SHOULDER RUMBLE STRIP EFFECTIVENESS:

DRIFT-OFF-ROAD ACCIDENT REDUCTIONS ON THE PENNSYLVANIA TURNPIKE

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ABSTRACT

To help decrease the number of accidents caused by drowsy drivers, engineers for the Pennsylvania Turnpike developed and installed an innovative type of shoulder rumble strip called the Sonic Nap Alert Pattern (SNAP). A distinct warning sound and vibration are produced when drowsy or inattentive drivers' vehicles drift so their tires cross this pattern of recessed grooves along the shoulder of the roadway. Various lengths and depths of grooves were tested to select a design with enough sound and vibration to be perceptible in a truck cab and yet not too severe for cars or motorcycles. Design features, testing and initial results were presented at the TRB Annual Meeting in January 1994. After installation of SNAP, drift-off-road accidents per month decreased by 70 percent. This study reviews those initial results, adds traffic exposure to compare accident rates per vehicle-distance-traveled, adjusts for a decline in all accidents during the years considered, and revises the initially reported accident reduction to 65 percent. Follow-on results are developed for reportable accidents from 1990-1995, singling out those that could be directly affected by SNAP. About 12 percent of all accidents were considered fully susceptible to SNAP treatment. A reduction of 60 percent in treatable accidents, or a decline in rate by 2.3 accidents per 100 million vehicle miles (1.43 per 100 million vehicle kilometers) was documented for 53 segments totaling 348 mi (560 km) of roadway.

Shoulder Rumble Strip Effectiveness: Drift-Off-Road Accident Reductions on the Pennsylvania Turnpike

John J. Hickey, Jr.

The Pennsylvania Turnpike developed and installed an innovative type of shoulder rumble strip called the Sonic Nap Alert Pattern (SNAP). Tires rolling over the strip produce a distinct warning sound and vibration alerting drowsy or inattentive drivers that their vehicles are drifting along the shoulder of the roadway. SNAP was developed by Neal E. Wood, P.E., Pennsylvania Turnpike Bridge Engineer (retired), who studied accident reports looking for possible engineering modifications to improve safety. He started with safety near bridges, but noted and kept track of the high percentage of accidents caused by drivers drifting off the road with no real explanation except inattentiveness or drowsiness. In 1984, Wood first envisioned SNAP as a narrow, continuous strip of grooves along the right side of the roadway. Other states were trying various rumble strips on roadway shoulders as warning devices for drivers whose vehicles stray off the road (*1*, *2*); many of these patterns were raised strips or grooves that were installed across the full width of highway shoulders, which adversely affected use of shoulders by service vehicles and could catch snowplow blades. Therefore, at an abandoned stretch of turnpike, Pennsylvania Turnpike engineers tested only narrow and recessed rumble strip patterns with varying lengths and depths and selected an effective design with enough sound and vibration to be perceptible in a truck cab and yet not too severe for cars or motorcycles (*3*).

All tested patterns used an indentation spacing of one every foot (.305m) along the direction of travel so vehicle tires could not miss them at typical departure paths. This length between grooves was selected based on vehicles drifting off at a shallow 3-degree departure angle, striking a succession of indentations to produce a tone with enough duration to awaken a drowsy driver. All test patterns were 16 in. (40.64cm) wide, (transverse to the direction of travel) so that wide truck tires would drop in enough indentations along any likely departure path. By trying several depths, it was found that 0.50 in. (1.27cm) was deep enough for tire drop to produce an alerting sound, provided that the opening (length in the direction of travel) was large enough for various sized tires. Grooves 2 in. (5.08cm) were not heard over a 79 decibel noise level in truck cabs. Openings 4 in. (10.16cm) long with 8 in. (20.32cm) between produced sound audible in both cars and trucks with 86 decibels in a truck cab at 65 mph (105 kph).

After the first highway installation, project contractors asked to try milling SNAP in existing shoulders rather than rolling or impressing it in hot asphalt during paving. The milling head was 24 in. (60.96cm) in diameter, which produced a 7 in. (17.78cm) opening while grinding to the specified 0.50 in. (1.27cm) depth. This modified design with 7 in. openings 5 in. (12.7cm) apart was 3 decibels louder (at 89 decibels) than the original rolled-in depressions with 4 in. (10.16cm) openings, which is a perceptible difference.

FIGURE 1: Sonic Nap Alert Pattern (SNAP) along shoulder of Pennsylvania Turnpike.

All but a few miles of initial SNAP installation projects are now 7x16 in. (17.78 x 40.64cm) indentations, 1 groove per foot (.305m), milled 0.50 in. (1.27cm) deep starting 4 in. (10.16cm) outside the roadway edgeline along the shoulder as shown in Figures 1 and 2. At highway speeds, a high enough acoustic pitch of 95 cps at 65 mph (105 kph) and tactile vibration is produced by vehicle tire drop to alert even truck drivers quite effectively. Turnpike maintenance vehicles can use the rest of the shoulder for routine work and can plow down to bare pavement without "shoes" on the snowplows. SNAP's shallow shape and proximity to passing traffic keeps them cleaned out. When milled in, they have not been wearing or smoothing out after use because material was physically removed in the milling process. Rolled-in or impressed patterns show some smoothing out since material was pushed out of shape for installation and flexible asphalt pavement can recover shape under traffic (**4**). SNAP has also been successfully "bull floated" into wet concrete but is more frequently milled into the completed concrete shoulders. Specifications now call for milling or grinding the 7 in. (17.78cm) openings. Costs are now less than $0.30 per foot (.305m) of asphalt shoulder. Installation of SNAP on both shoulders of 1 mile (1.61km) of highway can now be completed in 6 hours for less than $5000. Completion of the entire 506-mile (815km) system will end up costing the Turnpike between $2 and $3 million.

FIGURE 2: Close-up of SNAP.

INITIAL RESULTS

Initial results from the first five projects in reducing drift-off-road (DOR) accidents are shown in Table 1. Only reportable accidents (i.e., those involving fatality, injury or vehicle damage requiring towing) were used throughout this study. DOR accidents considered in Table 1 include single vehicles striking objects off the right side of the roadway where SNAP was installed and the accident did not result from a mechanical defect or blowout. Some accidents were included that were affected by adverse weather, alcohol or construction zones where the effectiveness of SNAP was limited or negligible. Project #1 was the 3-mile (4.8-km) segment where SNAP was first tested on actual Turnpike in 1989. After 18 months, a dramatic reduction in DOR accidents led to a decision to install SNAP systemwide as a part of all roadway resurfacing projects. In 1993, accident reports for the first five projects were evaluated in terms of DOR accidents per month. Seasonal effects were minimized by selecting roadway segments with over 12 months of accident data before and after installation of SNAP. A before-to-after reduction of 70 percent led to accelerating SNAP installation for all roadway segments including those that had been recently repaved and were not scheduled for resurfacing for several more years.

TABLE 1 First 5 Projects' Drift-Off-Road Accident Data

1 PROJECT # (MILES)	2 ACCIDENTS/ MONTHS BEFORE	3 ACCIDENTS/ MONTHS AFTER	4 TRAFFIC (AADT) BEFORE/AFTER	5 DOR RATE (ACC/100 MVM) BEFORE/AFTER

1 (3) 2 (4) 3 (10) 4 (5) 5 (6)	21/30 16/37 20/37 22/37 12/37	8/42 1/22 2/15 5/15 1/14	29500 / 30056 27360 / 24913 18376 / 17164 28913 / 26597 15279 / 16103	26.0 / 6.9 13.0 / 1.5 9.7 / 2.6 13.5 / 8.2 11.6 / 2.4
AVERAGE:	.518 ACCIDENTS per MONTH	.155 ACCIDENTS per MONTH (70% Reduction)		14.76/4.32 ACC per 100 MVM (71% Reduction)

Examining accidents and months (shown in Columns 2 and 3 of Table 1) numbers indicate accidents decreased from an average of 0.518 per month before SNAP was installed to 0.155 after SNAP treatment in five roadway resurfacing projects. More detail about SNAP's development, testing and initial 70 percent reduction in accidents was contained in a widely distributed report by Wood and presented to the annual Meeting of the Transportation Research Board in January 1994 (*3*). That presentation and report raised questions regarding traffic exposure, control segments for comparison, accident migration, and regression to the mean. Data in Columns 1, 4, and 5 of Table 1 supplement the PA Turnpike's earlier report by including projects' lengths in miles, average annual daily traffic (AADT) before and after SNAP installation, corresponding DOR accident rates per 100 million vehicle miles (MVM). Average DOR rates decreased by 71 percent. There was no practical way to retrieve before-and-after results for control segments for comparison with these data; therefore, this is included later in this study.

To consider regression to the mean, DOR rates before SNAP were compared with DOR rates for similar roadway segments. Project #1 had originally been selected for the first "live" testing of SNAP because it had such a high DOR rate. Moreover, it needed shoulder slope corrections that were included in resurfacing work that was done with the SNAP treatment. So Project #1 indeed had some likelihood of improving by chance (by regression to the mean) as well as by other improvements to the right shoulder. The next four projects were high in their DOR rates for the 37 months before SNAP treatment, but not extraordinary when compared to similar long stretches away from Pittsburgh and Philadelphia commuter traffic. They had been selected for SNAP treatment based on their sequence in resurfacing schedules rather than high DOR rates. Average DOR rates for Projects #2 to 5 decreased by 69 percent from 11.95 per 100 MVM before to 3.675 per 100 MVM after SNAP treatment (7.42/100 Million Vehicle Kilometers to 2.28/100MVK). Over the same period, all accidents on the Turnpike declined by 12%. Adjusting for this overall decline results in a 65% reduction in DOR rates attributable to SNAP.

FOLLOW-ON RESULTS

After reporting high DOR rates and impressive reductions attributable to SNAP treatment, a noticeable decline in single-vehicle, off-right-side accidents could reasonably be expected after SNAP was installed over more of the Turnpike system. This could be evaluated as persuasive evidence of SNAP's effectiveness. Table 2 shows a comparison of these single- vehicle accidents and traffic over the initial years of SNAP installation.

TABLE 2 Single-Vehicle Accidents and "SNAP" Treatment

	Year:	1990	1991	1992	1993	1994	1995
1	% Traffic Encountering SNAP	1 %	2 %	7 %	26 %	56%	82 %
2	All Single Vehicle Accidents Hit First Object Off Right Side	313	251	280	300	270	297
3	Not Treatable; & Affected by Weather, Variables, etc.	141	79	119	175	202	223
4	Susceptible to "SNAP:" • "Drowsy, Fatigue:" • Truck Accidents:	172 (55) (19)	172 (57) (11)	161 (57) (14)	125 (38) (14)	68 (28) (4)	74 (27) (8)
5	All single Vehicle Accidents: All Reported Accidents:	1107 1620	918 1352	969 1390	1033 1482	1072 1675	1186 1688
6	Traffic (in 100 MVM)	43.00	41.77	41.95	42.74	43.55	45.53

The first line of Table 2 shows the percent of traffic for each year that would have encountered SNAP on the shoulders. For example, while 80 percent of the Turnpike had SNAP installed by the end of 1994, most installation was actually done in the Fall at the end of the construction year. Therefore only 56 percent of 1994's traffic would have been affected by that treatment. The second line of the Table shows all single-vehicle accidents where the first object hit was off the right side of the roadway. There was no immediately observable effect from SNAP, but unusual amounts of snow and ice during 1993 and 1994 were suspected to have influenced these results. Therefore, details of these accidents needed to be screened to determine the numbers of accidents that were clearly affected by annually variable weather as well as those accidents that could not have been affected by SNAP at all. The numbers of these accidents that were screened out for each year are shown on the third line of Table 2. After subtracting these, the numbers shown in bold on the fourth line represent accidents that were susceptible to SNAP treatment and not affected by annually variable snow, ice and slippery conditions. These numbers can be compared with percentages of traffic encountering SNAP treatment shown on the first line of Table 2 to see the effect over these six years. They show a reduction from 172 to 74, or 57 percent, from 1990 to 1995. Of these, the numbers listed as "Drowsy, Fatigue" were coded with that as a contributing factor on police accident reports. Also included are "Truck Accidents," for large trucks only; results look promising with a 60 percent reduction from 1990+1991 (30 treatable accidents) to 1994+1995 (12 treatable accidents).

Table 3 is provided for a closer look at the kinds of single-vehicle accidents excluded from "SNAP" evaluation and shown as "Not Treatable" on the third line of Table 2. These were excluded to compare only those accidents that SNAP could affect and not those primarily affected by weather or other variables.

TABLE 3 Single-Vehicle Accidents Excluded for "SNAP" Evaluation

Year:	1990	1991	1992	1993	1994	1995
Not Susceptible to SNAP; Subject to Annual Variables	141	79	119	175	202	223

• Weather: Snow, Ice, Slippery, Wet, & Spun Out	(69)	(38)	(63)	(96)	(129)	(139)
• Blow Out, Flat, Mechanical Defect, Improper Towing	(19)	(8)	(12)	(20)	(20)	(18)
• Forced Movement, Evading Object, Animal	(24)	(14)	(17)	(18)	(17)	(18)
• Other: Work Zone, Blackout, Inside Vehicle Event	(29)	(19)	(27)	(41)	(36)	(48)

Not all accidents affected by weather were beyond help by SNAP. The pattern is audible and tangible as a vibration even through some snow and ice. Drivers report that SNAP is useful to tell where the edgeline is through snow, and snowplow operators report they sometimes guide on the rumble pattern. Weather-related accidents were subtracted to remove an annual variation that could mask SNAP's effectiveness, not necessarily because SNAP could have no effect. Non-weather-related accidents excluded from comparison generally involved a substantiated causation factor, driver action, or event occurring in the travel lanes that made the accident inevitable before the vehicle passed over the shoulder rumble strips. The influence of weather and the plausibility of it masking SNAP's effectiveness can also be evaluated by examining data on all reportable accidents directly from the Pennsylvania Department of Transportation's Accident Record System shown in Table 4.

TABLE 4 All Reportable Accidents

Year:	1990	1991	1992	1993	1994	1995
Total:	1620	1352	1390	1482	1675	1688
• Multi-Vehicle	513	434	421	449	603	502
• Single Vehicle	1107	918	969	1033	1072	1166
Probable Factors:						
• "Slippery"	74	50	103	110	186	109
• "Drowsy"	143	117	114	84	81	91
Surface Condition:						
• Dry	1110	1007	892	957	980 386	1084
• Snow, Ice	129	85	171	223	309	236
• Wet	381	260	327	302		368
Weather:						
• OK	1157	1033	918	987	1102	1135
• Snowing, Sleet	125	94	175	242	289	257
• Raining, Fog	338	225	297	253	284	296
Traffic (100 MVM)	43.00	41.77	41.95	42.74	43.55	45.53

"Slippery" and "Drowsy" in Table 4 were numbers of accidents coded with those probable factors and totaled in accident summaries for each year. Pavement "Surface Conditions" and

"Weather" were also coded and summarized by year. An increase in accidents due to slippery, snow and ice is evident for 1993 to 1995. A drop in traffic in 1991 and 1992 was due to an economic downturn and fare increase. The drop in drowsy-related accidents could be evaluated as further support for SNAP's effectiveness, but its relationship is not clear. Probable factors coded for each accident are based on investigators' judgment at the time of the accident. Special emphasis on speed, driving under the influence (DUI), or other safety enforcement programs can influence coding and the distribution of accidents by category. This coding may not entirely reflect real change or useful data for calculating DOR accident rates or evaluating SNAP treatment; these numbers can only be viewed as indicators and some support for SNAP's effectiveness.

Accidents listed in Tables 2 to 4, presented earlier, were screened and categorized for susceptibility to SNAP treatment without regard for whether SNAP had been installed or not. The next step for this follow-on analysis was to locate each of these accidents by roadway segment for each year in a timeline that included SNAP installation dates. SNAP and Recessed Reflective Pavement Markers (RRPM) were routinely included in repaving projects after 1991. RRPM are installed along the skip-line between same-direction travel lanes and are not believed to have much effect on the off-right-side accidents considered in this evaluation of SNAP effectiveness. The accelerated SNAP and RRPM installation program starting in 1993 resulted in 25 roadway segments treated without other roadway work in order to improve safety on that segment before its scheduled full rehabilitation in several more years. There were also 13 roadway segments where no treatment took place during the study period.

Table 5 compares DOR rates for all roadway segments excluding those with less than 12 months of data BEFORE or AFTER and excluding construction periods. This minimized seasonal effects and discounted any unusual traffic patterns during the entire time of construction. BEFORE periods averaged 41.1 months and AFTER averaged 24.8 months. Fifty-three treated segments experienced a 60 percent reduction in treatable-type accidents per Vehicle-Miles-Traveled (VMT) as shown across the first row of Table 5. This was a reduction of 2.3 accidents per 100 MVM (1.43 accidents per 100MVK) or 6.6 percent of annual accidents.

TABLE 5 DOR Rates BEFORE & AFTER SNAP/RRPM Treatment

	BEFORE	AFTER	Reduction
53 Treated Segments (348 miles)	**3.81 per 100MVM** (421 Accidents/ 110.6 x 10^8 VMT)	**1.54 per 100MVM** (105 Accidents/ 68.4 x 10^8 VMT)	60 %
25 Segments Treated with only SNAP & RRPM (186 miles - no repaving)	**3.84 per 100MVM** (275 Accidents/ 71.7 x 10^8 VMT)	**1.41 per 100MVM** (56 Accidents/ 39.8 x 10^8 VMT)	63 %
13 Untreated Segments; 1990-92 vs 1993-95 (90 miles - interspersed)	**3.97 per 100MVM** (93 Accidents/ 23.4 x 10^8 VMT)	**2.74 per 100MVM** (58 Accidents/ 21.2 x 10^8 VMT)	31 %

Twenty-five segments treated with only SNAP and RRPM, without any other pavement or shoulder work, are shown on the second row of Table 5; they exhibited a reduction of 63 percent. This suggests that the other work that was usually performed along with SNAP treatment did not contribute to the DOR accident reductions.

Untreated segments shown on the bottom row of Table 5 could represent control sections, except that DOR accidents selected for comparison were very likely to have been affected by SNAP installed in adjacent sections of roadway. Roadway segments are 2 to 11 miles (3.2 to 17.7 km) in length and average 6.6 miles (10.6 km). A spillover effect is probably evident here as drivers alerted to their drowsiness or inattention could remain affected for the 2 - 10 minutes required to traverse untreated segments at highway speeds.

OTHER OBSERVATIONS

Use by Other States.

SNAP is being used or tested in many states including Pennsylvania, New York, New Jersey, Massachusetts, Idaho, Montana, and others. Some install it more than four inches (10.16 cm) from the edgeline to reduce incidental noise. Environmental noise that disturbs nearby residents is possible, especially if patterns are placed at exit ramps, access points for service or maintenance facilities, or other locations where noise will be generated by more than the occasional errant vehicle. Most nearby residents seem to appreciate the safety benefit of alerting errant vehicles provided the noise is unintended and not too frequent.

Drowsy Drivers.

Sleep-deprived drivers cannot predict or prevent their next onset of drowsiness. SNAP can alert drowsy drivers to their dangerous condition, but it is only a warning for drivers to take some countermeasure such as a nap (even a short "power nap"), fresh air, coffee, a walk, or changing drivers. These countermeasures are being publicized, while also emphasizing the need to get enough sleep before starting on a trip.

Drivers Reaching for Things.

In screening accident reports it was noted that some accidents are caused by drivers reaching for things such as cigarettes, lighters, cassette tapes, CDs, cellular phones, toll tickets, or children, or reacting to other events in their vehicles while driving. They may not realize that they drifted, most often to the right. SNAP on right shoulders may alert some of these drivers before roadway departure has progressed too far to recover. SNAP can also be installed on left shoulders of divided highways where medians are wide enough for an appropriate reaction to the rumble strip warning.

CONCLUSIONS

Accidents involving apparently mechanically-sound, single vehicles that drove, rather than slid, off the right side of the roadway were reduced from 3.81 accidents per 100 MVM (2.37/100MVK) before SNAP-design shoulder rumble strip treatment to 1.54/100 MVM (.96/100MVK) after treatment, for a DOR accident reduction of 60 percent over 53 segments totaling 348 miles (560 km) of roadway. This type of accident was 11.6 percent of 2,972 total accidents on the Pennsylvania Turnpike in 1990+1991 before the SNAP installation program could have had any appreciable effect. Reductions of 2.3 accidents per 100 MVM

(1.43/100MVK) or about 100 accidents per year on the Pennsylvania Turnpike system are considered to be attributable to SNAP. This demonstrated a substantial safety benefit.

REFERENCES

1. Chaudoin, J.H., and G. Nelson. *Interstate Routes 15 and 40 Shoulder Rumble Strips.* Caltrans-08-85-1, Traffic Operations Branch -- District 8, California Department of Transportation, August 1985.

2. Ligon, C. M., E. C. Carter, D. B. Joost, and W. F. Wolman. *Effects of Shoulder Textured Treatments on Safety.* FHWA/RD-85/027. FHWA, U.S. Department of Transportation, May 1985.

3. Wood, N. E. Shoulder Rumble Strips: a Method to Alert "Drifting" Drivers. Presented at the 73rd Annual Meeting of the Transportation Research Board, Washington, D. C., 1994.

4. Harwood, D .W., *NCHRP Synthesis (191): Use of Rumble Strips to Enhance Safety. A Synthesis of Highway Practice.* TRB, National Research Council, Washington, D. C., 1993.