in. microfloppy disk drive. The HP-3497A data acquisition controller provides the necessary digital counters and relay-operated control of peripheral devices for friction tests. Because the amperages of some devices were near the maximum load for the 3497A's device actuator circuitry, an additional bank of heavy-duty relays was added between the 3497A and the water pump, brake relays, and water valves.

The HP-IPC was designed for scientific system development and as the replacement for the HP-85 data collection microcomputer. The HP-85 microcomputer had become a standard in field data collection. The HP-IPC microcomputer came configured as follows:

- HP-IB (IEEE 488) equipment interface bus,
- Electroluminescent display screen,
- 3.5-in. microfloppy disk drive,
- Detachable 101-key keyboard,
- Built-in ThinkJet printer,
- 512 KB of memory, and
- UNIX operating system in ROM.

The following were purchased as options:

- HP Technical Basic (HP-TB) in ROM,
- 256-KB plug-in memory card,
- Modem card, and
- RS-232c interface card.

All of the peripherals IDOT specified were built into the HP-IPC. It also interfaced directly to the HP-3497A device control unit with a single cable The 3497A may be optionally configured with up to five cards available from the company. IDOT configured the 3497A with a 16-channel digital actuator and four digital accumulator cards. Using HP-TB, the HP-IPC can control all the functions necessary to do a friction test. These two pieces of equipment and the heavy-duty relay chassis control the entire system. The options to the HP-IPC were added to simplify system operation and enhance the system's capabilities.

The 3497A controls the devices associated with the friction tester through an auxiliary box for high-current relays. One card slot in the 3497A contains the 16-line controller device that activates system components through high-current relays. The other four slots contain digital counter devices that accumulate digital counts for torque, speed, and water flow and those from the wheel pulse transducer on the test wheel. Twelve power relay control devices are controlled by the control device in the 3497A.

HP-TB was purchased in ROM to eliminate the need for two disks in the field. Without this feature, one disk would be necessary for HP-TB and one for the friction control software. RAM was added to ensure that no shortage of memory would affect the testing cycle. The modem and a single RS-232 interface were added to ensure compatibility with the office systems. An HP-IPC is used in the office to preprocess

data and serves as a backup unit should a field unit fail during the test season.

The test-cycle control software was developed using HP-TB by the University of Illinois Civil Engineering Department to specifications provided by IDOT. The software was debugged and later modified by IDOT to provide header information to identify test sites.

The friction test program loads automatically if the program disk is in the HP-IPC's internal drive when power is applied to the computer. The operator is given a sequence of prompts to name a file and then identify the test location by answering a series of prompts and entering information from a field sheet generated by the PTIB.

Field crews fill in header information about the test location, direction of test, number of lanes, ID number, construction contract number, their initials, and the system number. Once the header information is entered, a test can be initiated by pressing a single function key on the computer keyboard. There are 16 function keys that can be programmed from HP-TB. Function keys are assigned to allow the test crew to select alternating wheel tests or single wheel tests with either wheel. Other function keys are assigned to denote direction changes, lane changes, and section changes during a test. Friction tests are printed out on the built-in printer and displayed on the HP-IPC's screen. The test data are recorded to the floppy disk as the tests are taken. Header information entered by the field crews is also recorded to disk and allows automatic processing and printing of reports when used in conjunction with the PTIB.

In the office, test data are sorted, verified, and merged into the PTIB electronically for processing. The results are matched to existing records on the PTIB using the header information entered by the field crews. Printed reports, generated by the PTIB, consist of a detail report, listing each test by log mile, a test section summary that shows the average of all the treaded-tire tests (FNt), and the average of all the smooth-tire tests (FNs). The PTIB also contains information about mix and aggregate types, ADT data, and a history of friction test results at various sites. All of this information is synthesized into a single-page summary report. IDOT categorizes various testing projects as High Wet Accident, New Construction, Retest of New Construction, or Special Studies. A cover memo is generated automatically by the PTIB to the appropriate agency or individual.

ANCILLARY EQUIPMENT

In addition to the purchased equipment, a central power control panel was added to control 110 VAC and DC power. This panel also provides the operator with a switch to apply a calibration resistor across the system electronics to check their operation. AC power for the HP-IPC and the 3497A is provided by a generator powered by the two vehicles' two batteries. Friction tests are also recorded on a Gould strip chart recorder using a separate signal line. The strip chart recorder is used to record operator comments and visually check system functions such as locked brake and event timing. The strip chart can also be used to process data should the other electronic system fail.

Mechanical modifications to the existing system were handled jointly by the University of Illinois staff and the Materials and Physical Research staff. These included new torque transducers, signal amplifiers, and modifications to the trailers' axles and brake systems. IDOT's in-house electronics staff reviewed and developed boards for the heavy-duty relays and designed and built cables and connectors. A specially fitted water pump driven off of the drive shaft of the tow vehicle was fabricated by IDOT personnel.

The signals from the torque transducers are amplified using a high-gain bridge amplifier. The output from the amplifier is split; one signal goes to the strip chart and the other to a voltage-controlled oscillator (VCO). The VCO converts the input signal to torque. It is stored in one of the 3497's digital accumulators. The split system makes it possible to continue testing even if there is a problem with one of the recording devices.

The braking mechanism uses an air over hydraulic system. It took considerable research to obtain an off-the-shelf brake assembly that is self-retracting and rated to hold a locked wheel. IDOT finally settled on a brake designed for use on mining cars. Tow vehicles were ordered with on-board air compressors driven off of the engine. Air supply lines are run to the rear bumper to a quick disconnect air fitting. A flexible hose on the trailer connects to air lines run along the trailer frame to electric solenoids that control the brake for each test wheel.

When the test wheel is selected by the operator and the test sequence activated, air is applied to the brake modulator and the test wheel is locked. The original testers' electric brakes had problems with slippage during calibration and during the actual friction test. The current brake system has performed for several years with few failures except when testing high-friction mixes. Another modification to the brake system that uses brake calipers for each wheel is being considered. Each trailer's braking system components are examined during the off-test-season and repaired as necessary.

Water is delivered to the pavement from a 1.5-in. diameter water line connected to a pump driven off of the drive shaft of the test vehicle. The water output is then proportional to the tow vehicle speed. The water pump itself is mounted to the rear axle of the tow vehicle by a bracket welded to the rear axle. Belt tension may be adjusted by setting the bolt tension adjuster on the water pump mounting bracket. The water pump and water solenoid are the first devices activated when a test is initiated. A magnetic clutch on the water pump is engaged and the water solenoid for the selected test wheel is activated, and water is delivered to the pavement through the outlet of a 250-gal agricultural tank mounted in the bed of the tow vehicle. Water is pumped through the ASTM-specified nozzle (Ohio State nozzle). The test vehicle is equipped with 100 ft of fire hose and adjustable fire hydrant wrenches and thread adaptors. The water tank is filled through the water tank fill tub assembly. A shut-off handle is included to stop the water flow from the fire hydrant.

During the correlation tests, results from the three trailers were virtually identical over the entire process. Test sites for the correlation were chosen to represent several ranges of friction numbers. Tests were conducted with one test vehicle leading and the other following and locking up the test wheel at the same locations. After the pavement dried, the vehicles switched positions and crews and reran the courses.

SMOOTH- AND TREADED-TIRE TEST RESULTS

Since 1985 IDOT has routinely performed friction testing using both a smooth and a treaded tire on the same axle at every test location. The test is performed alternating between the smooth and the treaded tires at 0.1-mi increments. This is routinely done for testing for high wet-pavement accident locations, new construction, follow-up retests of new construction, and special studies.

Figure 1 shows the number of sites tested from 1984 through 1990. The equipment upgrades during 1985 and 1986 provided a dramatic increase in the number of sites tested. The breakdown of sites tested in 1990 included approximately 23 percent high wet accident sites, 20 percent new construction sites, 35 percent reruns of new construction, and 22 percent special study projects.

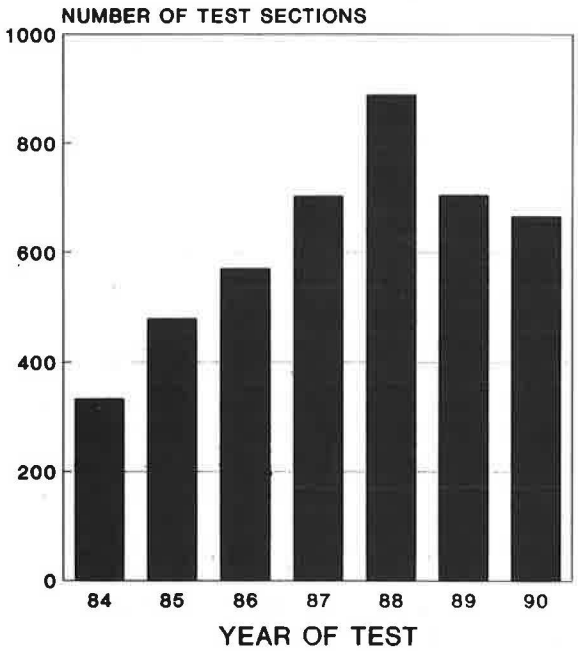

FIGURE 1 Histogram of friction test sections by year of test.

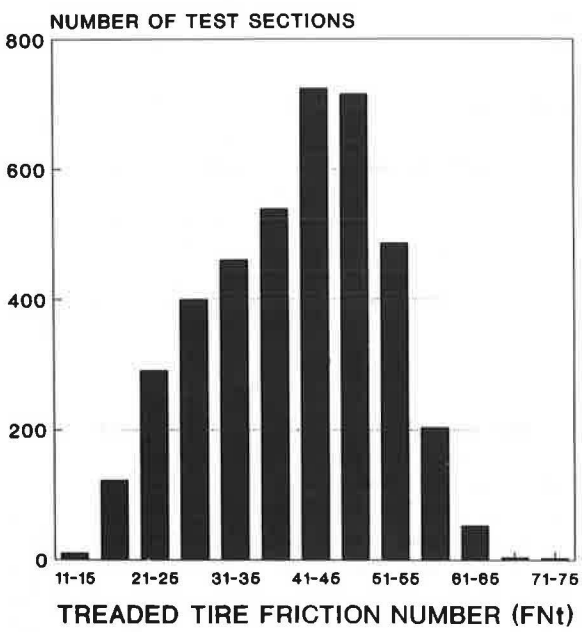

FIGURE 2 Histogram of average treaded-tire friction test values for all sections.

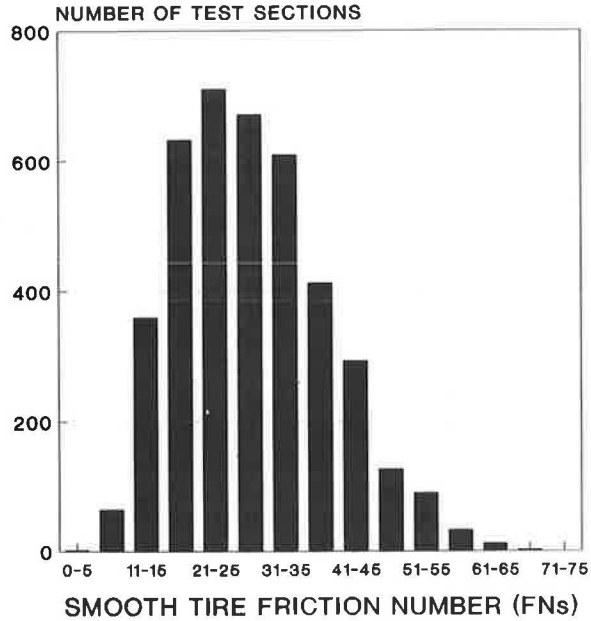

FIGURE 3 Histogram of average smooth-tire friction test values for all sections.

The treaded-tire friction number (FNt) and the smooth-tire friction number (FNs) test results summarized in the following figures are averaged over the length of the test section. For ease of data analysis, only one direction of travel was selected.

Figures 2 and 3 show the histogram of the range of average friction numbers for the test sites for treaded tire (FNt) and smooth tire (FNs) test data respectively from 1985 through 1990.

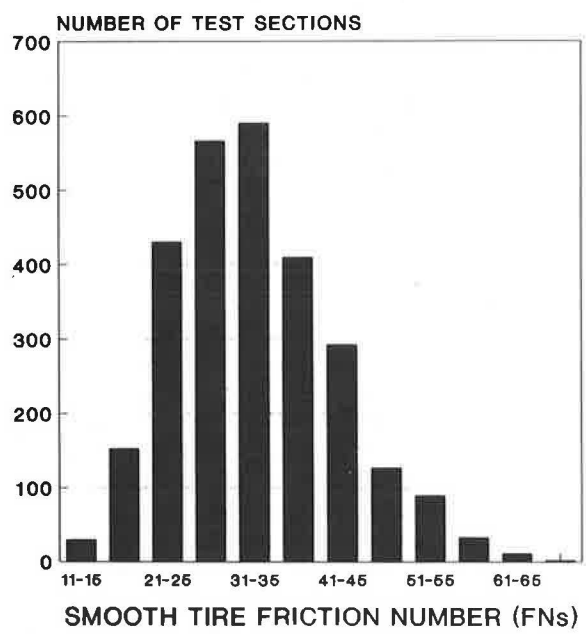

FIGURE 4 Histogram of average smooth-tire test values for sections with FNt greater than 35.

TABLE 1 TENTATIVE GUIDELINES FOR EVALUATING FRICTION AT HIGH WET ACCIDENT SITES BEFORE 1987

Friction Number Range	Tentative Guidelines
1. FNt 30 or less	Friction is probably a factor contributing to wet-pavement accidents.
2. FNt between 31 and 35	Uncertainty exists as to whether pavement friction is the primary factor.
3. FNt is 36 or more	Probably some condition other than pavement friction may be the primary factor causing wet pavement accidents.

TABLE 2 TENTATIVE GUIDELINES FOR EVALUATING FRICTION AT HIGH WET ACCIDENT SITES AFTER 1987

Friction Number Range	Tentative Guidelines
1. FNt 30 or less or FNs less than 15	Friction is probably a factor contributing to wet-pavement accidents.
2. FNt greater than 30 and FNs between 15 and 25 or FNt between 31 and 35 and FNs greater than 25	Uncertainty exists as to whether pavement friction is the primary factor.
3. FNt is 36 or more and FNs is greater than 25	Probably some condition other than pavement friction may be the primary factor causing wet pavement accidents.

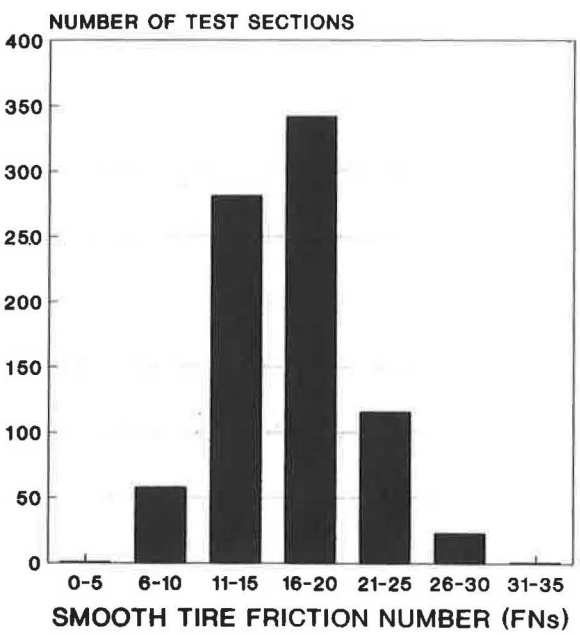

FIGURE 5 Histogram of average smooth-tire test values for sections with FNt less than 31.

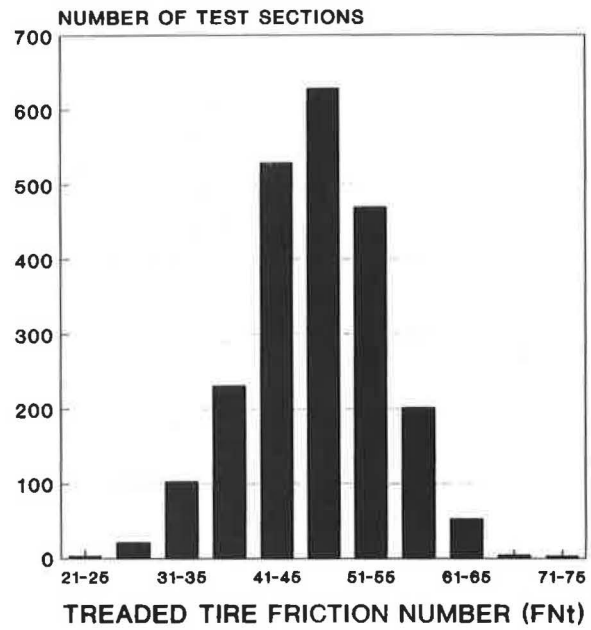

FIGURE 6 Histogram of average treaded-tire friction test values for sections with FNs greater than 25.

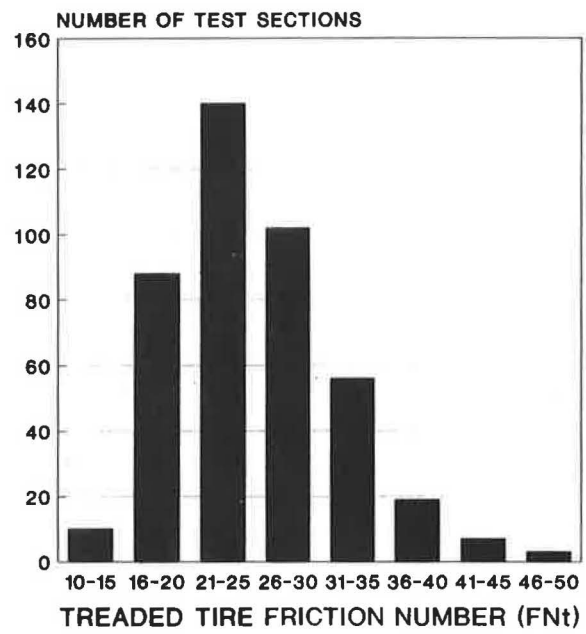

FIGURE 7 Histogram of average treaded tire friction test values for sections with FNs less than 15.

In the 1970s, tentative guidelines were developed for evaluating treaded friction numbers for high wet-pavement accident sites. These are given in Table 1.

In 1986, somewhat on the basis of IDOT's limited experience with smooth-tire data, the tentative guidelines shown in Table 2 were established, incorporating smooth-tire friction data in evaluating high wet-pavement accident sites. This was done to address the concern that whereas the treaded tire is a measure of surface microroughness (microtexture), the smooth tire pro-

vides a measure of surface drainage (macrotexture) in addition to microtexture. Thus, test results from each tire should be evaluated.

Figure 4 shows the histogram of FNs data for FNt greater than 35. Figure 5 portrays FNs data for FNt less than 31. Figure 6 shows the histogram of FNt data for FNs greater than 25. Figure 7 portrays FNt data for FNs less than 15. It appears that pavements can show adequate friction characteristics with either tire, yet exhibit inadequate friction characteristics with the other.

FUTURE EFFORTS

IDOT plans to continue actively testing pavement friction characteristics in the categories outlined. It appears that both the treaded tire and smooth tire tests provide needed information on the frictional characteristics of the pavement. The use of both tests appears appropriate.

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