OPTIMIZING THE DESIGN OF A DUAL FUNCTION BRAKE ACCELERATOR PEDAL

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INTRODUCTION

"Automobiles are intended to be used in an environment in which a traffic death occurs every eleven minutes and an injury every nineteen seconds". This is how Time magazine expressed the hazard of being on an American road in a car in 1967. A none too complicated calculation puts the annual number of dead at over 50,000 and the annual number of injured, some in the "band aid" category, others maimed and rendered incapable of leading a normal life forever, at over a million and a half. On the more materialistic side it meant a loss of nearly ten billion dollars in 1966 (NSC, 1967).

The figures are staggering - and voluble too. The problem is immense and deserves a careful analysis so that remedies can be suggested. As at other institutions, research is underway at the Kansas State University to find ways to reduce the problem.

The man/machine/environment components of the automobile driving situation are represented by the driver, the car, and the road; each needs a careful scrutiny for possible modifications leading to the goal of safer driving.

Although we are on the threshold of breaking the genetic code, we are far from exercising any control on the human characteristics - except perhaps by training. Not belittling the effects that can be achieved by better training through improved techniques, the scope of improvement in "system performance" is not too reliable in the case of man element of the system. An annual expenditure of a billion dollars spread over a hundred million drivers is only $10 per driver per year. It is doubtful that much benefits can accrue out of this amount of direct training. The same amount spent on advertising safety may be more beneficial.

Roads can be redesigned. But here we have to contend with the thousands of miles of existing roads and obscuring structures in urban environments. These act as formidable constraints when this portion of the system is modified. Taking a conservative estimate of the interstate highway construction costs at a million dollars a mile, one billion dollars would change a thousand miles of the 3.5 million miles of existing public highways. This represents a meager three hundredths of a percent of the total length of highways.

Automobiles have a high turnover; it may be because of a newer, sleeker model or just to keep up with the Schultz's next door. The estimated half life of cars in America is five years that is, in five years from now more than half the cars on the roads in the U.S. will be manufactured after today. Thus, new cars offer not only a chance of increased sex appeal but also increased safety. Economically, at 8,000,000 autos sold per year, one billion dollars would allow $125 per automobile or approximately 5% of the cost of an average auto. Therefore the modification of the automobile seems the most cost-effective approach.

Increased safety can be viewed both in terms of avoiding accidents and less serious accidents. One of the parameters which affects safety is the permissible margin of error. The greater this margin, the less the chances of an accident (or less the severity of accident). This margin is dependent on design and one of the facets of design is the time between the decision of the controller and the reaction of the machine. This time, the human time lag or reaction time, is the time between the appearance of a stimulus and the beginning of the machine's response to neutralize the presented condition.

It is assumed that shorter the reaction time, the greater is the permissible margin of error. This axiom is based on the premise that the greater the time available for the automobile to attain a specified condition (that of lower speed or zero speed) from another given condition (that of moving at certain higher speed), the greater is the possibility of its achieving it.

Reaction time as defined above comprises:

i. Sensing time: the time required to sense a signal. This is a function of the properties of the signal (size, intensity, duration, etc.).

ii. Decision time: the time required to complete the neurological process of selection of the right response to the presented stimulus. This depends upon the complexity of the decision to be made and the number of times the response has been practiced.

iii. Response time: the time required to respond to a signal. This is a function of the complexity of the response (e.g. force, displacement and precision requirements) and of the body member being used.

Sensing time and decision time together are often referred to as response latency while response time is akin to movement time. If any of these factors can be so controlled that their time of execution is reduced, the reaction time will be decreased.

Sensing time is of the order of a few hundredths of a second. The mode of the sense used for sensing the presented signal affects this time. Of the visual, auditory and tactual modes of sensing, tactual is regarded the fastest, auditory second fastest and visual last (McCormick, 1964). The comparison, however, is not very meaningful as sensing time is known to depend upon signal characteristics such as size of source, intensity, duration, and location (Teichner, 1954).

The decision time is comprised of the time taken by the perceptual, translation and central effectory mechanisms, and is proportional to the logarithm of the number of alternative choices (Hicks, 1952; Crossman, 1956). Although models have been proposed for describing the functioning of human sensory - motor performance (Welford, 1960), the process is far from clearly understood.

A memory drum theory of neuromotor reaction (Henry & Rodgers, 1960) proposed a nonconscious mechanism using stored information (motor memory) to channel the existing nervous impulses and presented stimuli into appropriate neuromotor coordination centers causing the desired movement. As the complexity of the response movement increases, the response latency period also increases.

Kramer (1949) suggested three basic types of latency periods: the simple, choice and discriminative periods. Each succeeding type requires the use of higher centers of cortical brain activity than the preceeding one.

Response (movement) time does not seem to have any correlation with response latency (Slatter - Hammel, 1952; Pierson, 1956; Henry, 1961). It does, however, depend upon factors like movement complexity and, obviously, distance to move, precision of movement, etc. It is of the order of a tenth of a second for very simple tasks but increases to a second or even more for complex tasks (such as precise positioning of levers) (Morgan et al., 1963). Hands are found to be 20% faster than feet and the preferred limb is about 3% quicker than the non-preferred one (Teichner, 1954).

PREVIOUS WORK

Three of the five experiments conducted in this series at the Kansas State University have already been reported (Konz and Daccarrett, 1967) and are briefly referred to below. These were of an exploratory nature and served as pointers for the design of subsequent work. The fourth and fifth are given in some detail to bring out the progress of the project and to help illustrate the 'raison d'etre' for the present experiment.

In the first experiment, relative quickness of activating a control by hand and foot were compared. The following four conditions were studied:

i. Honk horn; starting position - hand on the horn rim.

ii. Honk horn; starting position - hand on steering wheel.

iii. Depress brake; starting position - left foot on brake.

iv. Depress brake; starting position - right foot on depressed accelerator.

The times for actuation in conditions i. and iii. were not significantly different from each other but were significantly faster than in conditions ii. and iv. The improvement of .2 seconds found in conditions i. and iii. over the other two conditions would mean a saving of approximately 18 feet in stopping distance if the initial car speed was 60 miles per hour.

The advantage obtained in conditions i. and iii. was primarily because of reduced (eliminated) response time rather than the difference of latency lags in arms and legs. Two possible design feasibilities emerged from the experiment: One; design the control so that the effector limb is able to be poised on it for actuation at all times. This control could be properly positioned for left foot actuation as the left foot is free in nearly 80% of the cars on the road. Two; one of the other three limbs (right foot, right hand, left hand) is given the additional task of braking along with its present job. This could be achieved by some integrated control. From the design point of view, in the second alternative, it would be easier to combine the braking function with the accelerator pedal than with the steering wheel because the foot is in a relatively fixed position while hands move.

The second experiment was done on a combined brake and accelerator pedal designed by Mr. C. N. Winkleman (U.S. Patent no. 2,878,908) because of its availability.

This pedal activated the accelerator when the toe was pressed down and activated the brake when the heel was pressed down. There was an interlock between the two controls to prevent simultaneous actuation of both controls.

Actuation times, of the same subjects, for braking from a starting position of a depressed accelerator were found to be significantly faster ($p < .01$) when compared with those in condition iv. of experiment one.

In experiment three an American Automobile Association (AAA) reaction timer comprising a conventional system of clutch, brake and accelerator pedal was compared with the Winkleman integrated control.

Three conditions tested were:

i. Depress conventional brake; starting position - left foot on brake.

ii. Depress conventional brake; starting position - right foot on depressed accelerator.

iii. Depress experimental brake; starting position - right foot on depressed accelerator position of integrated control.

Actuation times were significantly faster in i. compared to iii. and in iii. compared to ii. ($p < .05$).

The preceeding three experiments conducted in a laboratory indicated some of the potential advantages. Only suggestive statements about advantages could be made even for the systems studied since conditions on the road are far different from conditions in a laboratory.

The next experiment was therefore conducted on the highway. The integrated control was mounted in a 1960 Rambler. It was made interchangeable with the conventional accelerator and brake pedals and the two were tested for actuation times while driving on a highway.

The set up consisted of a 2" diameter red lens with a 12 volt light with an intensity equal to the brake light installed on the hood six feet ahead of the driver. A strip chart recorder powered through an inverter by a separate 12 volt battery was installed in the rear seat. Pressing of a light switch caused a jog to be made on the strip chart and the depressing of the brake control by one sixteenth of an inch caused another jog to be made. With the paper moving at a known speed (50 mm/

sec), the reaction time could be found from the distance between the two jogs.

Sixteen subjects drove two miles along a two lane highway without intersections with one of the two conditions, stopped at the end of two miles and drove back with the changed condition. Data for three subjects had to be dropped because of recorder malfunction.

An average of four cars passed in the opposite lane during each two mile trial. Subjects were given four practice trials and then ten randomly spaced trials were recorded for the reaction time.

Average reaction time with conventional brake and accelerator was 0.57 sec.; the combined control, with mean reaction time of 0.47 sec., was significantly faster ($p < .01$). However, an increase of nearly 34% was noted in the actuation time with both the integrated and the conventional controls in the highway condition over the laboratory condition. This, in terms of Kramer (1949), was because of the replacement of the simple response latency of the laboratory situation with discriminative response latency in the highway situation.

In the fifth experiment, back in the laboratory, a new integrated pedal prototype (without interlock) was used; reaction times were tested for:

i. The AAA reaction timer; starting position - right foot depressed on accelerator.

ii. A 1960 Rambler equipped with automatic transmission; starting position - right foot on depressed accelerator.

iii. Integrated brake and accelerator pedal (without the interlock) mounted on a test box; starting position - depressed accelerator.

The task consisted of applying brakes from the specific starting position as soon as a 25 watt red bulb came on.

Seventy two subjects, both male and female, volunteered at an engineering open house at Kansas State University. Twelve subjects followed each of the six sequences. Each subject was given 3 to 5 practice trials and then had 10 trials recorded in each of the conditions.

The new integrated brake pedal with a reaction time of 0.323 seconds was found to be significantly quicker ($p < .01$) than both the AAA reaction timer (reaction time 0.482 sec.) and the 1960 Rambler conventional (reaction time 0.435 sec.). It also showed a saving of .09 seconds when compared with the Winkleman integrated pedal reaction time in experiment two (average reaction time for 121 subjects = .41 seconds). The integrated brake pedal had the minimum learning effect (Fig. 1). Trial x condition variability (that is, within a subject) of the integrated brake pedal ($\sigma = .008$ seconds) was much narrower than that of AAA reaction timer (.034 seconds) but was larger than that of Rambler conventional (.005 seconds). The subject x condition standard deviations, (that is, within the set of 10

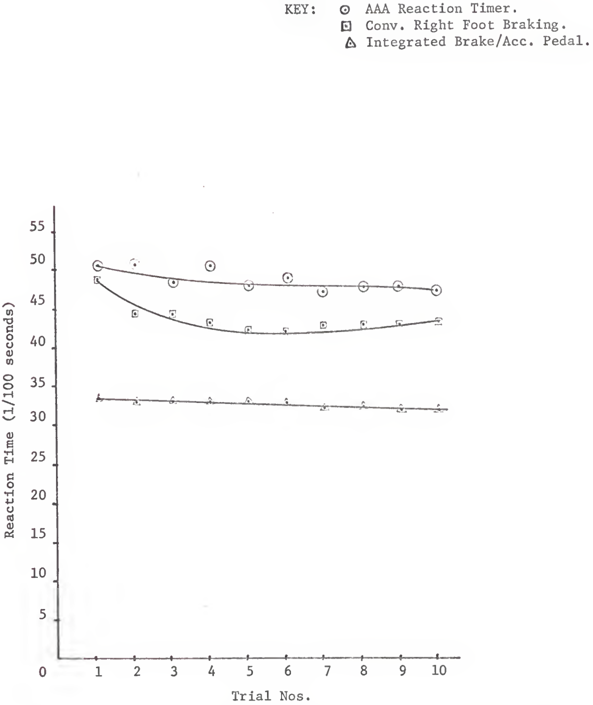

Fig. 1. Learning effect for AAA reaction timer, conventional right foot braking and integrated brake pedal in experiment five.

trials) in the three conditions i., ii. and iii, were .037, .057 and .040 seconds respectively.

PROBLEM

In the set of experiments outlined above, left foot braking with a relocated brake pedal was shown to be a superior design. Acceptance of a new design is, however, a formidable imponderable where human likes and dislikes are concerned. A design which does not find acceptance is useless, whatever its merits. The integrated control, although not the best in theory, was better than the existing system. Unlike the left foot braking, the integrated control prevents the driver from getting into a "strait jacketed" situation with both the hands and the feet "frozen" on the controls. It is operationally compatible with cars using a clutch and needs lesser retraining because it does not require a redistribution of present tasks of the limbs. All this may mean easier adoption. Also, it offers an additional option (possibly at some extra cost) to the customer to exercise his whims in the final selection of a vehicle's accessories. For these reasons the integrated brake-accelerator pedal was selected for further development.

Experiment six was run to check the effect of varying some of the parameters in the design of the integrated pedal. More specifically, referring to the sketch (Fig. 2) of the integrated control, the optimum values of ℓ and L, the distances of the

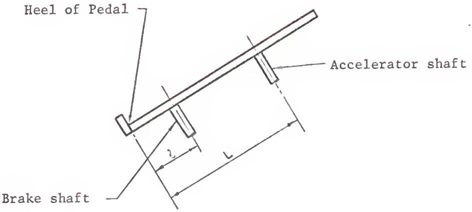

Fig. 2. Sketch of integrated control showing the variables studied (ℓ & L) in experiment six.

brake shaft and the accelerator shaft from the heel of the pedal respectively, were sought. The criterion for an optimum was the minimum reaction time.

METHOD

Experimental Arrangement

The new pedal for experiment six was designed by Mr. B. Koe and did not have an interlock between the brake and accelerator modes of application. The experimental arrangement is shown in Fig. 3. The elements of the set up were (referring to Fig. 3):

A. Control switch

B. 1/100 second reaction timer

C. 60 watt electrical lamp covered with red cellophane

D. D.C. supply source

E. Integrated brake/acceleration pedal test box.

F. Actuation indicator bulbs

G. Chair

Some of the design considerations of the integrated control are given in Appendix I. Fig. 4 gives a side view of the control. The distances of two shafts, nos. 1 and 2 (Fig. 5), from the heel of the pedal were adjustable. The foreshaft (no. 1) represented the connection to the accelerator linkage and the rearshaft (no. 2) represented the connection to the brake linkage.

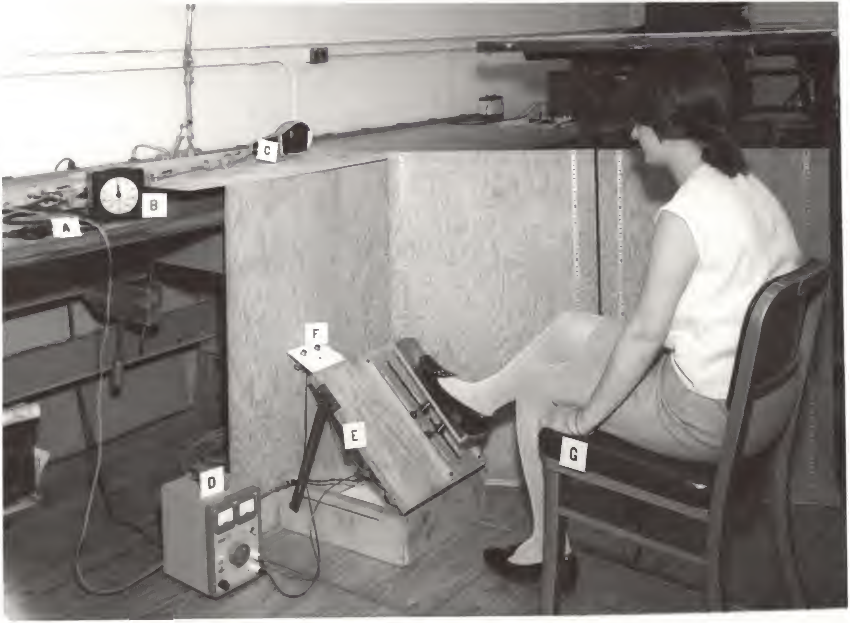

Fig. 3. The experimental arrangement showing the elements of apparatus.

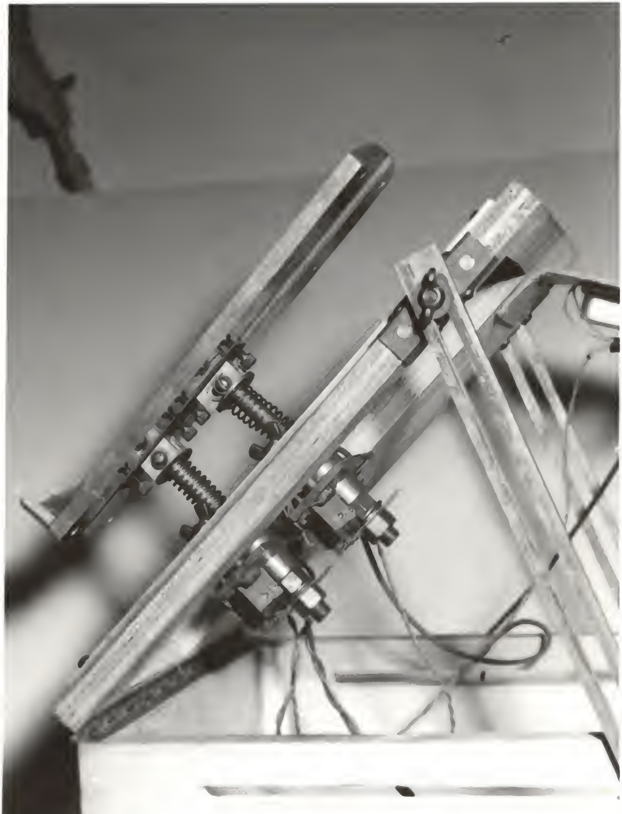

Fig. 4. A side view of the integrated control.

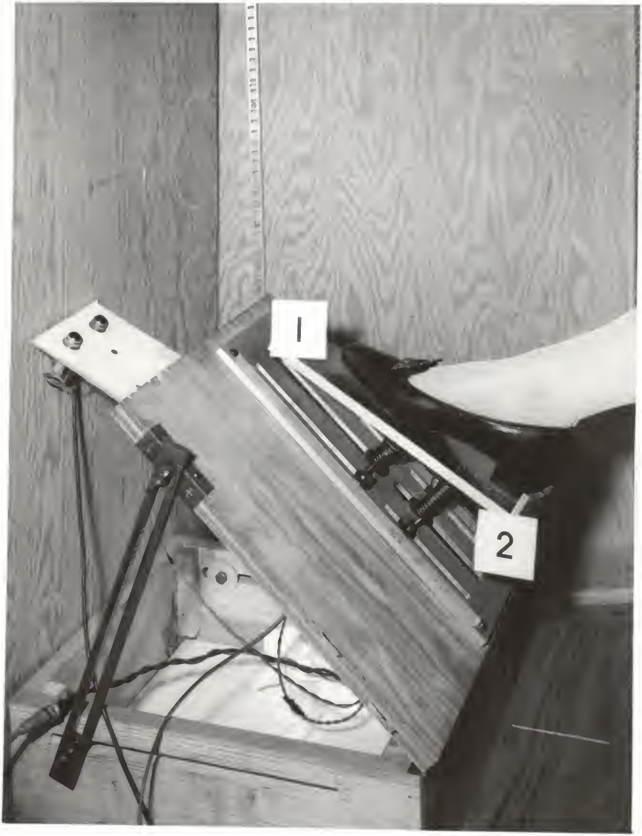

Fig. 5. View showing the fore and aft shafts of the integrated control.

The shafts were connected to two cut out switches which were connected to the two "actuation indicator bulbs", one green and the other red. An 8 to 10 volt D.C. current passed through the switches and to the bulbs. The bulbs were in off position normally; the green one came on when the foreshaft of pedal was in a depressed condition and the red one came on when both shafts were in a depressed condition showing both the controls were simultaneously on.

The reaction timer was connected through a control switch to both the rear shaft relay switch and the 60 watt lamp. The control switch was a dual purpose switch. One of its functions was to control the onset of the 60 watt lamp and start the reaction timer to record the reaction time simultaneously; the second was to reset the reaction timer to zero position after the reaction time for one trial had been recorded.

The reaction timer was electronically connected through the rear shaft cut out switch and its needle was stopped as soon as the rear shaft (brake) was pressed down a sixteenth of an inch.

The chair had a normally cushioned seat and back.

The red cellophane paper covering on the 60 watt lamp was provided to simulate the tail light of a car.

The D.C. supply source was an A.C./D.C. converter from 110 volts A.C. to 10-12 volts D.C.

Design of Experiment

It was decided to use an optimum searching technique called EVOP (EVolutionary Operation of Processes)(Box and Hunter, 1959) for optimizing the ℓ and L values. The technique, primarily designed for production processes, calculates a response surface and determines the optimum values of the parameters. Two basic elements in the technique are:

1. introduction of systematic small changes in the levels of the parameters.
2. analysis of the result of these changes so that a direction of steepest ascent (descent) can be approximated and new changes in parameters incorporated to move toward the optimum in the next phase of testing.

To study the effects of any change, it is required that the process be run for some number of cycles at one level of variables. The result, or response surface, is determined and then new changes are introduced. The "evolution" thus is a step by step process - each change representing a new step and with the direction of the step so selected as to lead to the optimum.

A 2^2 factorial design with a center point, Fig. 6, was used for this experiment. The variables ℓ and L were selected. Other variables that could have been studied were the inclination of the pedal, size of the pedal, spring tensions in springs on the two shafts, seat reference distance, seat height in relation to pedal, etc. The specific values selected for ℓ and L are

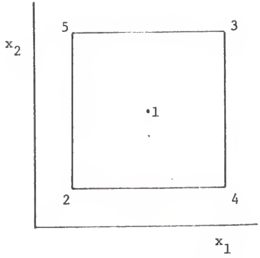

Fig. 6. Sketch showing a 2^2 factorial design with a center point

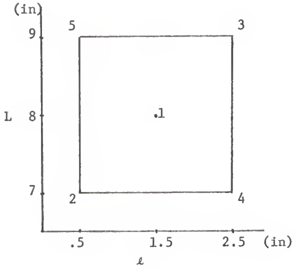

Fig. 7. Specific values chosen for the variables "ℓ" and "L" for phase I.

shown in Fig. 7 giving five conditions for the experiment. A data recording sheet (Appendix II) was designed to record the data.

Subjects

Sixteen paid subjects, eleven male and five female, with at least two years of driving experience were used. Average age was twenty three and average years of driving experience was five. Shoe length ranged between 9.5" to 12.5". Height range was 5' 1 1/2" to 6' 3" with an average of 5' 7 1/2".

Experimental Procedure

The personal data of the subject, name, sex, years of driving experience, height and shoe length were recorded.

The seat reference distance (SRD), the distance between the heel of the pedal and the intersection point of the seat surface with the back rest surface of the seat, was defined as 50% of the subject's height (McFarland, 1966). The inclination of the pedal to the floor was fixed at 45° for all subjects. (The accelerator pedal inclination varies from one model of a car to another and was found to range between 45° to 65° in the six different models checked -- Model T Ford, Volvo, Chevrolet, Corvair, Chrysler and Pontiac.) This condition was to assure that the operation of the pedal with the foot was within the comfortable range of 78° to 96° of the foot movement about the tibia (Ayoub & Trombley, 1967). The chair of the subject was adjusted for each subject so that the necessary SRD was maintained.

The 60 watt lamp covered with red cellophane was fixed at a height of three feet above the floor and about five feet in front of the subject's eyes. (The relative distance between the pedal and the lamp was fixed which meant that the distance of five feet was not constant from subject to subject because of varying SRD and a consequent shift of several inches in the subject's sitting position.)

The subject was told the purpose of the experiment. He was told to hold the pedal with the accelerator in a depressed position and look at the red lamp in front. When the lamp came on, he was to release the accelerator and press the brake shaft.

In the initial condition of depressed accelerator, it was made certain by the experimenter that both the controls were not in the depressed condition. When the brake was being applied after the presentation of the stimulus, however, the condition of dual operation (i.e. both the controls being on simultaneously) was disregarded. The author feels that in an actual system the operator should be informed when he is in "dual"; it may even be desirable to automatically disengage one mode if a certain percent of the other mode is actuated.

The subject was given three to five practice trials at each condition.

Twenty times were recorded for each condition for a subject before the condition was changed to the next one.

The time between two successive stimuli (four to seven seconds) was sufficient to prevent the treating of them by the subject as a single stimulus (Welford, 1960), or his anticipative response to a signal about to occur (Morgan et al., 1963).

While the condition was being changed, the subject was idle. No other rest time was allowed.

The experiment was held at the Industrial Engineering department of Kansas State University. Sometimes there were strong alternative signals (like the ringing of a bell, coming on of a machine, etc.). Reaction times influenced by these external factors were not recorded.

It was decided to run the experiment in two phases, I and II. The values of the parameters ℓ and L were to be selected for phase I and were to be changed in phase II in the direction of steepest descent determined during phase I.

Sequence

In experiment five, the effect of learning on the integrated brake pedal was found to be negligible (Fig. 1). Still the performance of first three subjects was plotted to detect any appreciable learning effect. As no positive learning effect was discernible from the data on first three subjects, the sequence varied from subject to subject and was determined to reduce the effort in changing values of ℓ and L after each set of conditions was tested.

RESULTS

Phase I:

The values selected in phase I for the parameters ℓ x L were (numbers in inches) 1.5 x 8, .5 x 7, 2.5 x 9, 2.5 x 7 and .5 x 9 identified as conditions 1 through 5 respectively in Fig. 7. Reaction times for the first eight subjects are summarized in Table I. The times, given in hundredths of a second, are the mean times per trial based on the 20 readings taken in each condition.

Table I
Mean reaction time (1/100 sec.) of twenty trials in Phase I.

	Reaction Time (1/100 sec.)					
	Condition					
sub. no.	1	2	3	4	5	shoe length (in.)
1	33.65**	32.25	31.8	30.4*	31.7	10.75
2	33.3*	35.1	35.05**	33.35	34.8	10.5
3	37.45**	35.85	35.95	34.1*	34.6	12.0
4	39.45	38.65*	44.0	39.35	44.75**	11.0
5	39.0**	38.3	36.2*	38.85	36.3	9.5
6	41.9	39.85*	44.05**	40.25	41.7	9.5
7	43.9	43.1	41.3	45.6**	38.0*	12.5
8	35.45	35.6	35.25	35.7**	33.0*	12.5

* Subject's min. mean time for his five conditions (row min.)
** Subject's max. mean time for his five conditions. (row max.)

EVOP was used to evaluate the significance of main effects (ℓ and L) and interaction effects (ℓ x L). Running averages Y_i's (i identifying the conditions 1, 2, . . ., 5) were calculated after obtaining mean times for each subject. The effects were calculated as follows:

ℓ effect = $1/2(Y_3 + Y_4 - Y_2 - Y_5)$

L effect = $1/2(Y_3 + Y_5 - Y_2 - Y_4)$

ℓxL interaction = $1/2(Y_2 + Y_3 - Y_4 - Y_5)$

Change in mean = $1/5(Y_2 + Y_3 + Y_4 + Y_5 - 4Y_1)$

Sample calculations for two successive cycles illustrating the use of EVOP in calculating Y_i's, the ℓ, L and ℓ x L effects and the 95% error limits for these effects are given in Appendix III.

The results of calculations after each cycle are consolidated in Table II. The 95% error limits are also shown for various effects.

As can be seen from the table, there were no significant main or interaction effects at the completion of Phase I. In other words, the response surface was fairly flat within the area studied and no direction of descent was found to be steeper than any other (at 95 percent confidence level) in this phase. Looking at individual reaction times of Table I, the reaction times are maximum at condition one for subjects 1, 3 and 5, at condition three for subjects 2 and 6, for condition four

Table II

Consolidated main effects and 95% error limits (Phase I)

Cycle No.	Cumulative Effects: ℓ	L	ℓxL	Change in mean	95% Error Limits: New Avg.	New Effects	Change in Mean
2.	-.81	1.13	1.97	.33	±1.50	±1.50	±1.32
3.	-.66	.47	1.17*	-.84	±1.12	±1.12	±1.00
4.	-.46	1.70*	.70	-.46	±1.52	±1.52	±1.37
5.	-.32	.89	.49	-.40	±1.45	±1.45	±1.29
6.	.03	1.29*	.50	-.40	±1.28	±1.28	±1.14
7.	.42	.46	.49	-.58	±1.43	±1.43	±1.28
8.	.57	.18	.56	-.56	±1.28	±1.28	±1.16

*Significant effects.

for subjects 7 and 8 and, for condition five, for subject 4. Although not conclusive, a slightly higher response area is indicated in the region 1, 3, 4 and 5; that is, reaction times were higher for increasing values of L. Noting the size of the shoes, there seemed to be a relationship. While the subjects with smaller shoes seemed to perform better at conditions 2 and 3, ones with larger sizes showed a bias for positions 3 and 5. Subjects 3, 7 and 8, all males, had large shoes and were probably in the upper 1/6 th range of U.S. male population foot sizes.

It was decided to increase the area of search for the optimum combination of ℓ and L by reducing L in the second phase. It was also decided to limit the subjects to those with foot sizes within 66% of total U.S. population. For U.S. men, sixty six percent of foot sizes are within the range 9.93" - 10.87"; for U.S. women, 66% of foot sizes are within the range 8.96" - 9.84" (McFarland et al., 1966). It was decided to eliminate the lower 1/6th of the female population and the upper 1/6th of males and work in the range 9" to 11".

Phase II

The new values of variables selected are shown in Fig. 8. Values of ℓ could not be reduced because of physical limitations of the pedal.

The mean times per cycle for subjects 8 to 16 are tabulated in Table III. Table IV shows the cumulative effects and 95% error limits for various effects. The overall results for the two phases are shown in Fig. 9. Because the interaction effects were nonsignificant in both the phases, conditions 2 and 5, and 3 and 4 were combined together and the ℓ and L effects were calculated for each subject in both the phases. The ℓ and L effects for each subject were plotted against his shoe length (Fig. 9 and Fig. 10 for phase I and phase II respectively).

The Spearman rank correlations (Table V) between ℓ and L effects and the subject shoe lengths were all nonsignificant at the 5 percent level.

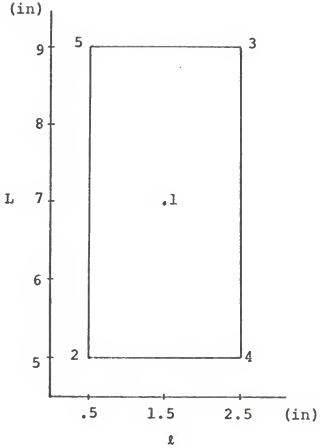

Fig. 8. Values of variables "ℓ" and "L" for Phase II.

Table III

Mean reaction times (1/100 sec.) of twenty trials in Phase II.

	Reaction Time (1/100 sec.)						
	Condition						
sub. no.	1	2	3	4	5	Shoe length (in.)	Foot length (in.)
9	33.5	35.6**	34.15	33.9	33.4*	10.5	9.25
10	31.7*	32.75	33.45	35.85**	32.9	12.0	11.0
11	34.1	37.55**	34.1	37.5	33.6*	11.0	9.0
12	35.7**	30.85	35.1	33.4	32.6	9.5	9.0
13	36.8	38.7	34.45	33.85*	37.75	11.5	9.5
14	30.9	35.55**	30.5	30.05*	30.75	10.0	9.0
15	29.1	29.25	35.3**	34.15	28.15*	11.25	10.0
16	30.8	30.4	32.75**	29.55*	30.4	12.25	11.0

* Subject's min. mean time for his five conditions. (row min.)

** Subject's max. mean time for his five conditions. (row max.)

Table IV

Consolidated main effects and 95% error limits (Phase II)

Cycle No.	Cumulative Effects				95% Error Limits		
	ℓ	L	ℓxL	Change in mean	New Avg.	New Effects	Change in Mean
2.	.61	- .99	-.07	.54	±3.60	±3.60	±3.24
3.	.49	-1.89*	.04	1.18	±1.68	±1.68	±1.5
4.	.99	- .98	.02	.35	±1.86	±1.86	±1.67
5.	-.01	- .82	.17	.18	±1.75	±1.75	±1.56
6.	-.50	-2.70*	.56	- .40	±1.61	±1.61	±1.44
7.	.44	- .90	.66	.52	±1.84	±1.84	±1.65
8.	.47	- .58	.77	.45	±1.50	±1.50	±1.35

*Significant effects.

Table V

Spearman's rank correlation coefficients for ℓ & L effects and subject shoe size.

Phase	Correlation Coefficient	
	ℓ effect	L effect
I	.23	-.38
II	.06	.00

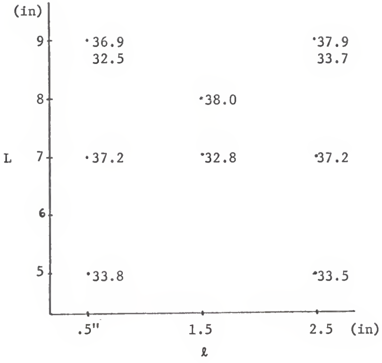

Fig. 9. Reaction times (1/100 sec.) for phases I and II.

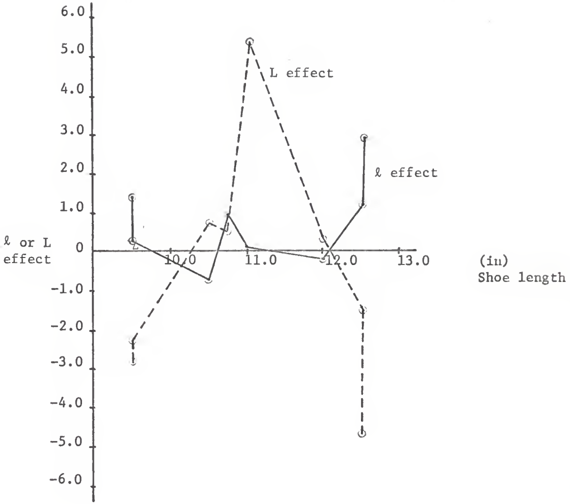

Fig. 10. The "ℓ" effect and "L" effect plot against shoe length (Phase I).

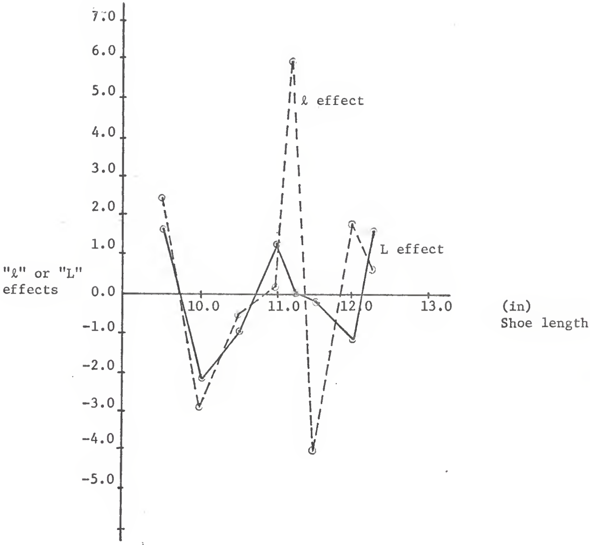

Fig. 11. The "ℓ" effect and "L" effect plot against subject shoe length (Phase II).

CONCLUSION

No main effects were found to be significant after the completion of Phase II. In cycles three and six of this phase reaction time was significantly lower for the lower value of L (5"). This could be dismissed as an individual effect because of subject preference. Within the studied ranges of ℓ (.5" to 2.5") & L (5" to 9"), therefore, no specific values of these variables or any combinations of them were better than the others. Contrariwise, it can be said that the criterion of least reaction time does not act as a constraint in the tested range of pivot distances from the heel of the pedal.

The above conclusion is significant for designers. It provides a fairly wide working range to select the values of these variables on criteria of more mechanical nature. Mechanical ease of positioning the shafts, linkage design for brake and accelerator actuation, space constraints,etc. may well be chosen to determine exact values of these variables. Also, within the studied range, the nonsignificant correlations between the design parameters of ℓ and L and subject shoe length are suggestive of relative independence of these variables - - useful information for the designer.

This experiment by no means provides an answer to an optimum integrated control design. It merely suggests range of working of just one set of variables. Other variables as optimum inclination of control pedal to ground, optimum height of control pedal from floor, optimum relationship to seat height, optimum seat reference point, optimum spring rates for fore and aft shafts, are other variables that need studying before an optimum design of the integrated control can be made. Again, the testing of these variables can use different criteria. Reaction time is only one criterion. Another one could be fatigue associated with the relative frequency of application of brake and accelerator under different driving situations viz. city driving, highway driving, etc.

In conclusion, an analysis of the auto-road-driver system indicates modification of the automobile is the most cost-effective approach, a combined accelerator-brake control is both feasible and effective and the designer of a dual function pedal has considerable freedom in its design.

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APPENDIX I

Some of the design considerations for the integrated control

The shape of the pedal was selected to be rectangular with the dimensions of 3.5" width & 12" length. (McFarland et al., 1966). The pedal was spring supported on both shafts to bring it to null position on release of load, and also to prevent it from being actuated by the weight of the foot and leg. For ankle operated pedals, the optimum resistance is 6.5 - 9 lb. (Morgan et al., 1963).

Because the distribution of weight on the foot is more concentrated towards the heel end, the spring for the rear shaft had a higher spring rate (18.5 lb. per in.) than for the front shaft (spring rate = 3.5 lb. per in.).

Pedals operated by ankle action should have a maximum travel of 2 in. (McCormick, 1964). Also, the angle of inflexion about the ankle should not be greater than 30 degrees because this is about half the total range of ankle movement. The minimum permissable fulcrum distance from the end of the pedal (longitudinal end), x, can be found from

$$\frac{2}{x} = \tan 30°$$

or

$$x = \frac{2}{\tan 30°} = 4"$$

In no condition of testing were the shafts to be placed so that the fulcrum shaft was less than 4" from the end of the pedal which was being depressed.

A heel support was provided at the end of the pedal to prevent the foot from slipping off the inclined pedal.

Appendix II

The facsimile of the data recording sheet

Date ____________ S. # ____________

Name ____________ M or F ____________ Yrs. of Drvg. Exp. ____

Height ____________ SRD ____________ Shoe Length ____________

Trials	Conditions											Total
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
Tot.												
Ave.												

Data are brake reaction times in 1/100 sec.

Appendix III

Sample Calculations for Two Successive Cycles in Phase I.

EVOP Work Sheet

Cycle: $n = 4$
Response: Reaction time

Project: Dual Brake/Accelerator Pedal.
Phase: I
Date:

Calculation of Averages

Operating Conditions	(1)	(2)	(3)	(4)	(5)
a. Prev. cycle sum (prev. e)	104.4	103.2	102.8	97.85	101.1
b. Prev. cycle avg (prev. f)	34.8	34.4	34.27	32.62	33.7
c. New Observations	39.45	38.65	44.0	39.35	44.75
d. Diff. (b-c)	-4.65	-4.25	-9.73	-6.73	-11.05
e. New sums (a + c)	143.85	141.85	146.8	137.2	145.85
f. New avgs (Yi), (e/n)	35.96	35.46	36.7	34.3	36.46

Calculation of Std. Deviation

g. Prev. sum, S, (prev. i) = 1.68
h. New S = Range x K = (-4.25+11.05).37
i. New sum, (g + h) = 4.20
j. New avg, $s = \frac{\text{New sum}}{n-1} = 1.40$
k. Prev. Avg, s_a, (prev. j) = .84

Calculation of Effects

"ℓ" Effect $= 1/2(Y_3 + Y_4 - Y_2 - Y_5) = 1/2(36.7 + 34.3 - 35.46 - 36.46) = -.46$

"L" Effect $= 1/2(Y_3 + Y_5 - Y_2 - Y_4) = 1/2(36.7 + 36.46 - 35.46 - 34.3) = 1.70$

ℓ x L Interaction $= 1/2(Y_2 + Y_3 - Y_4 - Y_5) = 1/2(35.46 + 36.7 - 34.3 - 36.46) = .70$

Change in Mean $= 1/5(Y_2 + Y_3 + Y_4 + Y_5 - 4Y_1) = -.46$

Calculation of 95% Error Limits

For New avg. $= \frac{t}{\sqrt{n}} s = \text{L.s.} = 1.09 \times 1.40 = \underline{+}1.52$

For New Effects (A,B,AB) $= \frac{t}{\sqrt{n}} \text{L.s.} = \underline{+}1.52$

For change in mean $= \frac{2t}{\sqrt{5n}} s = \text{M.s.} = .98 \times 1.40 = \underline{+}1.37$

Factors: for a 5 point design

n	K	L	M
2	.30	1.96	1.76
3	.35	1.33	1.19
4	.37	1.09	.98
5	.38	.95	.85
6	.39	.85	.76
7	.40	.78	.70
8	.40	.72	.65

Appendix III (Cont.)

Sample Calculations for Two Successive Cycles in Phase I.

EVOP Work Sheet

Cycle: $n = 5$
Response: Reaction time

Project: Dual Brake/Accelerator Pedal.
Phase: I
Date:

Operating Conditions	(1)	(2)	(3)	(4)	(5)
	Calculation of Averages				
a. Prev. cycle sum (prev. e)	143.85	141.85	146.8	137.2	145.85
b. Prev. cycle avg (prev. f)	35.96	35.46	36.7	34.3	36.46
c. New Observations	39.00	38.3	36.2	38.85	36.3
d. Diff. (b-c)	-3.04	-2.84	+ .5	-4.55	.16
e. New sums (a + c)	182.85	180.15	183.0	176.05	182.15
f. New avgs (Yi), (e/n)	36.57	36.03	36.6	35.21	36.43

Calculation of Std. Deviation

g. Prev. sum, S, (prev. i) = 4.20
h. New S = Range x K = (.5+4.55) .38 = 1.92
i. New sum, (g + h) = 6.12
j. New avg, $s = \frac{\text{New sum}}{n-1} = 1.53$
k. Prev. Avg, s_a, (prev. j) = 1.40

Calculation of Effects

"ℓ" Effect $= 1/2(Y_3 + Y_4 - Y_2 - Y_5) = 1/2(36.6 + 35.21 - 36.03 - 36.43) = -.32$

"L" Effect $= 1/2(Y_3 + Y_5 - Y_2 - Y_4) = 1/2(36.6 + 36.43 - 36.03 - 35.21) = .89$

$\ell \times L$ Interaction $= 1/2(Y_2 + Y_3 - Y_4 - Y_5) = 1/2(36.03 + 36.6 - 35.21 - 36.43) = .49$

Change in Mean $= 1/5(Y_2 + Y_3 + Y_4 + Y_5 - 4Y_1) = -.40$

Calculation of 95% Error Limits

For New avg. $= \frac{t}{\sqrt{n}} s = L.s. = \pm 1.45$

For New Effects (A,B,AB) $= \frac{t}{\sqrt{n}} L.s. = \pm 1.45$

For change in mean $= \frac{2t}{\sqrt{5n}} s = M.s. = \pm 1.295$

Factors: for a 5 point design

n	K	L	M
2	.30	1.96	1.76
3	.35	1.33	1.19
4	.37	1.09	.98
5	.38	.95	.85
6	.39	.85	.76
7	.40	.78	.70
8	.40	.72	.65

OPTIMIZING THE DESIGN OF A DUAL
FUNCTION BRAKE ACCELERATOR PEDAL

by

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AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

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Manhattan, Kansas

1968

ABSTRACT

The design parameters, for a combined brake-accelerator pedal, of relative locations of the brake and accelerator shafts were tested for optimality. An operations research searching technique based on the line of steepest descent down the reaction time response surface was used.

The experiment was conducted in two phases. "ℓ", the distance between the heel of the pedal and the brake shaft, was tested at three values of .5, 1.5 and 2.5 inches in both phases. Distance "L", that of accelerator shaft from the heel of the pedal, was tested at 7, 8 and 9 inches in Phase I and at 5, 7 and 9 inches in Phase II.

A 2^2 factorial design with a center point was used for the experiment.

No value of either design parameter tested was found to be significantly better than the others; this indicates that the designer may select the values of these parameters on criteria other than reaction time.