Driver Response to Radar Brakes

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• SINCE World War II there has been talk of reducing accidents by providing cars with a device that would sense when a traffic situation was critical and then automatically apply the brakes. Radar can see in the dark, hence should be able to provide warning for such items on the road as the following:

1. Slow trucks with poor rear lighting.
2. Stalled cars.
3. Oncoming cars.
4. Children running into the car's path.
5. Obstacles on the road.

There are other advantages suggested, such as:

1. It could be constantly alert and undistractible.
2. Its reaction time would be reliably small.
3. It could be arranged to automatically calculate safe distance and be consistently accurate.
4. It could lead to automatic spacing in traffic.
5. It should lead to reduced driver tension because of his peace of mind in knowing he is protected.

There probably are many other possible advantages.

Concluding then that it is worthwhile to consider such a device, one is faced with two interlocking problems: what should the system characteristics be, and how should the system be evaluated for its effectiveness? There are no doubt many ways of assembling such a system. This report is mainly concerned with the evaluation of a "black-box" system, that is, one whose input and output and their functional relationship are described with relatively less concern for the components that make it go. However, some consideration of the components likely to be in the black box is necessary in order to be able to specify, realistically, the input and output and their functional relationship. Thus, if one component is a radar set, the limitations imposed by the nature of radio transmission must necessarily influence the concept of the whole system. For example, if a particular shape of radar beam in front of the car is desirable, the practical state of the art will tell a lot about what input requirements would be feasible. Also, if another component of the system is the car's brakes, then despite the desired output, it must work within the limitation that it would be impossible to get more deceleration than 32 ft per second per second, and a child darting into the street could still be killed, even if the whole system worked perfectly, just because of the physics of the situation. Again, if it is desired that the system integrate a wide variety of events in traffic so it will make a wise decision for action, there will arise the practical problems of economic feasibility, including size, weight, number of vacuum tubes, complexity, reliability, and cost.

In view of the many natural limitations, the system must necessarily be a compromise between what would be desired and what could reasonably be obtained. Accordingly, several characteristics were derived and an automatic braking system, still with many idealized features, was simulated for preliminary evaluation tests. No doubt alternative systems could be proposed; in this study the one delineated had three aspects: input, computation, and output.

INPUT

Distance to an obstacle must be determined for the system to function, and distance can be computed from a frequency-modulated radar signal.

The relative velocity between the radar car and an obstacle must be determined so that automatic braking will occur when the closure rate becomes too great for the clearance available. Distance determination alone would be insufficient, for it should be possible to follow another car on an expressway at 50 mph, whereas it would be unsafe to initiate braking at the same spacing if the car ahead were standing still. A frequency-modulated doppler-shift radar could supply both distance and velocity information to the computation component of the system.

The velocity of the car over the ground may be used. Whether a radar-detected relative velocity was the result of a stationary or a moving obstacle could then be determined. Thus, if the relative velocity is equal to car speed, the obstacle must be standing still; if the relative velocity is greater than car speed, the moving obstacle is coming toward the radar car; when it is less, the obstacle is moving away. An alternative source of this information would be a doppler radar. In such a radar, the radio frequency of the reflected signal is higher than that transmitted if the relative velocity is in the direction of closure. A radar brake system that failed to make this distinction would cause the controlled car to automatically brake whenever another car overtook and passed it.

Wheel rotation knowledge is necessary to furnish brake-line pressure relief whenever a wheel stops rotation and the car is still in motion. This reduces skidding under all highway surface conditions.

The direction of the obstacle may be a necessary item of information, particularly to discriminate between targets that should be ignored (such as oncoming cars in the adjacent lane) and those that should be avoided. This can be obtained by using a split antenna or an oscillating antenna. Such a direction-determining arrangement with its associated circuitry may be quite complex for automotive purposes.

COMPUTATION

The computer would be required to continuously solve the equation

$$a = V^2/2d \tag{1}$$

so that brake-line pressure can be made proportional to a when it exceeds some small preset threshold.

There is the problem of dealing with parked cars and approaching cars in the adjacent lane. This problem arises, of course, because it is impossible to get a really sharp radiation pattern from practical radar antennas, and because streets and traffic are just not arranged so that cars are always on perfectly parallel paths. One way this can be handled is by limiting the operation of the system to closure velocities which are less than 10 mph above car speed. For example, if the controlled car is traveling at 45 mph and it approaches another car traveling toward it at the same speed, the relative velocity would be 90 mph. These situations could be ignored, allowing passing on a two-lane highway, but this approach has obvious disadvantages; particularly, there would be no protection against oncoming cars in the same lane.

By going to the more complex antenna lobing arrangement, the radar system might be made to work only on obstacles that are within an extremely narrow fan directly ahead of the car. This would provide protection against head-on collisions while not allowing cars in the opposite lane and parked cars to interfere. Whether such a scheme, operating reliably, could be incorporated in an automobile as an accessory is doubtful. An alternative would be to make the radar of sufficiently low power that off-center energy would be too low to operate the system. This has its problems, too, in that radar power is required for good reflection from non-metallic obstacles, and it may be possible to outrun a low-power radar at high speeds.

Making a turn could lead to trouble, for roadside objects like signs, houses, people, stopped and parked cars, and so on, would be right in the radar beam. Swerving in traffic to pass another car might often place an oncoming car in the adjacent lane, or some roadside object, directly in the radar beam even though it was not in the driving path. It would seem desirable that the radar system be disengaged when the car is in a turn.

OUTPUT

The output of the system operates the brakes by controlling the brake-line pressure. A preset threshold of brake-line pressure may be provided such that it should be exceeded before any automatic deceleration occurs. This would prevent light brake drag, enable parking, garage entry, and provide deceleration only when necessary to insure safety. A throttle application threshold may also be desirable. A minimum brake-line pressure could be held after any degree of automatic braking until the throttle is depressed. This would insure fully automatic stops and furnish anti-creep.

A means to disable the system would be convenient because certain driving conditions may require sustained conventional operation. Instantaneous override should be available to allow for acceleration out of critical situations. Simultaneous visual and/or aural warning should accompany automatic braking to prepare the driver for deceleration. The system should revert automatically to conventional operation whenever component failure introduces dangerous inaccuracies. An aural indication of this is also necessary to warn the driver so that he will assume immediate control.

SPECIFICATIONS

For the purposes of testing the simulated system, the specifications were established as follows:

1. The radar beam would have very sharp boundaries at the car's edge and would be to all intents and purposes contained within the lane of the car's travel.
2. The system would not function when the steering wheel was turned more than 30 deg.
3. Deceleration would start after closure had become definitely apparent and would increase smoothly.
4. There would be anti-creep once the car had stopped.
5. Override was provided by touching the brake pedal.
6. No aural or visual warning of brake operation was included.

Several aspects of a real situation were ignored. One of the most damaging of likely circumstances would no doubt be the extreme interference due to spurious radar input if all other cars were to be so equipped. There is not sufficient spectrum space to begin to provide all cars with individual channels, so radar jamming may be such a limiting factor that only little reliance could be placed on such a system.

Another factor that may be bothersome in hilly sections of the country would be the forced slowing down of the car as it approached a grade. No attempt was made in these tests to distinguish relative reflectances of different obstacles, although in a real system the operator would have to expect that some nonmetallic obstacles might not be responded to. At this point it should again be emphasized that even an ideal radar system could not be an accident panacea, for deceleration of a car cannot be greater than $1g$. A child darting into such a car's path could still be run over by a car with a perfectly functioning system.

EVALUATION

The purpose of equipping a car with an automatic braking system is to increase safety by reducing the number of accidents caused by inattention, poor visibility, etc. Therefore, the test of whether such a system accomplishes this objective would be to see if these cars were found to be involved in a significantly smaller number of accidents than cars not so equipped. However, the decision to equip a few hundred thousand cars with such a device should depend on whether the device was available. (A large number is needed not only to provide statistical power, but also to achieve a realistic radar jamming situation.)

From the preceding discussion of likely system functioning, it is seen that the developmental problems, for an effective and practical automotive accessory, would be great. It would also be good to know how well such a system works prior to all the engineering required to develop it into production form.

If the procedure of providing a statistically sufficient number of test cars must be ruled out, how can such a system be evaluated when just one car is equipped? One way would be to count the number of times the device avoided an accident when a car without it would not have. Accidents are statistically very rare; the bulk of the driving public will drive an entire lifetime without a single accident. Therefore, an attempt to count the number of successes compared to the number of expected collisions in a limited exploratory study is not apt to provide any data.

The approach taken in this study was to determine in which way driver behavior in a car with automatic brakes would be different from ordinary driving behavior, and to obtain the opinions of a number of supervisory-level engineers. To obtain the opinions of a number of responsible engineers is not a new method: but in this particular experiment, all their comments and reactions while driving the car were recorded by an engineering psychologist in the rear seat, and a content analysis of these comments was later made.

The apparatus was not an actual radar system. To develop the machinery for a system that would function like that described earlier would have been far outside of the scope of this investigation. Instead, an idealized system was provided by merely using a car with dual brakes. An experimenter in the front seat acted as the radar and applied brakes in accordance with the operational characteristics that were compromised upon. Since the objective of this exploration was not to see if a radar system could apply the brakes, but to see what driver behavior with a reasonable automatic system would be, the method used was quite adequate.

Ten managing engineers drove the car in city traffic. Results and conclusions are strictly limited to city driving; a very different story might be true for the open highway.

There are a number of problems that must temper one's conclusions. The engineers who drove the car were not typical of the driving public, so their reactions may not be representative. On the other hand, they are also more sensitive to automotive and traffic problems, so their observations should be valuable. In this study, engineers were obviously putting the car through its paces, so their responses might not be typical of their reactions after becoming more used to it, but that is more apt to lead to a change in emphasis than an invalidation.

Certain aspects of the procedure should be noted. Ten persons drove the car, not just a couple. Those chosen to drive it were relatively disinterested; all were higher-level engineers. They were instructed to freely express all thoughts and observations on the car, traffic, anything. All pertinent responses were recorded. This is a procedure which can deteriorate into the selection of those dramatic incidents which support the bias of the investigator if the attitude of fact finding is contaminated by personal opinion. This is admittedly difficult to control, especially in an investigation of this sort.

RESULTS

The logical examination of the situation, and the system characteristics needed to meet it, immediately allow some evaluations to be made. For example, if the system is such that it must be disabled when going around corners, then there is no protection on corners. In less obvious traffic situations, the recorded remarks were valuable in uncovering other problems.

There were several hundred responses and these were concentrated into a smaller number of categories. From these it was relatively easier to state the results, make interpretations, and draw conclusions. The responses were classified as follows:

1. Statements and questions concerning the operating characteristics of the system.
2. Favorable comments on the operation.
3. Favorable subjective reactions.
4. Unfavorable comments on the operation.
5. Unfavorable subjective reactions.

The following were typical remarks:

I didn't like that — the sudden braking when that car crossed out in front. The radar couldn't interpret the move . . . I'd have been relying on the radar if the car ahead had run through the light. Would need to make an even faster decision than normally. Maybe there should be a radar in the traffic light.

The wheels might lock when I want to suddenly swerve out from the lane.

With this radar I wouldn't be in the frame of mind for being braced for what's going on up ahead. (With reference to following too closely.)

That was too fast— I forget it wouldn't work when I turned.

Oh! It won't help me at this light.

What was that for? (Car suddenly crossed in front.)

Didn't like that action (car pulling out from curb); had every expectation of missing him.

That didn't feel natural. (Having to brake at a red light after getting used to automatic stops behind other cars.)

It's easier darting in and out of traffic.

It's pretty good, I can look any place without bothering where I am going.

Wonderful! If it stops like this there is less work in driving. If I turn my head it will stop.

It's nice; I don't like to brake coasting at a stop light.

You're going to need a computer — may as well include everything else, steering, throttle, etc.

I'm actually having to exercise more judgment than I would normally.

The various comments, after being sorted into the five categories previously listed, were scanned; from them the following conclusions were drawn:

1. There were more unfavorable than favorable remarks.
2. Most of the favorable remarks were made by one or two persons.
3. Many of the favorable remarks raise other safety questions, because they emphasized the potentiality of unconventional driving habits (for example, more opportunity for rubber-necking, reducing vigilance, closer packing, and tight maneuvers).
4. Other frequent favorable comments related to its anti-creeping characteristic, which, if desirable, in no way necessitates a radar brake system.
5. Most of the drivers reported an increasing confidence as they had more experience, but few felt they could get completely used to it.
6. Much of the favorable comment was conditional on the radar being as ideal as the simulated system. Approval was reduced or withdrawn as the characteristics of a technically feasible radar were pointed out.
7. Many of the unfavorable comments were concerned with the technological impossibility of providing a radar as good as that simulated.
8. The limitations of even the idealized system were considered so severe as to reduce its advantage. Some of these were: not effective on turns; not effective at stop lights and cross streets; and not able to "think," or anticipate actions which the driver ordinarily can easily account for.
9. The severest criticism was that human decision-making, far from being simplified, was actually made more complex because of a continuous need to discriminate the situations in which the radar assumed control and those in which it did not. This would require more complex and faster human decisions than one normally makes in conventional driving.
10. The bulk of the reactions to the automatic brake were lack of confidence, increased anxiety, confusion at its automatic operation when the driver had actually been thinking ahead of the im-

mediate situation, the concern over the additional thinking and decision-making required. The feeling was summarized in one complaint that the driver felt like he did when teaching a new driver for the first time.

11. There was substantial concern that the device would actually become a safety hazard.

12. The observations of the drivers in action revealed a tenseness and hesitancy — more pronounced at first — and occasional serious driving errors because of misjudgment and confusion.

These results must be viewed in the context of the system. It was necessarily a rather idealized system in its conception and because the radar experimenter could not help integrating some features of the situation and thus acted somewhat better than a completely naive automatic brake; also, there was no trouble with radar interference. Any adverse criticism of the system because of unfavorable driver reaction should, of course, be magnified when applied to a feasible mechanical system. Favorable response would have to be withdrawn to the extent that it referred to idealized aspects of the operation.

The evidence was very striking that the system would not be viewed as a safety and emergency device to operate only in those unusual circumstances when the driver is not in a position to exercise proper judgment or control. The device seemed to be accepted as a new way of braking, routinely and regularly. Most of the drivers immediately began to let the automatic system do all their braking in traffic, but at a red light would often neglect to assume control; and were not prepared for the sudden left turn, on red light, of a car ahead. Many other instances arose in which the driver fought the brake by stepping further on the accelerator pedal.

CONCLUSIONS

The system must have certain limitations, such as: ineffectiveness on turns; technical compromises with regard to whether protection against head-on collision should be traded-off for feasibility; it could not stop for traffic signals; it would not be a cure-all, even if it worked perfectly, because momentum could still cause an accident; it would be subject to unreliable and spurious action because of jamming from other radar cars.

Even a relatively ideal system had the following operational disadvantages: a great deal of complex decision-making goes on in driving which the relatively naive radar system could scarcely take into account. An example of this would be anticipation. Drivers complained that their decision-making was not simplified, but made more complex because of the continuous need to discriminate the situations in which the radar assumed control and those in which it did not; this came about because drivers began to use the system to supplant their normal braking behavior rather than reserve the action for emergencies. Reactions at first were lack of confidence, confusion, and discomfort, and although there was a diminution of these tensions with experience, few drivers indicated approval.

As a turnpike highway device, or as merely a warning system, it has as yet unknown usefulness; the present exploration had to do with city driving with a simulated complete automatic braking system.