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THE DEACCELERATOR: A BEHAVIORAL SOLUTION TO HIGHWAY SPEEDING

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Anyone engaging in highway travel can see that many motorists drive in excess of the posted speed limit. According to the U.S. Department of Transportation, speeding is of epidemic proportion on a national scale and has become the number one killer of teenage drivers and young adults. Moreover, excessive vehicle speed is responsible for the death of 1,000 Americans each month, while speed-related accidents take an economic toll estimated at $27.4 billion per year (U.S. Department of Transportation: National Highway Traffic Safety Administration as cited in National statistics about speeding, 1995-2003).

Putting the brakes on speeders is the responsibility of local and state police. However, the number of police patrols is sparse relative to the vast road mileage that carries a large and rapidly increasing number of motorists, rendering consistent enforcement of the posted speed limit an impossible task.

Effective speed control has been attained on a large but select population of motor vehicles by way of an in-vehicle solution. For decades, many vehicle fleet owners and managers have used speed governing systems to ensure that their drivers do not engage in highway speeding. The governor is an in-vehicle speed control system that imposes an artificial ceiling on the top speed a vehicle can be driven. The fleet operator can request any imposed unalterable maximum speed for fleet vehicles, and the governor is then preset for that speed. Thus, if a vehicle is governed for 65 miles per hour, the driver cannot, under any conditions, exceed this imposed maximum speed. Such a system reduces fuel and vehicle maintenance costs (e.g., tires, shocks, brakes, engine overhaul). Governing systems can be found in semi-trucks, small diesel and gasoline powered trucks, rental vans and vans used for other business purposes, and buses used by schools and the commercial transport industry.

Governors, while very effective as a form of speed control, do have drawbacks. First, the driver of a governed vehicle cannot engage in emergency or necessary speeding regardless of the need to do so. Great care must be taken by the driver not to get into a passing situation that necessitates increased speed beyond the governed speed. Second, the flow of traffic (variability within and between drivers' traveling speeds) can be dangerously disrupted when one governed vehicle passes another governed vehicle. Highway travelers often encounter a situation where the driver of a semi-truck ahead suddenly moves into the passing lane to overtake a slower moving semi-truck. Frequently it takes the semi-truck a relatively long time to pass, with motorists traveling behind having to reduce their traveling speed abruptly, creating a bottleneck in traffic.

The problem arises, in part, because many trucks are governed at similar highway speeds. If one truck, governed at a maximum speed of 66 miles per hour, is passing another truck governed at a maximum speed of 65 miles per hour, the unavoidable slow passage can set the stage for dangerous traveling conditions for motorists following in close proximity. Despite these problems, governing systems remain a popular OEM and after-market item for companies operating vehicle fleets that see a good deal of highway travel.

One might wonder why governors have not had appreciable market penetration with respect to vehicles driven by teenagers. After all, it has been established that teens often engage in dangerous driving behavior which is precisely why insuring this population is a costly undertaking. One guess is that many parents are not familiar with vehicle governing systems. A second guess is that even if they were, parents of teenage drivers could never forgive themselves if their son or daughter got into an accident because the governed vehicle did not permit an increase in speed beyond the governed speed when it was required for safety-related reasons.

The governor was not originally developed for vehicular speed control, but rather, came about as a means for preventing stationary motors from operating beyond their specified capacity (Pavlinovich, 2003). The transition to governing moving vehicles was a crude one indeed, involving an imposed ceiling on engine revolutions per minute (RPMs) followed by the development of a governing system that restricted fuel intake to directly limit top road speed to a preset and unalterable maximum value.

What follows is a behavior analysis of highway speeding, a proposed in-vehicle solution to the problem, and the results of a field test of that solution, the execution of which was an interdisciplinary endeavor involving behavioral, mechanical, and electrical engineering. It should be noted that the Federal Highway Administration, following a world wide review of over 200 speed control systems and concepts, ranked this behaviorally based speed control system as the most promising in-vehicle solution to the highway speeding problem (U.S. Department of Transportation, 1985).

A Behavioral Analysis of Highway Speeding

Many factors are responsible for highway speeding. And while the analysis that follows does not cover all of these factors, it does examine those required to formulate a solution to the problem.

Behavior is, of course, properly analyzed according to its controlling variables. Extending this analysis to highway speeding, it seems probable that two occasionally overlapping operant classes of behavior are of major concern. One class of behavior produces “necessary” highway speeding, and the other class produces “unnecessary” highway speeding.

Necessary Highway Speeding

Infrequent but compelling conditions occur when highway motorists must exceed the posted highway speed limit to preserve their safety. Necessary speeding occurs as a consequence of the motorist’s response (accelerator pedal depression) to these emergency situations and is reinforcing because of its past differential correlation with escape from these situations. Moreover, the value (Michael, 1982) of increasing speed as reinforcement increases as a function of the physical proximity and/or approach speed of the aversive stimulus conditions that characterize an emergency situation.

To illustrate, when one motorist passes another on an incline—only to discover a quickly approaching oncoming vehicle, while concurrently, the former road space is being closed by the vehicle(s) being passed—the threatened motorist will engage in behavior (depression of the accelerator pedal) that is reinforced by increasing vehicle speed. This increase in vehicle speed is reinforcing because it has been differentially associated with a successful escape from similar aversive situations in the past. As reinforcement, the value of increased vehicle speed and thus the current strength of behavior evoked by an emergency situation are determined by the proximity and the speed of the approaching vehicle. Most often, a successful (or unsuccessful) outcome regarding escape from an emergency situation is determined within a short time. Thus, besides the compelling nature of reinforcement (successful escape from a highly aversive situation) and the increased value of vehicle speed, the close temporal relationship between the required behavior and the reinforcing stimulus change that escape produces brings to great strength the response of accelerator pedal depression. This, of course, increases the future likelihood of necessary highway speeding.

Unnecessary Highway Speeding

A different analysis holds for unnecessary highway speeding and the operant class that generates and sustains it. Increases in vehicle speed reinforce behavior (again, accelerator pedal depression) that produces them because in the past each increment has reduced the time to reinforcement (arrival at one's destination) relative to the time that would have resulted from the maintenance of vehicle speed. The relative reduction in the time to arrival is also a function of the rate of acceleration in vehicle speed. With experience, the immediate stimulus changes correlated with a given rate of acceleration can function as a supplementary source of conditioned reinforcement and, as a controlling stimulus, can evoke behavior that generates a still greater rate of acceleration.

There are, however, constraints on behavior that results in continually increasing vehicle speed. As vehicle speed increases, the probability of an accident also increases, as does the likelihood of being stopped and ticketed by a police officer. Motorists have been exposed to a history of punishment that reflects these increased probabilities and have acquired contingency-shaped and rule-governed repertoires involving successful movement through space that is densely occupied by stationary as well as moving objects.

Under most conditions, this history ensures that a motorist will curtail further increases in unlawful speed at speeds well below the vehicle's maximum velocity. Consequently, what generally occurs is that a motorist accelerates to an unlawful speed and maintains that speed for extended periods of time. Not only is unlawful speed maintained at a given value because it cannot increase indefinitely, but it is also maintained because decreases in speed are punishing in that in the past these decrements have increased the time to reinforcement (arrival). The immediate stimulus changes correlated with a given rate of deceleration can come to function as a supplementary source of conditioned punishment and, as a controlling stimulus, can evoke behavior that generates an increase in speed.

This analysis of unnecessary speeding suggests that although both the onset of and increases in unlawful speed are indeed problems, the maintenance of unlawful vehicle speed presents a clearly greater problem since motorists allocate far more traveling time to the latter than to the former. Even when traveling a great distance, the overall decrease in the time to arrival by the onset of unlawful speed and its subsequent increase is slight. But maintenance of the increased velocity in comparison to a lesser vehicle speed appreciably reduces the time to arrival. An additional implication of this analysis is that any method that curtails behavior maintaining an unlawful speed will correspondingly decrease the value of the reinforcement produced by initiating unlawful speed.

Just as the intensity of the aversive stimulus (e.g., the proximity and/or approaching speed of an oncoming vehicle) determines the current strength of behavior producing necessary speeding, so there are motivational variables determining the current strength of behavior producing unnecessary speeding. The evocative potential of these motivational variables is determined, in part, by the motorist's history with the reinforcements and punishments relevant to these variables. Combined with prevailing conditions of deprivation, aversive stimulation, and/or other establishing operations, the present relationship of these past reinforcements and punishments to arrival determines the reinforcing value of vehicle speed. As is evident, a wide range of motivational variables can determine the value of vehicle speed and thus the subsequent strength of behavior that results in unnecessary highway speeding.

Consequences of behavior that generates unnecessary highway speeding are not nearly as immediate or potentially severe as are the consequences of necessary highway speeding. Much of the prolonged behavior (sustained accelerator pedal depression) producing unnecessary highway speeding does not share a close temporal proximity to its final consequence (arrival). These factors generally combine to ensure that behavior producing unnecessary highway speeding is quite weak relative to behavior producing necessary highway speeding.

The temptation to overestimate the strength of behavior generating unnecessary highway speeding arises from its frequency. This kind of speeding is indeed ubiquitous. Rather than being indicative of strong behavior, however, the frequency with which unnecessary speeding occurs can be more readily explained in terms of the ease with which the behavior is executed and sustained, its infrequent production of punishment relative to its occurrence across time, and the nearly continual opportunity it provides to alter favorably the time to arrival.

We may conclude that an ideal solution to the highway speeding problem entails meeting two criteria. First, the motorist's capacity to engage in necessary speeding (relatively strong but infrequent and briefly executed behavior) must always be preserved, and second, unnecessary speeding (relatively weak but frequent and prolonged behavior) must be reduced across the wide range of motivational variables that determine its strength.

The Deaccelerator: A Proposed Solution to Highway Speeding

Experimental research suggests that sufficiently increasing the force required to operate a manipulandum will, under similar stimulus conditions, decrease the future probability of the reinforced behavior producing that imposed force requirement (Chung,1965; Miller, 1970). That is to say, the stimulus change generated by a substantial increase in a force requirement functions as punishment. Miller addressed the problem of temporal simultaneity of response and consequence in defining an imposed force requirement as punishment. In the second link of a chain schedule, he increased the force required to operate the manipulandum. The result was decreased responding in the first link of the chain. Thus, even with temporal separation of response and consequence, an imposed force requirement functioned as punishment.

Recent research by Alling and Poling (1995) brought into question the assumption that an increased force requirement functions as punishment by demonstrating its differences from shock as an established punishing stimulus. Mid values of increased force did not yield response recovery over time, nor did increased force generate the higher response rates typical of punishment contrast in multiple schedules. Finally, unlike shock, increased force did not produce differential response rates as a function of the point in the schedule at which it was interpolated. Nevertheless, although this work examined the finer points concerning the exact function of increased force as a variable affecting behavior, it clearly showed that an imposed force requirement is a potent and enduring suppressor of responding. (For a succinct and informative review of the literature relevant to increased effort, see Friman and Poling, 1995.)

Experimental research also suggests that behavior that terminates an imposed force requirement produced by reinforced behavior will, under similar stimulus conditions, increase in its future probability of emission (Miller, 1968). That is, the stimulus change produced by the termination of an imposed force requirement functions as reinforcement.

A solution to the highway speeding problem may well consist of the immediate and systematic application of the principles of punishment and reinforcement to the behavior of the speeding motorist. Specifically, punishment and reinforcement may be used to alter the behavior of a motorist by way of a primary differential force schedule applied to the accelerator pedal of a motor vehicle as a function of respective increases and decreases in unlawful highway vehicle speed. A secondary force schedule involving differential punishment and differential reinforcement may also be applied to the accelerator pedal as a function of respective increases and decreases in accelerator pedal depression once highway speeding begins. (This supplementary force schedule may be effective because, at the very least, behavior producing changes in the degree of accelerator pedal depression is precursory to behavior that will effect changes in vehicle speed.)

The Deaccelerator, an in-vehicle speed control system, imposes a differential force schedule to the accelerator pedal of a motor vehicle to control behavior producing highway speeding. What follows are the particulars of the device, its behavioral evolution, and the results of field research. The latter entailed installing and testing the Deaccelerator in a state-provided car used by Western Michigan University faculty for work-related travel.

Selection of an Imposed Force Schedule

Time and expense rendered testing differently shaped force distributions prohibitive. The goal was to select a schedule that was effective and enduring at the lowest possible force value(s). The imposed force values (pounds of back pressure), chosen were based on “foot on” (as opposed to “hands on”) testing with a spring-loaded bathroom scale. As for selecting the shape of the force schedule, the basic principles of behavior served as the guide. What follows is the manner in which these principles were applied in selecting the shape of the imposed force schedule.

Figure 1 shows a force schedule that imposes a single high value of accelerator pedal resistance once the preset speed is exceeded. It is simple and easy to implement. But two potential variables are bothersome. First, once vehicle speed exceeds the preset speed, behavior producing further increases in speed is not differentially punished. Second, and more important, once speeding commences, behavior producing decreases in speed is not differentially reinforced. Only one class of behavior is punished (the onset of speeding) and only one class of behavior is reinforced (the cessation of speeding). Thus, once highway speeding begins, increasingly higher unlawful speeds are not differentially consequated, and neither are progressive decreases in unlawful speeds. One can imagine a stubborn long-time speeder who, on a fairly regular basis, accelerates to high speeds and attempts to maintain a high speed for extended time periods. Prolonged exposure to the single high value of imposed force could have a strengthening effect on the muscle groups used in maintaining a constant force against the pedal, permitting the motorist to speed for increasingly extended periods of time.

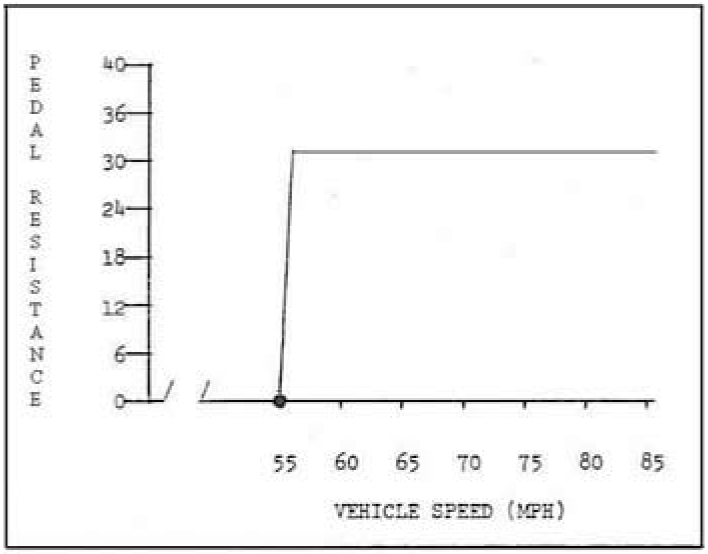

Figure 1
A Single High Value of Imposed Accelerator Pedal Resistance
As a Function of Unlawful Highway Vehicle Speed

The key seemed to lie in developing an imposed force schedule that limited the amount of time a speeding motorist spent at any incremental value of imposed accelerator pedal resistance, such as the linear differential force distribution shown in Figure 2. Behavior generating any increase in highway speeding is differentially punished, while behavior producing any decrease in highway speeding is differentially reinforced. Such a force schedule makes for a vast number of possible response classes to be consequated by corresponding changes in imposed accelerator pedal resistance.

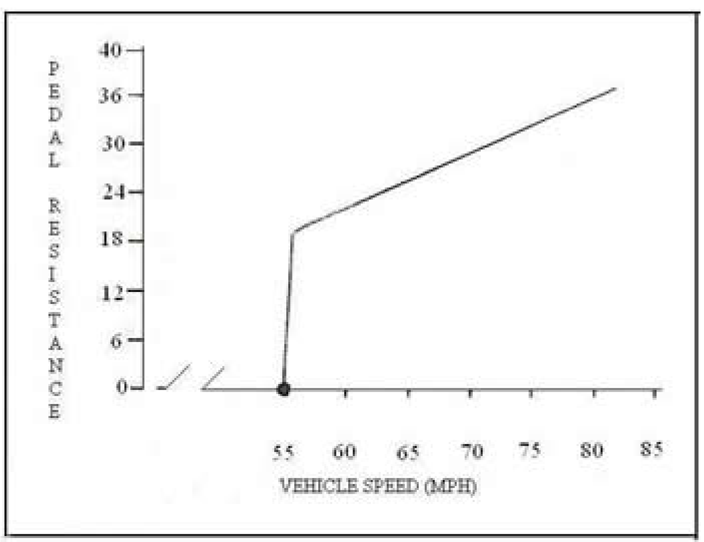

Figure 2
A Linear Distribution of Imposed Accelerator Pedal Resistance
As A Function of Unlawful Highway Vehicle Speed

However, by its very nature, this linear distribution of imposed accelerator pedal resistance as a function of unlawful highway speed renders behavior that decreases excessive highway speeds more reinforcing than behavior that decreases lesser highway speeds; the imposed values of accelerator pedal resistance and thus the aversive stimulation they generate are greater at higher unlawful speeds than at lower unlawful speeds. One option would be to raise sharply the incline of the slope of the linear distribution shown in Figure 2, thus increasing the absolute and relative magnitude of reinforcement of all imposed pedal resistance values across the unlawful speed range. This would increase the values of both aversive stimulation and subsequent reinforcing stimulus changes as a function of behavior that decreases unlawful speeds. Another alternative would be to begin the distribution at a higher initial resistance value while retaining the slope shown in Figure 2. This would increase the absolute magnitude of reinforcement for behavior that decreases unlawful speed, while the relative magnitude of reinforcement would remain unchanged. A third option would be to manipulate both the initial resistance value and the incline of the slope so as to increase the effectiveness of the linear distribution that makes up the imposed force schedule.

But a problem would remain. Putting any of these options in place would yield a distribution with excessively high end values. A solution might be to truncate the range of increasing values that make up the imposed linear force schedule. But then we would be left with a distribution that would provide differential reinforcement across a much smaller portion of the unlawful speed range leaving much of the higher end of this speed range with a flat, non-differential force function.

The solution to the problems inherent in a linear function is shown in Figure 3, which depicts a curvilinear differential force schedule as a function of unlawful highway vehicle speed. This negatively accelerated distribution of accelerator pedal resistance ensures that as unlawful speeding decreases to marginally unlawful speeds, the rate of decrease in accelerator pedal resistance increases. Thus, the relative magnitude of reinforcement (the rate of decreasing accelerator pedal resistance) increases with decreasing vehicle speed in the range of unlawful speeds that are marginally excessive. In addition, this function allows for latitude in the range of selected end values. High initial values do not have to yield excessively high end values. Also, the distribution of a differential force schedule across a large portion of the unlawful speed range need not be compromised.

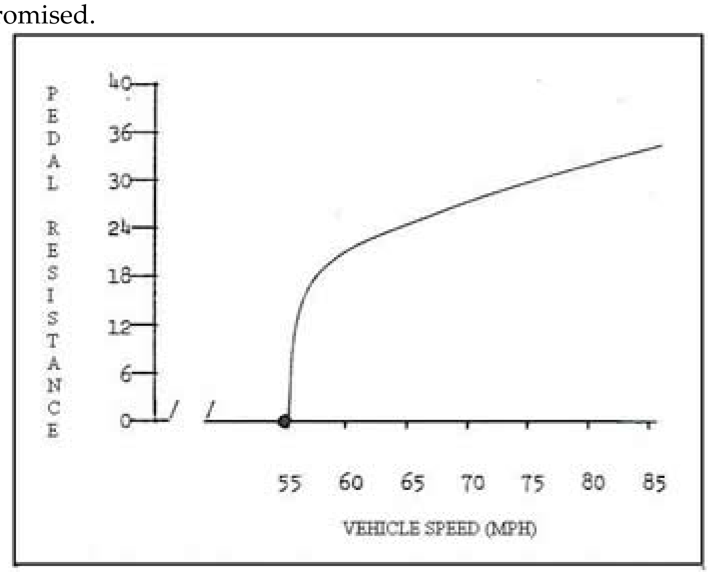

Figure 3
Negatively Accelerated Distribution of Imposed Accelerator Pedal Resistance
As a Function of Unlawful Highway Vehicle Speed

The function shown in Figure 3 was ultimately selected for the task at hand. But even this function, more so than the linear function shown in Figure 2, could present problems of a different nature than those previously discussed.

Increases and decreases in unlawful highway speeding are correlated with respective increases and decreases in accelerator pedal resistance. Thus, given potent motivational variables, increases in unlawful speed may function as a source of reinforcement which could render corresponding increases in accelerator pedal resistance a conditioned reinforcer as well as a controlling stimulus for behavior producing further increases in unlawful speed. Moreover, decreases in unlawful speed may function as a source of punishment which could render corresponding decreases in accelerator pedal resistance a conditioned punisher as well as a controlling stimulus for behavior producing increases in unlawful speed. Thus, the saliency of the stimulus changes produced by changing accelerator pedal resistance values is a concern. Unlike the saliency of the stimulus changes comprising the differential linear distribution shown in Figure 2, the saliency of stimulus changes making up the negatively accelerated distribution is not equivalent across all resistance values. Rather, it differentially decreases with increases in unlawful speed and differentially increases with decreases in unlawful speed across that portion of the distribution containing curvature.

As noted earlier, by sharply curtailing the maintenance of unlawful speed, the value of initiating unlawful speed decreases. So, regarding stimulus saliency, the increasing rate of change in pedal resistance values when a motorist decreases unlawful speed is far more critical than the decreasing rate of change that occurs with the initiation and subsequent increase in unlawful speed.

A possible solution to the potential problem caused by a differentially increasing rate of stimulus change that accompanies decreases in unlawful speed is to adjust the curvilinear force schedule so that it is less rounded at the portion of greatest curvature that occurs at marginally unlawful speed. This should render these stimulus changes less likely to generate problematic behavior. Moreover, the use of a curvilinear force distribution permits adjustment of the slope at the linear portion that is imposed at the higher end of the unlawful speed range.

After considerable fretting over all the issues taken into account regarding the selection of a differential force function and more trials with the bathroom scale and stretchable exercise springs, it seemed that the negatively accelerated function was, from a behavioral standpoint, and experience with the aforementioned makeshift equipment, the best way to go. Given these considerations, a negatively accelerated distribution of accelerator pedal resistance values as a function of unlawful speeding was selected.

Maxwell's Second Law of Thermodynamics

The first Deaccelerator was built and installed in a test vehicle. Then Maxwell reared his weary albeit ubiquitous head and entropy ensued. While the system worked very well at unlawful speeds, its performance was disorderly at the preset speed. The Deaccelerator had been designed to render the accelerator pedal a comfortable foot rest when the driver traveled at the preset speed. A motorist could just lay the natural weight of the foot on the accelerator pedal when traveling at that speed. As Figures 1, 2, and 3 show, each function has the steepest rise in accelerator pedal resistance from 55 mph to 56 mph. It was assumed that a motorist would find reciprocity between natural foot weight and imposed accelerator pedal resistance within this 1 mph speed range.

As the motorist approached an incline, highway vehicle speed would slow down, arbitrarily, from 55.6 mph to 55.2 mph. At this point, the motorist’s natural foot weight on the accelerator pedal would be slightly greater than the back pressure produced by the Deaccelerator at that reduced speed. The driver’s natural foot weight would then be expected to overpower and further depress the accelerator pedal until vehicle speed reached a point at which the corresponding accelerator pedal resistance was once again in a reciprocal relationship.

When the motorist encountered a downhill gradient, the vehicle would speed up and the imposed accelerator pedal resistance would then be greater than the motorist’s natural foot weight, and so the pedal would push the motorist’s foot up until the vehicle reached a speed at which the two were reciprocal. This is not what happened. Instead, the device would not allow the accelerator pedal to “settle down” when the motorist traveled at the preset speed. Rather, the system cycled around the preset speed, causing the piston to make the pedal rapidly pump up and down against the driver’s foot. It was a real conundrum. The rest of the Deaccelerator’s performance was excellent. Nevertheless, we had a completely unacceptable system performance. The marketplace would most certainly reject this potential product. And so would I!

Many engineers later, a proper electronics systems control analysis revealed the source of the pumping pedal problem that occurred at the preset speed. There was an inherently unstable loop in the pressure control circuit. This meant that the simple concept of a force only control system to curtail highway speeding, as shown in Figure 3, was not feasible. The Deaccelerator’s operation at the preset speed had to be supplemented by a position control system which was also critical to the development of cruise control.

The Final System

The Deaccelerator’s position control system, shown as the horizontal line from 54 mph to 56 mph in Figure 4, uses a 14 pound back force to limit the motorist’s degree of accelerator pedal depression to the position required to maintain the preset speed. The system’s piston operates across a 2 mph speed range, from 1 mph below the preset speed to 1 mph above the preset speed. As vehicle speed exceeds 1 mph above the preset speed, the negatively accelerated force schedule becomes active, while at speeds less than 1 mph below the preset speed the accelerator pedal functions normally. All the motorist has to do to maintain the preset speed is depress the pedal far enough so that it remains in sustained contact with the Deaccelerator’s piston, which, along with the actuator, is located underneath the accelerator pedal. In conjunction with the motorist’s accelerator pedal depression, the piston will make adjustments in accelerator pedal position so as to ensure travel at the preset speed.

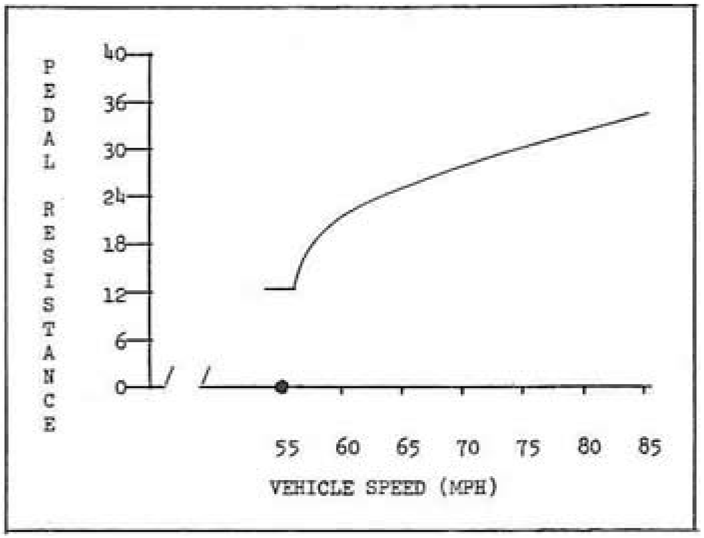

Figure 4
Negatively Accelerated Distribution of Imposed Accelerator Pedal Resistance as a Function of Unlawful Highway Vehicle Speed With a Position Control System Operating from 54 to 56 MPH

Note: The horizontal line at 14 pounds from 54 to 56 MPH corresponds to the position control system shown in Figures 5 and 6

To illustrate the system's operation, imagine a motorist accelerating on the highway. As vehicle speed exceeds 1 mph below the preset speed, the Deaccelerator's piston rises to precisely the position required to maintain the preset speed. The pedal will act as a rest for the driver's foot, making subtle adjustments to accommodate changes in the slope of the road or highway being traveled. (Figures 5 and 6 are simply different ways of illustrating the operation of the Deaccelerator's position control system.)

If the motorist is traveling at the preset speed, and encounters an uphill road gradient, vehicle speed will begin to drop. As shown in Figure 5, as vehicle speed decreases below the preset speed, the Deaccelerator's piston retracts downward, allowing the natural weight of the motorist's foot to further depress the accelerator pedal to the new position required to bring the vehicle back up to the preset speed. At 1 mph or more below the preset speed, the piston is completely retracted, allowing the motorist unopposed accelerator pedal depression.

If the motorist encounters a downhill road gradient, and vehicle speed begins to exceed the preset speed, the piston will move the pedal and thus the motorist's foot upwards to the new position required to bring the vehicle back down to the preset speed. At 1 mph over the preset speed, the piston moves the pedal upwards into a completely extended position.

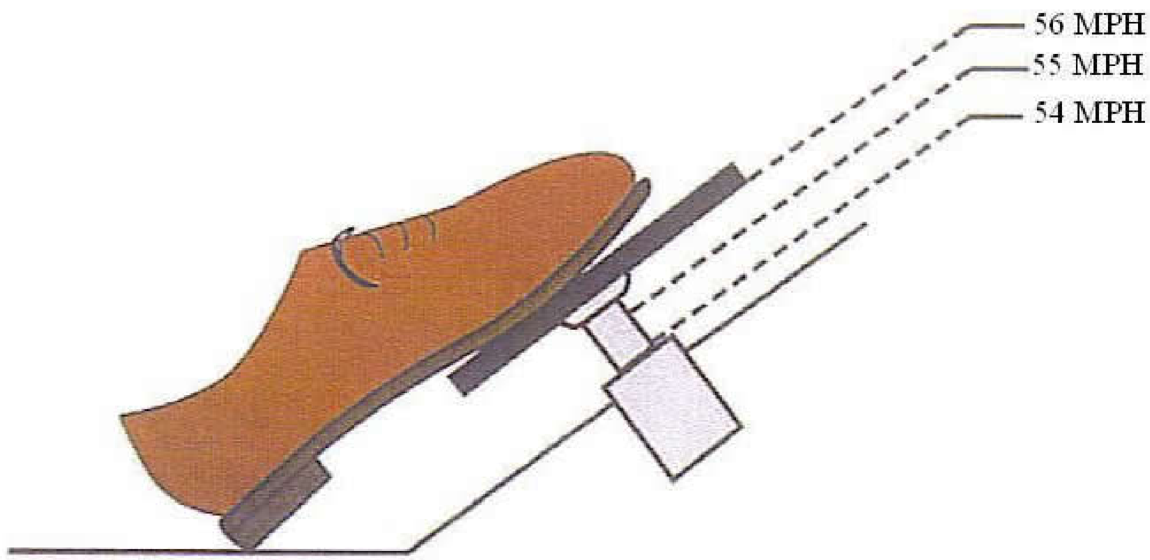

Figure 5. Illustration showing pedal position when maintaining preset speed of 55 MPH in a Deaccelerator-equipped vehicle as uphill and downhill gradients are encountered.

As can be seen in Figure 6, piston movement is linear as a function of changes in vehicle speed across the position control system's 2 mph operative speed range.

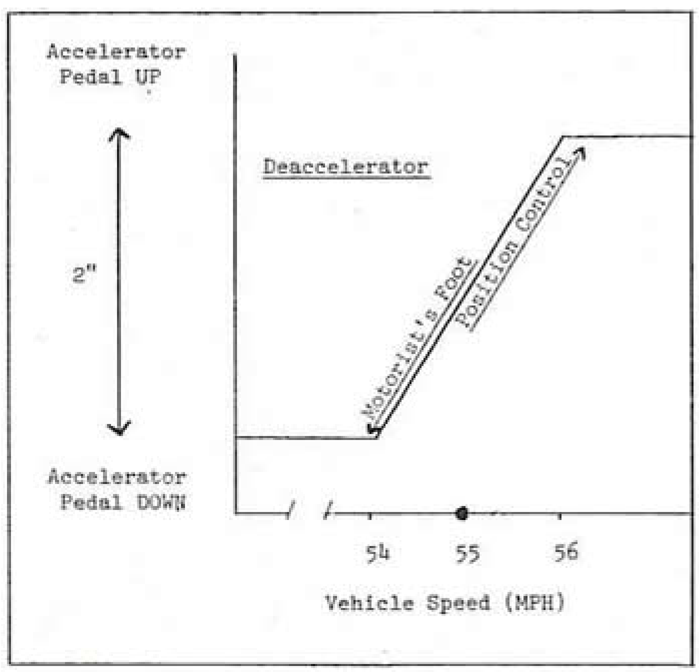

Figure 6
Position Control System Operating From 54 to 56 MPH

Accelerating to unlawful highway speeds simply entails overriding the 14 pound force that enforces accelerator pedal position, which then brings the motorist's behavior into contact with the negatively accelerated force schedule. As shown in Figure 4, as vehicle speed exceeds 1 mph over the preset speed, increasing accelerator pedal resistance is imposed as a function of behavior that increases the speed, and decreasing accelerator pedal resistance occurs as a function of behavior that decreases the speed, with the position control system resuming operation as speed drops below 1 mph above the preset speed. Accelerator pedal resistance as a function of unlawful highway speed ranges from 14 to 36 pounds.

As noted earlier, once highway speeding begins, the Deaccelerator has a supplementary or secondary force schedule comprised of linear increases and decreases in accelerator pedal resistance as a function of respective equal increases and decreases in accelerator pedal depression. As with the primary force schedule, execution of the secondary force schedule entails overriding the same 14 pound force used to enforce accelerator pedal position control.

We must emphasize that there is only ONE 14 pound force used to enforce position control at the preset speed, and that this same 14 pound force sums with the scheduled forces of the primary and secondary schedules to produce their respective resistance values once the preset speed is exceeded. Furthermore, the maximum value of accelerator pedal resistance (not including the 2-5 pound back-force produced by the vehicle's normal accelerator pedal return spring) that the Deaccelerator can generate is 36 pounds. This is due to an intentional blending of the primary and secondary force schedules so as to keep the maximum value of accelerator pedal resistance relatively low and still maintain tight speed control. This blending of schedules is outlined below.

The secondary force schedule, shown in Figure 7, ranges from 0 to 12 pounds. These accelerator pedal depression-based values sum with the 14 pounds used to enforce position control and actually provide a maximum depression-based accelerator pedal resistance of 26 pounds. Thus, if a driver fully depresses the accelerator pedal such that the vehicle begins to exceed the preset speed, imposed depression-based resistance totals 26 pounds (14+12=26). If the driver depresses the pedal one quarter of the way towards a fully depressed position and begins to exceed the preset speed, imposed depression-based resistance totals 17 pounds (14+3=17).

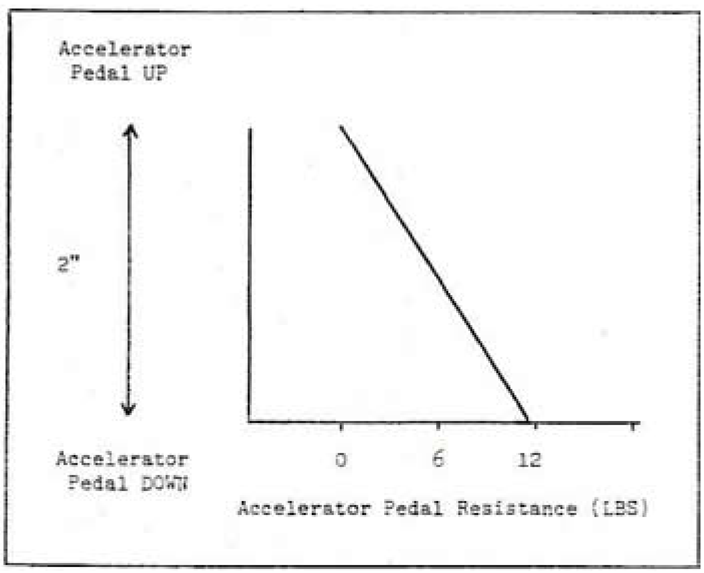

Figure 7
Increasing and Decreasing Imposed Accelerator Pedal Resistance
As a Function of Increases and Decreases in Accelerator Pedal Depression
Once the Present Speed is Exceeded

The primary and secondary force schedules share the same energy sources: engine manifold vacuum and an auxiliary vacuum assist pump to generate systematically imposed values of accelerator pedal resistance. To illustrate how these two schedules are blended (see

Figures 4 and 7), let us first look at a condition in which they act fully and independently. Assume that an accelerating motorist reaches a speed of 65 mph, which is 10 mph over the preset speed, and has depressed the accelerator pedal three quarters of the way between a fully extended and fully depressed position. Under these conditions, the primary force schedule imposes 24 pounds (14 of which are produced by the position control system backforce), and the secondary force schedule imposes 9 pounds, for a total of 33 pounds. Both force schedules are fully and independently executed.

However, as the motorist continues accelerating and reaches a speed of 75 mph and still has the accelerator pedal three quarters of the way depressed, the primary force schedule will impose 30 pounds (14 of which are produced by the position control backforce), as scheduled, and the secondary force schedule will impose just 6 of the 9 scheduled pounds, for a total of 36 pounds. Only the speed-based schedule is fully executed.

On the other hand, if the motorist eases up on the pedal so that it moves upwards to a one quarter depressed position, and assuming that speed has not yet begun to decrease below 75 mph (as when a downhill road gradient is encountered), the speed-based resistance will remain at 30 pounds, while the depression-based resistance will decrease by 3 pounds for a total of 33 pounds. Once again, both schedules are fully executed.

Thus, under conditions involving excessive highway speed coupled with the motorist's degree of accelerator pedal depression, these two force schedules blend in such a way that the primary or speed-based schedule is <u>always</u> fully executed. This blending of the primary and secondary force schedules ensures that the maximum imposed accelerator pedal resistance is at the lowest possible value without sacrificing system performance.

Furthermore, given most vehicles of almost any make produced within the last few decades, excessive highway speeds can be established and maintained with the accelerator pedal depressed to a level that is far below maximum pedal depression. This factor, coupled with the greater values of imposed accelerator pedal resistance that make up the speed-based force schedule as opposed to the depression-based force schedule, renders it likely that the former plays a far greater role than the latter in the effectiveness of the Deaccelerator's resistive-based speed control system.

Field Research

This field research was conducted in 1985, during which time a national speed limit of 55 mph was in effect. In the study that follows, 56 mph was considered the maximum lawful speed because in-vehicle speed control systems (cruise control, road and engine speed governors), including the Deaccelerator, will gain 1 mph when moving on a downhill road gradient. (When the motorist traveled at the Deaccelerator's preset speed, the position control system's actual speed error was less than +/-1 mph, which, by any automotive standard, is <u>exceptionally</u> tight speed regulation.)

Speed Control Equipment

A Deaccelerator was installed in a state provided 1981 AMC Concord four-door sedan used by faculty members at Western Michigan University (WMU) for work-related travel. This research vehicle will be referred to as Car 3028.

The Deaccelerator used for this research consisted of an actuator/piston assembly that was powered by vehicle engine vacuum and a commercially available vacuum assist pump that was activated when engine manifold vacuum fell below a certain value. A vacuum chamber reservoir was used to store vacuum. Rubber hoses appropriately attached at each end functioned as conduits between the energy sources and the vacuum chamber reservoir and actuator. A pressure sensor, position sensor, speed sensor, intake and exhaust solenoid valves, and controlling circuitry made up the rest of the system. The Deaccelerator was mounted in the vehicle's engine compartment and operated via a cable attached to the device's piston head on one end and the linkage closest to the accelerator pedal on the other end. The device could not be seen from the driving compartment. The Deaccelerator in this field study had an unalterable preset speed of 55 mph. The Deaccelerator was road tested to ensure sound performance following Car 3028's return to the motor pool by each faculty member assigned this vehicle for work-related travel. Moreover, vacuum readings on the system were frequently taken to ensure that the actuator's performance with respect to scheduled force output was not compromised due to leaks occurring as a function of a damaged or poorly connected hose and/or a malfunction of the vacuum assist pump.

Speed Recording Equipment

Two identical (for reliability) hand-made digital speed recorders that received input from the same speed sensor were hidden in two recesses on either side of the trunk of Car 3028 in such a manner as to be invisible even when the trunk was open. Each speed recorder stored, in an octal number base, the amount of time spent for each of the following eight speed categories: 53 mph, 54 mph, 55 mph, 56 mph, 57 mph, 58, mph, 59, mph, and 60 mph and above. The digital display of each speed recorder was comprised of eight vertical rows of light emitting diodes (LED's), with each row corresponding to one of the eight speed categories. Timing independently, each recorder sampled speed at 0.5 second intervals, and if the sampled speed fell into one of the eight speed categories, an LED was illuminated in the row corresponding to that speed category.

Each speed category could store up to 75.1 hours of data before that particular category began another cycle of counting. A reset switch on each recorder set the counter for all eight speed categories back to zero. A second switch on each recorder turned the activated LED's either on or off. This feature permitted illumination of the activated LED's only when extracting the stored data and thus helped preserve the battery in Car 3028.

Approximately every 2 weeks the speed recorders were removed from Car 3028 and bench tested to ensure that all LED's were operating and that the timers and frequency counters were calibrated as accurately as possible. Following successful bench testing, the recorders were reinstalled in Car 3028 and road tested. Faculty members assigned Car 3028 were not informed of the recording procedure for the duration of the experiment. All participating faculty drivers were fully debriefed at the experiment's conclusion.

The Procedure

Experimental Conditions

Baseline 1 condition: 24 drivers

The Deaccelerator was inoperative for the duration of this condition. Highway speeds traveled by Car 3028 were recorded for the duration of this condition.

Deaccelerator plus sign 1 condition: 6 drivers

The Deaccelerator was operative for the duration of this condition. Highway speeds traveled by Car 3028 were recorded for the duration of this condition. When requesting a vehicle for work-related travel, those faculty members assigned Car 3028 were sent the following notice:

IMPORTANT NOTICE—PLEASE READ
TO ALL USERS OF WMU STATE-OWNED CARS

A device that aids drivers in maintaining the legal highway speed has been installed in some WMU state-owned cars. Since there is a high probability that you will be assigned a car equipped with this device and since this device does discourage highway speeding, it is a good idea for faculty and staff using state cars to leave for their destinations early enough to ensure arrival at the scheduled time assuming a highway traveling speed of 55 mph. Your cooperation is appreciated.

WMU Communications and Transportation

When faculty members assigned Car 3028 picked up the keys, they were asked by Transportation personnel to read the following sign, posted in the Motor Pool:

VEHICLE USERS: PLEASE NOTE

The DEACCELERATOR is an energy-saving safety device that is being rotated among WMU vehicles. The DEACCELERATOR operates by producing increases in accelerator pedal resistance with increases in speed above 56 mph and decreases in accelerator pedal resistance as vehicle speed decreases toward 56 mph. At 56 mph the accelerator pedal functions like a foot-operated cruise control by gently positioning your foot so as to maintain 56 mph. You will easily be able to overcome the increases in accelerator pedal resistance that accompany increases in speed above 56 mph for emergency or necessary speeding (speeding to avoid an accident). If the DEACCELERATOR is operating in the vehicle you are driving and malfunctions (causes increased accelerator pedal resistance at any vehicle speed), please call collect (telephone #) day or night and identify yourself as a DEACCELERATOR driver. Your cooperation is appreciated.

VEHICLE USERS: PLEASE NOTE

A copy of this notice is affixed to the sun visor on the driver’s side of the vehicle.

Sign only condition: 6 drivers

The Deaccelerator was inoperative for the duration of this condition. Highway speeds traveled by Car 3028 were recorded for the duration of this condition. The sign procedure described in the Deaccelerator Plus Sign 1 Condition was in effect for the duration of this condition.

Deaccelerator plus sign 2 condition: 3 drivers

This condition was identical to the Deaccelerator Plus Sign 1 Condition.

Baseline 2 condition: 3 drivers

This condition was identical to the Baseline 1 Condition.

Results

Figures 8 through 12 show the percentage of time spent at recorded highway speeds (53 mph to 60+ mph). Also shown are the total number of highway hours (53 mph to 60+ mph) recorded during each experimental condition. Finally, shown below each graph are percentages of the total highway hours spent at lawful highway speeds (53 mph to 56 mph) and unlawful speeds (57 mph to 60+ mph).

Figure 8 shows that Car 3028 was driven at unlawful speeds a substantial percentage of the time during the Baseline 1 Condition. Moreover, a great majority of this speeding was recorded in the 60+ mph category as compared with the amount of speeding for each of the other categories.

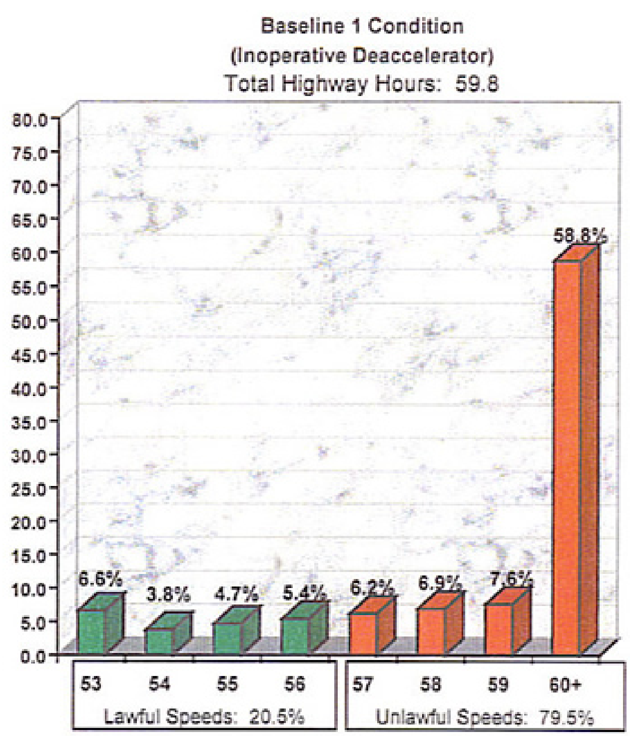

Figure 8. Baseline 1 Condition.
Percent of Time Spent at Recorded Highway Speeds

The effect of the Deaccelerator Plus Sign 1 Condition, as reflected in Figure 9, was, for all practical purposes, to eliminate highway speeding. In addition, a substantial amount of highway traveling time was spent at speeds of 55 mph and 56 mph, the two speeds that entail the motorist's use of the Deaccelerator's position control system to maintain the preset speed. During the Deaccelerator Plus Sign 1 Condition, not only was there minimal overspeeding, there appears also to have been very little underspeeding. Very little time was recorded for the two speed categories below the preset speed. Thus variability in highway speed was kept to a minimum for drivers traveling in Car 3028.

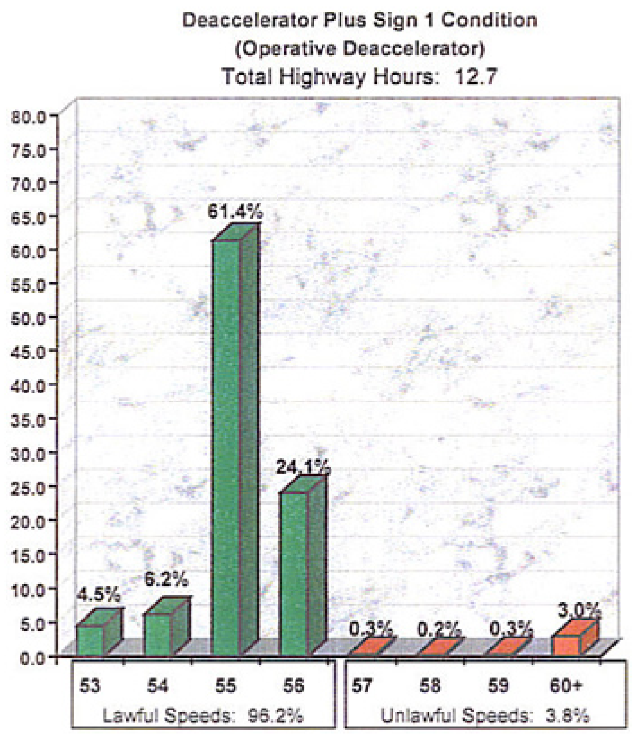

Figure 9. Deaccelerator Plus Sign 1 Condition.
Percent of Time Spent at Recorded Highway Speeds.

The Sign Only Condition was imposed to determine if the sign, by itself, played a role in controlling highway speeding. Figure 10 indicates that the sign itself played no role in controlling highway speeding; during the Sign Only Condition, speeding was prevalent, especially in the 60+ mph category.

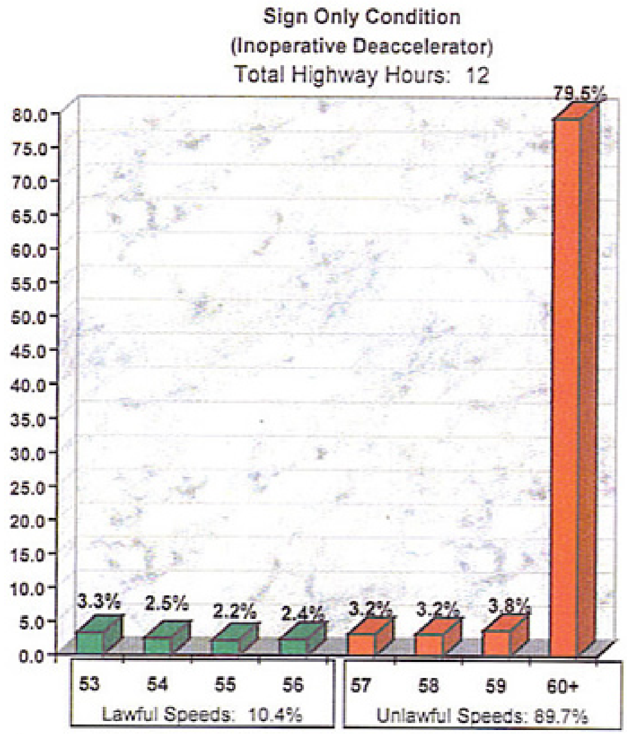

Figure 10. Sign Only Condition.
Percent of Time Spent at Recorded Highway Speeds.

As shown in Figure 11, the Deaccelerator Plus Sign 2 Condition demonstrated that the Deaccelerator was close to 100% effective in controlling unlawful highway speeding. As in the Deaccelerator Plus Sign 1 Condition, the vast majority of highway traveling time was spent at 55 mph and 56 mph.

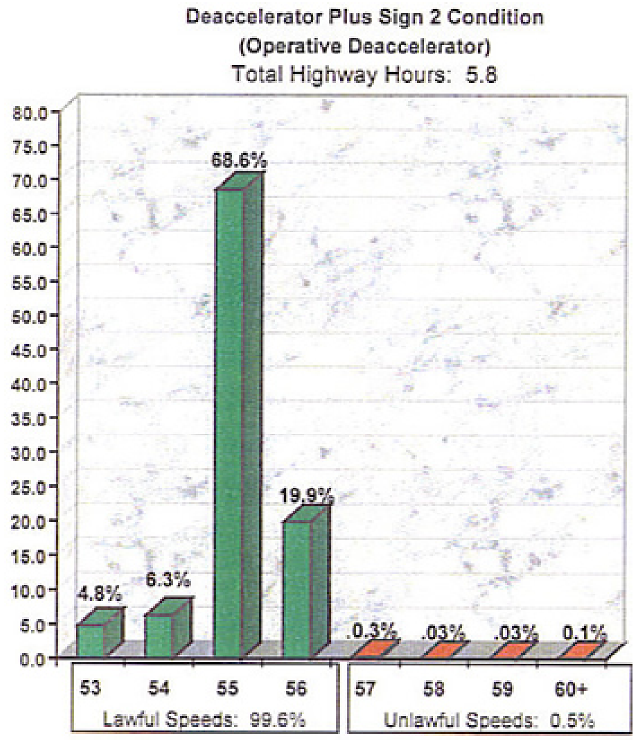

Figure 11. Deaccelerator Plus Sign 2 Condition.
Percent of Time Spent at Recorded Highway Speeds.

As in the Baseline 1 and Sign Only Conditions, data for the Baseline 2 Condition, illustrated in Figure 12, again show that Car 3028 was driven at unlawful highway speeds for a substantial amount of time. A large portion of Car 3028's driving time was allocated to the 60+ mph category.

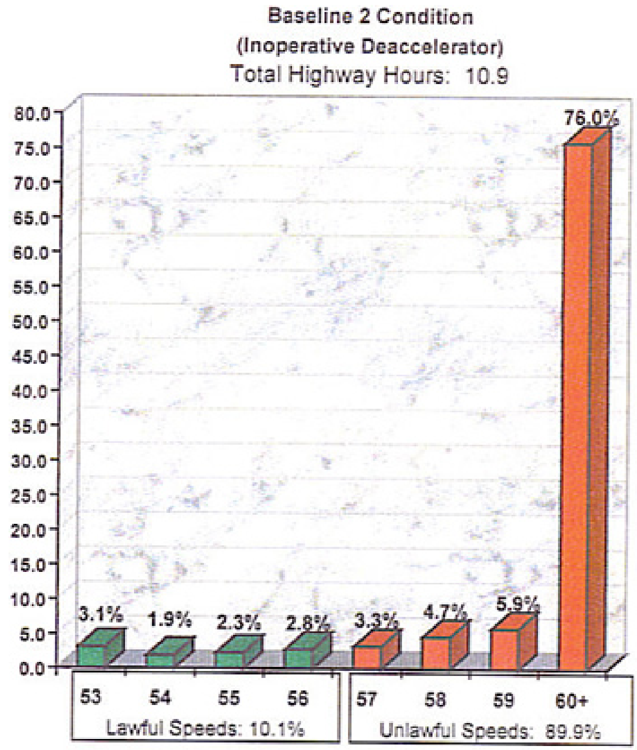

Figure 12. Baseline 2 Condition.
Percent of Time Spent at Recorded Highway Speeds.

In summary, this field test showed that when an operative Deaccelerator was part of the experimental condition, highway speeding was, for all practical purposes, eliminated, and that when an inoperative Deaccelerator was part of the experimental condition, highway speeding was substantial, especially at speeds of 60 mph or more. Thus, this field test indicates that the Deaccelerator is a highly effective speed control system.

Conclusion

The Deaccelerator field research entailed testing the application of a differential force schedule to the accelerator pedal of a motor vehicle to curtail behavior generating highway speeding. That the system did so in such an effective manner corroborates prior research suggesting that an imposed force requirement is a highly effective means for achieving enduring response suppression.

What might the future bring regarding the behavioral use of imposed force requirements in the applied world? As noted by Friman and Poling (1995), imposing a force requirement is not subject to regulatory restrictions as are some other methods designed to suppress responding. Thus, the climate is ripe for behaviorally designed systems that take advantage of the suppressive properties of an imposed force requirement to address problems that might not be as effectively or benignly dealt with by other means.

What follows are some potential applications that make use of technically feasible imposed force schedules to alter human behavior. All the behavioral, mechanical, and electronic engineering elements required to carry out these applications are available.

Before moving on, however, a word about force as a behavioral tool is imperative. Contingencies involving force schedules can be used in two ways to achieve desired changes in behavior. In some situations the suppressive effects of force are imposed to curtail a specified undesirable behavior. Such is the case with the Deaccelerator. The system is designed to decrease behavior producing unlawful highway vehicle speed.

In other situations, increased force is imposed to generate more forceful behavior. This kind of contingency almost always requires a verbal community's support and entails rendering a substantial increase in a force requirement a powerful conditioned reinforcer and a motivational variable that increases the value of further increases in the force requirement. In the examples that follow, the reader will discern the difference between applications designed to decrease behavior that increases force and other applications designed to increase behavior that increases force.

Let's look at some potential applications of force schedules involving safety, energy savings, physical rehabilitation, and sports. Beginning with safety and energy savings, a differentially imposed force schedule, similar to the Deaccelerator's schedule, could be used to curtail highway speeding by motorcycle drivers. The force schedule would be applied to the cycle's knurled hand throttle, the rotation of which, in tandem with the road gradient and wind conditions, determines an increase in the rider's speed when rotated clockwise and a decrease in the rider's speed when rotated counter clockwise. When cycle speed reached the highway speed limit, a position control system would become active, followed by a differentially imposed force schedule should highway speeding commence. (A small reversible rotary motor, coupled with appropriate circuitry, could power the device.) Such a system is clearly intended to take advantage of the powerful suppressive effects of increasing force.

Furthermore, by making use of satellite signals and a motorcycle equipped with a receiver sensitive to these signals, the position control system could, with properly programmed circuitry, operate so as to adjust the rider's speed to match that of the speed limit in any given location. Thus, if the rider moved from a 65 mph speed zone to a 55 mph speed zone, the position control system would make adjustments at the hand throttle to produce a match between the cycle's speed and the newly encountered speed limit.

In addition, the motorcycle could be equipped with a radar system and additional circuitry such that the position control system at the hand throttle would activate counter clockwise to slow the motorcycle if the cyclist was tailgating the vehicle ahead. If the cyclist overrode the position control system, the force schedule would be imposed to exert its suppressive effects on tailgating behavior. If a tailgating accident was imminent, the brakes could be applied automatically as well.

Lastly, there may be a role that a position control system can play in helping prevent tipping of a motorcycle. Indeed, there are different and more complicated variables (especially related to balance) regarding the physics involved in tipping a motorcycle over versus rolling a car or truck. Nevertheless, it may be possible to use these physical principles in such a way that a position control system could respond to sensors that monitor speed, front wheel angle, and the rider's weight, as well as responding to a gyroscope that senses the bike's tilt. This complex would aid in preventing the rider from tipping over. While intuitively it seems that avoiding a tip over would always dictate decreasing speed, there <u>are</u> conditions where increasing speed is required to prevent a motorcycle from tipping over. Circuitry could likely be developed that employed an algorithm permitting the position control system to adjust the hand throttle to slow the rider down, or, allow the rider to increase speed without resistive impediment, depending on prevailing conditions. Again, these would assist in preventing bike tip over.

Another potential application involves a system designed to increase behavior that contacts a force schedule. The physical rehabilitation of humans often involves machines that require an output of force by the patient. The machine's operation may be critical to the patient's rehabilitation. It seems possible that behavioral scientists, after reviewing such physical rehabilitative systems, could make significant improvements.

Rehabilitative force schedules could operate in accord with a behaviorally designed algorithm that makes within-session adjustments in the force required for the system's operation based on a given patient's performance. Conditioned reinforcers in the form of auditory and/or visual stimuli could be programmed into the behavioral algorithm. Post-session data on a given patient's performance could be part of the system's operation. A behaviorally based algorithmic machine of this kind would not only be very sensitive to the patient's performance, but also would free up much of the therapist's time for other rehabilitation related tasks. Gymnasiums around the country might well provide a lucrative market for a system that automatically adjusts within session force requirements to a given user's performance.

Sports are another area where the goal of training is often to increase behavior that contacts an increasing force schedule. One example involves boxing, a sport demanding, among other skills, punching power and hand speed. The harder and faster a boxer can deliver a blow, the greater the probability of a successful career as a pugilist. Boxing gloves could be imbedded with force sensors in that portion of the glove deemed "legal" in terms of delivering a blow. The gloves would also be capable of emitting a very brief tone. Finally, small digital counters would be embedded in the portion of the glove that encircles the wrist.

Each glove could take a separate baseline reading on the boxer's punching power for each hand and then automatically set the force required for a left-handed or right-handed punch to produce a brief tone. The counters in each glove's wrist band would record data on the boxer's performance. Moreover, by way of an algorithm, the force requirement for each hand could be automatically adjusted within each session as a function of the boxer's performance.

With the simple addition of built-in timers, along with the equipment described above, the gloves could also be used to improve a boxer's hand speed (the inter-punch interval). A conjunctive schedule could be put in place in which both punching power and hand speed requirements must be met to produce a brief tone. (A schedule involving simultaneous differential reinforcement for two response properties may require the use of a tone that varies along a specific dimension depending on whether one or both requirements have been met.) The boxer could practice on the punching bag as well as with a sparring partner, and following each session, the trainer could examine the fighter's performance by reviewing the data accumulated in the counters of each glove.

As the above examples suggest, the use of imposed force schedules appears to have a place in the world of human application. And while professionals from many disciplines are potential contributors, behavior analysts possess the very tools that should yield a more comprehensive analysis, and thus a superior final system custom tailored to the task at hand.

In order to develop a useful force control system, or almost any useful and sophisticated physical system, behaviorists must be willing to collaborate with scientists from other disciplines in providing technology critical to an optimal behavioral product. Otherwise, good behavioral machines will not be produced in the abundance that reflects the true potential of behavioral science.

Given the wealth of sophisticated technology developed by other sciences, it is propitious for behavioral analysts trying to develop a behavioral solution to a given problem to ask this question: Could a behavioral machine be developed that would be more effective in solving the problem in a cost-effective manner than would an approach not involving a machine?

For example, conventional instructional materials (such as manuals laden with instructions regarding safe motorcycle travel) have been developed over the years to address a diverse set of problems. And many, no doubt, have had a positive impact on the problem being addressed. However, one problem with such materials is that they have to be read and understood, and the instructions must be followed if a positive outcome is to be expected. The weak link is the end-user, who cannot always be relied upon to read, understand, or faithfully execute the behavior required to carry out such instructions.

A well designed behavioral machine should, at the very least, reduce the number of instructions required to yield an effective system. Machines always read, understand, and execute their programmed instructions, leaving end-users controlled by the direct contingencies such machines generate. Finally, letting a good machine effectively control behavior often helps humans save the most valued commodity of all. Time.

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