DESIGN CONSIDERATIONS OF A DUAL-FUNCTION PEDAL

by

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INTRODUCTION

The people of America, who had been quick to regard the locomotive and airplane as dangerous, were startled to discover that "horseless carriages" were killing people in large numbers. In the four years of America's participation in World War II, 1,070,000 American servicemen were killed or wounded in combat; during the same period, 3,394,000 people were killed or injured in traffic accidents on the home front. In fact, more people have been killed or injured on highways than have been killed or wounded in all the wars in which the United States has been involved. These facts are presented, not to detract from the horror and suffering due to war, but to give perspective to the magnitude and seriousness of the traffic problem (Center for Safety Education, 1959).

Driving an auto is a complex task, involving the highest stakes of life, limb, and money. Yet most of the people think that they are able to drive, and, in fact, more than 96 million persons in this country are licensed to do so.

The statistics show that a traffic death occurs every ten minutes and an injury every 19 minutes. In 1967, there were more than 53,100 deaths and about 1,900,000 injuries. In addition to the suffering and sorrows from death or injury, there is the dollar, $10.7 billion of them in 1967 (NSC, 1968). So it can be realized that beside sufferings there is a tremendous loss of money. The problem is complex and needs a proper solution as soon as possible. To reduce this tremendous toll, many groups are trying to make automobile travel safer. Safer driving, safer cars and safer highways tend to improve the situation. Most of these efforts may be classified under these general headings: man, machine, and environment.

The man - machine - environment components of automobile driving are represented by the operator, the car, and the road. Which one of the three should be modified to obtain optimum results?

We are far from exercising any control on human characteristics except perhaps by training. Basically, the ability of human beings to use various devices depends on their psychomotor abilities and anthropometric characteristics (McCormick, 1964). An expenditure of a billion dollars distributed over a hundred million drivers is only $10 per driver. It is not expected that a driver would benefit much from this amount of direct training. Next consider the development of the road. On an average, one mile of road costs between .5 to 3 million dollars a mile, depending upon the environment and the type of the highway. One billion dollars would pave one thousand miles and keep 99.06 per cent of existing roads untouched. Thus neither the man nor the environment is economic to modify to increase safety.

In the U.S.A., automobiles are sold at an average rate of 8.1 million per year. The estimated half life of cars is five years; that is, five years from today more than half of the cars on American roads will be manufactured after today. One billion dollars would allow $135 per automobile. Therefore, the modification of the automobile seems the most cost-effective approach.

Safety depends upon the permissible margin of error for the operator. The greater this margin, the less would be the chance of an accident. It is assumed that the shorter the operator's reaction time, the greater the permissible margin of error and thus the greater the time that will be available to control the automobile to attain a specified condition. In other words, the car can be driven at higher speeds or closer intervals with equal safety or maintain the same speed or interval with increased safety; which option the driver will select is unknown.

When you are driving and the light changes to red, there is always a delay before you begin the sequence of responses that will slow your car. The delay between the occurrence of a stimulus event and the initiation of a response of the vehicle to it is called the reaction time (Fitts and Posner, 1968). If the time to apply the brakes on the presentation of a stimulus is reduced, the overall reaction time of braking will be decreased. Reaction time as defined above comprises:

1. Sensing time is the time required to sense a signal. It is a function of the properties of the signal (i.e., size, intensity, duration).
2. Decision time is the time required to complete the neurological process of selection of the correct response to the presented stimulus. Decision time varies widely, depending on the complexity of the decision to be made.
3. Response time is the time required to respond to a

signal and is a function of the complexity of the response (i.e., force, displacement, and precision requirements), of the body member being used and the amount of practice.

If any of these factors can be controlled so that their time of execution is reduced, the reaction time will be reduced.

Under simple conditions, sensing time is up to 50 milliseconds. Sensing time depends upon the signal characteristics such as the size of the source, intensity, duration, and location. The larger the size of the visual signal, the faster to some extent is the sensing time. Simultaneous stimulation of more than one sense modality produces faster reaction times than stimulation of just one. On the other hand, successive stimulation of different senses produces slower reaction times than stimulation of a single sensory channel (Teichner, 1954).

Decision time depends upon the central transmission of the sensory impulses to the motor fibers. This is comprised of the time taken by the perceptual, translation, and central effectory mechanisms (Hicks, 1952). In general, decision time is proportional to the logarithm of the number of alternative choices (Morgan, et. al., 1963).

Some of the factors that affect sensing and decision time (Morgan, et. al., 1963) can be listed as follows:

a. The sense used.

b. The characteristics of the signal.

c. The complexity of the signal.

d. The signal rate.

e. Whether or not anticipatory information is provided.

f. The response characteristics of the body-member used.

Response time is approximately 20-30 milliseconds faster for hand movements than for foot movements (Fitts and Posner, 1968). Response with the preferred limb is about 10 to 15 milliseconds faster than with the nonpreferred limb (Teichner, 1954). So, if the speed of activation of a control is the prime factor, the order of selection for right-handed operators should be right hand, left hand, right foot, and left foot.

The extent of variation in the reaction time also depends on the environmental conditions as well as the persons involved (Woodworth and Schlosberg, 1954).

The emphasis in designing a brake control system was to reduce the response time, because it is not economically feasible to modify the input signals (sensing time). Since the hands, while driving, have many tasks to perform, it is desirable to assign the control of braking to the feet. Which foot?

Konz and Daccarett (1967) demonstrated that reduction in reaction time occurs only when the foot is on the brake pedal; there is no savings if the foot must move to the pedal. The left foot could be used in the cars with automatic transmission but, in this situation, the operator would be denied the freedom of movement of any of his limbs. It appears that this way of driving a car is not comfortable. Also, left foot braking is not possible in the automobiles without automatic transmission. Thus it was decided to combine braking and acceleration in one control. The question then arises: what is the optimal design of a dual-function pedal?

LITERATURE SURVEY

Single-Function Pedals

The first efforts to determine the optimal design of foot pedals were made by Barnes, et. al. (1942). The five pedals investigated differed primarily in the location of the fulcrum. Fifteen operators (twelve male and three female) performed the routine twice, first using the pedals in order, 1, 2, 3, 4,5, and the second time in the reverse order. Using a 90-second session of continuous up and down movement, it was found that the foot pedal with the fulcrum at the heel had 109 milliseconds for the downward stroke; the worst pedal had 137 milliseconds.

Some formal studies on the man-machine aspects of a foot pedal have been advanced by Trumbo and Schneider (1963). Their criterion was the number of times the subjects could depress and release the pedal pivoted at the heel. The pedal having a downward movement of the toe resulted in the maximum number of responses per minute.

Ayoub and Trombley (1967) measured reaction time to a stimulus of light and travel time to move the pedal to a fixed stop. Five subjects performed the experiment in a single session requiring approximately two hours and 15 minutes. The position of the fulcrum at the heel, with the load attached at the ball of the foot, provided minimum time of 247 milliseconds; the worst pedal had a time of 258 milliseconds. The foot tibia angle should be between 78 to 96 degrees, with 84 degrees the recommended angle.

McFarland, et. al. (1966) suggested that for light pedal pressures (under 20 pounds), the axes of the foot and lower leg should form a 90-degree angle, the angle which needs the least possible muscular effort, to hold the foot in position. They recommended that, for the light pedal forces, the knee angle should be at least 90 degrees, with 135 degrees or more preferred.

Every operator has an optimum pedal location, or range of locations, requiring the least energy expenditure and providing the most comfort. This location is specified with reference to the seat reference point (S.R.P.), the intersection of the back of the seat surface with the back rest, in the midline. The S.R.P.-pedal distance should be such, so as to provide maximum comfort to the operator. McFarland, et. al., recommend 55 per cent of the person's height.

Dual-Function Pedals

One type of "one-pedal control" of a car has been developed by Humphrey, Inc. (1968). In this design three different zones are provided: an upper braking zone, a middle neutral zone, and a lower acceleration zone. The limitation in this design is that the driver has to keep his foot constantly on the pedal. If, due to fatigue or some other reason, the foot is removed from the pedal, the car will come to a sudden stop.

Versace (1966) in the human factors department at the Ford Motor Company conducted some preliminary investigation of a dual brake-accelerator system on automobiles but failed to show any "unusual advantage" over the conventional two-pedal system.

To the author's knowledge, no experimental investigation of reaction times on dual-function systems has been done except at Kansas State University.

To date eight experiments have been conducted on dual-function pedals at Kansas State University. The first three of these experiments have been described in detail by Konz and Daccarett (1967). Experiment number four, five, and six have been described in detail by Kalra (1968).

In the first experiment the relative quickness of activating a control by hand and by foot was compared for twelve subjects. The conditions were:

1. Honk horn. Starting position--hand on horn ring.
2. Honk horn. Starting position--hand on steering wheel.
3. Depress brake. Starting position--left foot on brake.
4. Depress brake. Starting position--right foot on depressed accelerator.

The average time found for condition 1 was 380 milliseconds, for 2 was 560 milliseconds, for 3 was 390 milliseconds, and for 4 was 590 milliseconds. A Wilcoxen Matched-Pairs Signed-Ranks test showed that 1 and 3 were not significantly different, and 2 and 4 were not significantly different. However, 1 and 3 were significantly shorter than 2 and 4.

Experiment two, on 121 subjects, used a dual-function (brake and accelerator) pedal designed by Winkleman (U.S. patent 2,878,908). In this system pressing of the toe resulted in acceleration while depressing the heel provided the braking action. An interlock prevented simultaneous operation. It was found that the average time for the dual-pedal system (410 milliseconds) was significantly lower than that for condition four in experiment one (590 milliseconds).

Experiment three provided more direct comparison of the conventional system versus the dual-function pedal system. The three conditions were as follows:

1. Depress conventional brake. Starting position of the left foot on the brake.
2. Depress conventional brake. Starting position of the right foot on the depressed accelerator.
3. Depress dual-function pedal. Starting position of the right foot on depressed accelerator position of dual-function pedal.

It was found that times of 25 subjects were significantly ($p < .05$) less in condition 1 (290 milliseconds) than 3 (360 milliseconds) than 2 (450 milliseconds).

Experiment four was conducted on the highway with the experimental pedal mounted on a 1960 Rambler having automatic transmission. It was found that the time for the dual-function pedal system (470 milliseconds) was significantly ($p < .01$) lower than that for the conventional system (570 milliseconds).

Experiment five was performed without the interlock which prevents the simultaneous operations of both controls. The three conditions were:

1. AAA reaction timer. Starting position of the right foot was on the depressed accelerator.
2. 1960 Rambler parked in the lab. Starting position of the right foot on the depressed accelerator.

3. Dual-function control without interlock. Starting position--depressed accelerator.

It was concluded that the combined pedal with a reaction time of 323 milliseconds was significantly ($p < .01$) faster than Rambler (432 milliseconds) and the American Automobile Association (AAA) reaction timer (482 milliseconds).

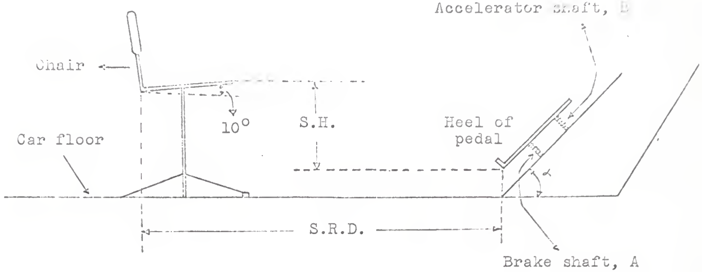
Experiment six was conducted to find the effect of varying some of the parameters in the design of the dual-function pedal system. The distances from the heel of the pedal to the accelerator and to the brake shaft were altered. The purpose was to obtain the minimum reaction time. No specific values of the variables or any combinations of them were better than others.

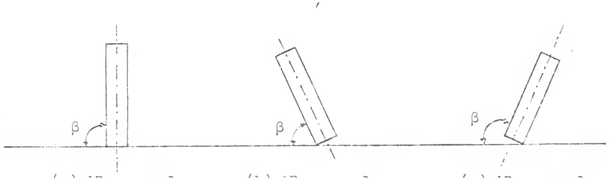
Experiment seven (Wadehra, 1968) was conducted to determine the optimum values of the pedal angle with the floor, seat reference distance (S.R.D.), brake force, and accelerator force for minimal reaction time. It was concluded that the brake and accelerator force had little effect on the reaction time. The recommended accelerator force was within the range of 4 to 8 pounds which is quite in agreement with that of Morgan, et. al. (1963) who recommended 6.5 to 9 pounds. The recommended range of brake force was between 13 to 21 pounds, without losing more than 15 milliseconds. The optimum range of pedal angle was between 40 to 50 degrees. S.R.D. seemed to be optimum between 45 to 55 per cent of the subject's height.

Experiment eight (Sathaye, 1969) was conducted to determine the effect of varying some of the parameters in the design of the dual-function pedal. Four subjects were used for the experiment. Ten trials were taken for each of the ten conditions. It was found that the range of optimum pedal angle was between 30 to 45 degrees without losing more than 10 milliseconds. β, the angle by which the pedal unit was twisted in the clockwise direction around the vertical axis (range considered 90 to 104 degrees) did not have a significant effect on the reaction time. The optimum value of the seat height was recommended to be around nine inches; however, the range from 8 to 10 can be used without losing 10 milliseconds. The recommended range of S.R.D. was between 40 to 50 per cent of the subject's height, without losing more than 15 milliseconds.

PROBLEM

Experiment nine was conducted to investigate the effect of varying some of the parameters in the design of the dual-function pedal. The parameters involved were (1) α, inclination of the foot pedal with the floor,(2) S.R.D., the seat reference distance, the distance between the heel of the pedal and the intersection of the seat surface with the back rest of the seat, (3) β, the angle by which the pedal unit was twisted in the clockwise direction around the vertical axis (Fig. 1). The purpose of this investigation was to determine the combination of these variables which have the minimum reaction time.





(a) When angle β is 90°

(b) When angle β is less than 90°

(c) When angle β is more than 90°

(Front views of the pedal showing angle of twist)

Fig. 1. Sketch of dual-function pedal showing the variables (α, β, S.R.D.) in experiment nine.

METHOD

Experimental Apparatus

The experimental arrangement used, shown in Plate I, was similar to that of Sathaye (1969). The arrangement for experiments six and seven consisted of the following:

1. Biomechanic chair
2. Integrated accelerator/brake pedal unit
3. Actuation indicator bulb
4. 1/100-second reaction timer
5. 100-watt lamp covered with red cellophane
6. Control switch
7. D-c power (12-V/200-ma).

Experiments six and seven were conducted in the Human Engineering Laboratory, without providing a driving environment.

On the other hand, experiments eight and nine were conducted in an automobile (1956 Chevrolet) with its engine in gear and running. The subject felt engine noise and vibrations and had to watch through the windshield for the red light. The 100-watt lamp covered with red cellophane was kept 15 feet away from the operator at eye level.

The front seat of the automobile was removed and a biomechanic chair was installed. The seat was rectangular in shape (17.5 inches wide and 15 inches long) with the corners rounded off. It had a backrest. A seat pad provided comfort. The height of the chair was kept constant at 10 inches (Sathaye, 1969). The lower half of the steering wheel was cut in order

PLATE I

to make room for the subject's legs. The accelerator portion of the pedal was attached by a link arrangement so that the engine speed could be varied by the subject.

The accelerator force was held constant at 6 pounds and the brake spring force was held constant at 15 pounds (Wadehra, 1968). In experiment seven, Wadehra found that accelerating spring force affects the reaction time no more than 20 milliseconds, if varied between 4 to 8 pounds. The optimum range recommended for the brake force is between 13 to 21 pounds, without losing more than 15 milliseconds. The distances of the brake shaft and accelerator shaft from the heel of the pedal were kept fixed at 4.5 and 7.5 inches respectively, although these distances presumably have no significant effect on the reaction time (Kalra, 1968). The rear shaft (Fig. 1), A, acted as a fulcrum when the pedal was pressed in the forward direction and the foreshaft, B, acted as a fulcrum when the pedal was pressed in backward direction. The forward and backward pressing motions correspond to the accelerating and braking the car, respectively.

The two shafts of the pedal were connected to two cut-out switches which, in turn, were connected to the two actuation indicator bulbs, one green and one red. The bulbs were off when no operation was executed. When the accelerator was depressed, the green bulb went on, and when it was released and the brake depressed, the green bulb went off. If, by chance, both the shafts were depressed, the buzzer sounded with the red bulb on, indicating the faulty operation to the operator. A d-c power supply (12-V/100-ma) was used in the circuit (Fig. 2).

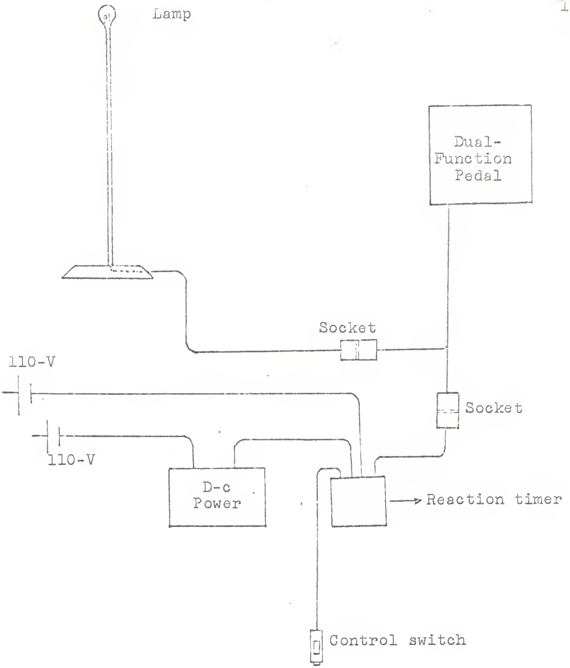


Fig. 2. Circuit diagram showing the apparatus used in experiment nine.

The "reaction timer" was connected through an operating switch to both the rear shaft relay switch and the 100-watt lamp. The control switch had a dual role to play; one was to turn on the bulb along with starting the reaction timer at the same time and the second was to reset the reaction timer to zero position after the reaction time of one trial had been recorded. The reaction timer was electrically connected through the rear of the shaft cut-out switch and was stopped as soon as the rear shaft (brake) was depressed by 1/16th of an inch. Then the time was recorded from the reaction timer by the experimenter. The reaction timer used is of The Standard Electric Time Co., Mass. (Type S-1, Inst. No. 47450, Speed 1 RPS, Cycles 60).

The reaction timer was calibrated against a strip chart recorder. It was found that the reaction timer was recording about 1.5 per cent more time than the strip chart recorder. This indicates that the reaction times recorded by this reaction timer in this experiment are reasonably accurate.

Design of the Experiment

A searching technique called EVOP (Evolutionary Operation of Processes) (Box and Hunter, 1959) was employed for calculating the effect of the variables being considered in this experiment. The main features of the EVOP are:

a. Variation.

b. Selection of favorable variables.

The parameters are changed in small intervals so that, due to changes made, the path of the steepest descent (ascent) can be approximated to head toward the extremum. In EVOP a single performance of a complete set of operating conditions is called a cycle, and the repeated running through of a cycle of operating conditions is called a phase. A new phase of EVOP begins when new conditions are explored with the help of information from the previous phase.

Before any change in the selection of variables is made, the process is run for a number of cycles at one level of the variables. The response surface is determined, and the new changes introduced so as to lead to the extremum. 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 extremum.

A 2^3 factorial design (Fig. 3) with a center point was used in the experiment. Three-variable EVOP was employed to evaluate the significance of the main effects (A, B, C) (Fig. 3) and the interaction effects (A x B, A x C, B x C). Running averages, Yi's (i = 1, 10 conditions), were calculated from the mean times for each subject. A single cycle was broken into two blocks of five runs each as indicated by the open and solid circles (Fig. 3). The values of E_1, E_2, . . ., E_7, are given by the following set of equations:

$$E_1 = (A-BC)\text{ effect} = 1/2(Y_3 + Y_4 - Y_2 - Y_5)$$
$$E_2 = (B-AC)\text{ effect} = 1/2(Y_3 + Y_5 - Y_2 - Y_4)$$
$$E_3 = (-C+AB)\text{ effect} = 1/2(Y_2 + Y_3 - Y_4 - Y_5)$$
$$E_5 = (A+BC)\text{ effect} = 1/2(Y_8 + Y_9 - Y_7 - Y_{10})$$
$$E_6 = (B+AC)\text{ effect} = 1/2(Y_8 + Y_{10} - Y_7 - Y_9)$$
$$E_7 = (C+AB)\text{ effect} = 1/2(Y_7 + Y_8 - Y_9 - Y_{10})$$

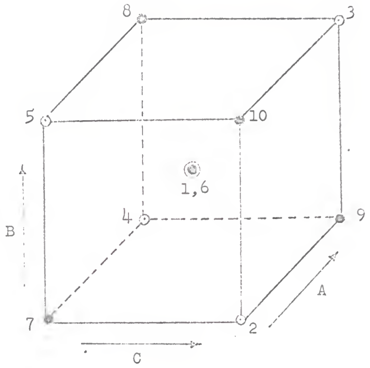


Fig. 3. Sketch showing a 2^3 factorial design with a center point.

○ --- Conditions of a cycle for Block I.

● --- Conditions of a cycle for Block II.

From the combined information of Block I and Block II, the main effects (A, B, C) and the interaction effects (A x B, A x C, B x C) were calculated as given below:

$$A \text{ effect} = 1/2(E_5 + E_1)$$

$$B \text{ effect} = 1/2(E_6 + E_2)$$

$$C \text{ effect} = 1/2(E_7 - E_3)$$

$$A \times B \text{ interaction effect} = 1/2(E_7 + E_3)$$

$$A \times C \text{ interaction effect} = 1/2(E_6 - E_2)$$

$$B \times C \text{ interaction effect} = 1/2(E_5 - E_1)$$

A data recording sheet is given in Appendix 1. Sample calculations for four successive cycles illustrating the use of EVOP in calculating Yi's (i = 1, 10 conditions), the main effects, interaction effects, and the 95 per cent standard error limits for these effects are shown in Appendix II. The EVOP calculation form used is that given by G. Box and S. Hunter (1959). In this experiment, the effect of each variable used 320 time values and the error used 400 times.

The three variables studied were α, S.R.D., and β. In Phase 1, the angle of the pedal with the floor was varied from 35 to 45 degrees (Sathaye, 1969), in steps of 5 degrees. S.R.D., the seat reference distance, was varied from 40 to 50 per cent (Sathaye, 1969) of the subject's height, in steps of 5 per cent. β, the angle of twist, was varied from 85 to 105 degrees, in steps of 10 degrees. S.H., the seat height from the heel of the pedal, was kept fixed at 10 inches (Sathaye, 1969). The specific values taken in Phase I are shown in Fig. 4.

Subjects

Four staff members (3 male) from Kansas State University, each having at least 35 years of driving experience, were used as subjects; the average age was 60 years. Older subjects were chosen because subjects in former experiments primarily had been students. All were between 64 to 69 inches in height. The same four subjects were run in all the phases in order to minimize the subject effect.

Also, 50 subjects (40 male and 10 female) were used from an Engineering Open House held on March 15 and 16, 1969 at Kansas State University. For each of these 50 subjects, ten reaction times on the dual-function pedal and ten times on a conventional brake-accelerator system (AAA reaction timer) were taken.

Sequence

Some learning effect was noticed in experiment seven (Wadehra, 1968). To reduce this effect each subject was given 15 to 20 practice trials at each of the ten conditions (only in Phase I) before the actual experiment started.

The sequence of the first subject was arranged in such a manner so as to reduce the effort of changing the experimental set-up. The sequence of the subject two was the mirror image of subject one's. Subject three followed a different sequence and subject four's sequence was the mirror image of subject three's. The sequence was varied in each phase (consisting of four cycles).

Experimental Procedure

Before the experiment was started, the personal data of the subject (name, age, sex, height, and years of driving experience) were recorded. The subject was told the purpose of the experiment. Questions, if any, were answered. The rear wheels of the car were lifted up from the ground with the help of a jack. The engine of the car was started and it was put in drive gear during the experiment. The subject was asked to depress the accelerator so that the speed indicated by the needle was between 20 to 30 miles per hour and watch the red lamp through the windshield. As soon as the bulb under the red cellophane was on, the subject was to release the accelerator and apply the brake. When the brake was applied the red light went off and the reaction time was indicated on the reaction timer in milliseconds. During the experiment the subject kept his hands on the steering wheel. No special rest period was provided except the one available during the changing and fixing of conditions. A time gap of five seconds is quite enough to prevent treating the two consecutive stimuli as one stimulus (Telford, 1931).

Twelve readings were taken for each condition and the highest and the lowest eliminated. The experiment was run in four phases. The values of the parameters for each phase were selected after analysis of the previous phase.

RESULTS

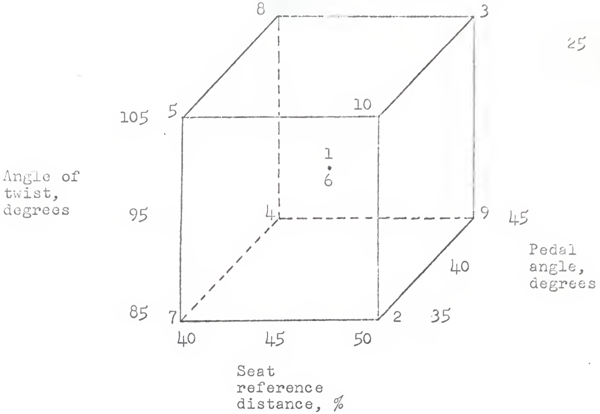
Phase I

The parameters under study were the angle of twist (β), seat reference distance (S.R.D.), and the pedal angle (α). The points 1 through 10 are given in Fig. 4 (a). Block I (Appendix II) consists of points 1 through 5 and Block II (Appendix II) consists of points 6 through 10. Reaction times for the four subjects are given in Table 1. The reaction times, in milliseconds, are the mean times taken at each point for each subject, based on ten readings (twelve readings at each point were taken and the lowest and the highest were eliminated) and are shown in Fig. 4 (b).

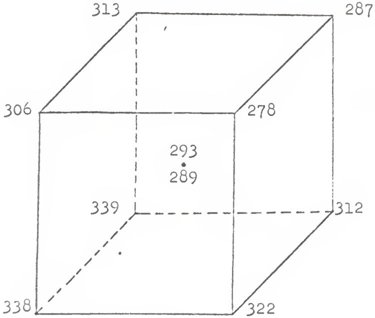
Three-variable EVOP was used to calculate the significance of the main effects of α, β, S.R.D., and the first order (two factor) interaction effects of α x β, α x S.R.D., and β x S.R.D. The results of each cycle of Phase I are summarized in Table 2. The 95 per cent error limits are also tabulated.

The average response was 308 milliseconds. At the end of Phase I, the variation of the response surface at 95 per cent error limits was ±8.00 milliseconds by chance. Therefore, the effects above or below ±8.00 milliseconds were significant.

As seen from the Table 2, the main effects of β and S.R.D. had a significant effect on the reaction times at the completion of Phase I. A change of 20 degrees in β changed the response 31.7 milliseconds; the surface sloped upward from 85 degrees by 1.6 milliseconds per degree. A change of 10 per



(a) Cycle of variants



(b) Mean reaction time (milliseconds) after 4 cycles (seat height constant at 10 inches)

Fig. 4. Pattern of variants and results for three variables for Phase I.

Table 1

Mean reaction time (milliseconds) of ten trials in Phase I.

Subjects	Points 1	2	3	4	5	6	7	8	9	10	Average
L.W.	307	349	304	362**	338	295*	352	334	337	305	328
E.B.	298	301	277	329	300	288	334**	288	299	263*	298
T.P.	286	321	284	354**	301	278	328	327	319	277*	307
H.S.	283	319	282	311	284	294	337**	305	292	268*	298
Average	293	322	287	339	306	289	338	313	312	278	308

*Subject's minimum mean time for his or her ten points (row minimum).

**Subject's maximum mean time for his or her ten points (row maximum).

Table 2

Consolidated main effects and 95 per cent error limits (Phase I).

Cycle No.	Cumulative Effects α	β	S.R.D.	$\alpha \times \beta$	$\alpha \times$ SRD	$\beta \times$ SRD	95% Error Limits
2	-1.75	-31.75*	25.25*	0.75	-1.25	2.75	±11.78
3	3.25	-32.25*	25.75*	1.25	3.25	3.75	± 8.96
4	1.75	-31.75*	24.25*	6.25	2.25	2.75	± 8.00

*Significant effect.

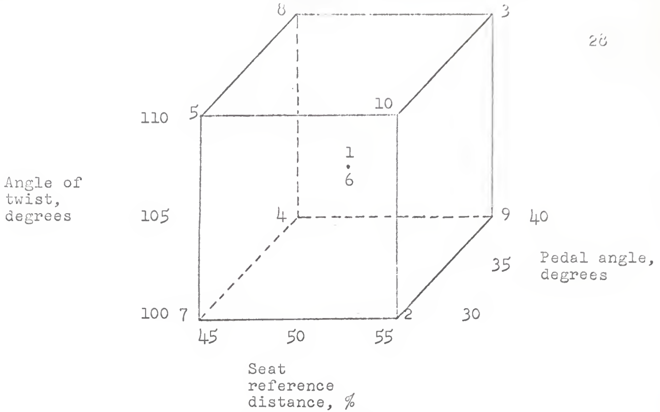
cent in S.R.D. changed the response 24.3 milliseconds; the surface sloped down 2.4 milliseconds per per cent from 40 per cent. The effect of α was not significant. None of the interactions were significant.

Phase II

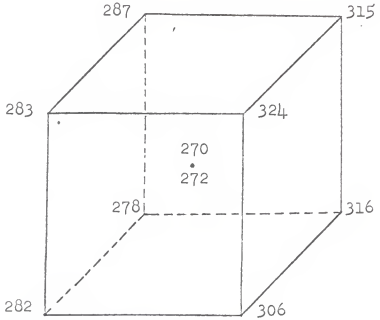
As β, the angle of twist, was significant in the last phase, the higher angles being more favorable, it was decided to vary β at 100-105-110 versus the 85-95-105 of Phase I. Also, S.R.D. was significant, the higher values of percentages being more favorable, so it was decided to vary S.R.D. at 45-50-55 per cent of the subject' height instead of 40-45-50. In order to have two points in common between Phase I and II, the pedal angle was varied at 30-35-40 instead of 35-40-45.

The new values of the variables selected are shown in Fig. 5 (a). The mean reaction times for the ten points after completion of four cycles are shown in Fig. 5 (b). The mean times for each cycle are given in Table 3. Table 4 shows the cumulative effects and 95 per cent error limits for various effects; the average response was 294 milliseconds; the error was ± 8.90 milliseconds. Only the main effect of S.R.D. was found significant. The change of 10 per cent in S.R.D. changed the response 33.3 milliseconds; the surface sloped upward 3.3 milliseconds per per cent from 45 per cent.

The results of Phase I and II show that the optimum value of S.R.D. lies between 45 to 50 per cent of the subject's height.



(a) Cycle of variants



(b) Mean reaction time (milliseconds) after 4 cycles (seat height constant at 10 inches)

Fig. 5. Pattern of variants and results for three variables for Phase II.

Table 3

Mean reaction time (milliseconds) of ten trials in Phase II

Subjects	Points										Average
	1	2	3	4	5	6	7	8	9	10	
L.W.	275	309	320	268*	314	279	302	311	321	333**	305
T.P.	257*	321	323**	280	262	266	267	277	311	318	288
H.S.	277*	300	314	295	286	278	291	280	323	330**	298
E.B.	273	296	302	268	272	266*	270	281	311	317**	286
Average	270	306	315	278	283	272	282	287	316	324	294

*Subject's minimum mean time for his or her ten points (row minimum).

**Subject's maximum mean time for his or her ten points (row maximum).

Table 4

Consolidated main effects and 95 per cent error limits (Phase II)

Cycle No.	Cumulative Effects α	β	S.R.D.	$\alpha \times \beta$	α x SRD	β x SRD	95% Error Limits
2	-1.75	9.75	-34.25*	2.75	-0.25	2.25	±22.26
3	-1.00	6.50	-32.50*	-2.00	-1.00	-2.50	±13.16
4	0.35	6.75	-32.75*	-2.75	-0.25	-1.65	± 8.90

*Significant effect.

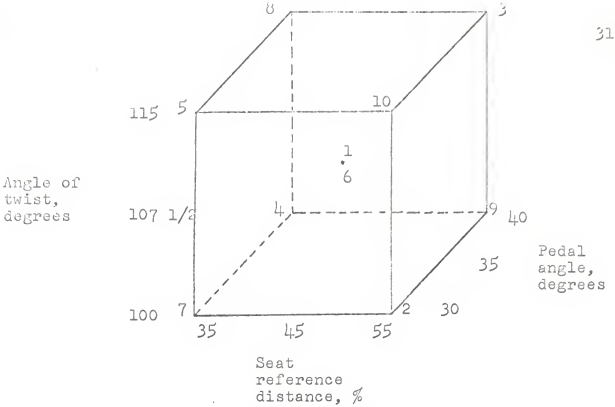
Phase III

As the effect of β was not significant in Phase II, it was decided to explore the range of angle β further. In the Phase III, β was varied at 100-107.5-115 versus the 100-105-110 of Phase II. It was decided to vary S.R.D. at 35-45-55 to have a wider range of contours (for showing the best and the worst designs) versus the 45-50-55 of Phase II. The pedal angle was kept the same as that of Phase II (30-35-40).

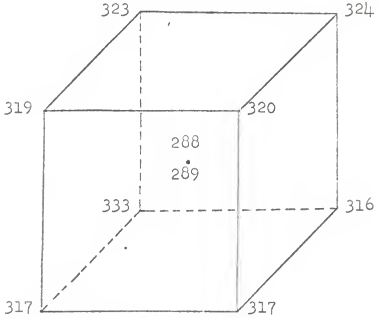
The new values of the variables selected are shown in the Fig. 6 (a). The mean reaction times for the ten points after completion of Phase III are shown in Fig. 6 (b). Reaction times for the four subjects are given in Table 5. Table 6 shows the cumulative effects and 95 per cent error limits for various effects in Phase III; the average response was 315 milliseconds and the error was ± 5.72. The main effect of α was found significant. A change of 10 degrees in pedal angle changed the response 5.8 milliseconds; the surface sloped upward from 30 degrees by 0.6 millisecond per degree. The S.R.D. response, when 35 per cent was contrasted against 55 per cent, was not significant. Angle of twist, β, was not significant.

Phase IV

To explore the lower and higher levels of α, it was decided to vary α at 25-40-55 instead of the previous 30-35-40. S.R.D. was kept the same as that of Phase III (35-45-55). As the main effect of β and its interaction effects with the other two variables (α, S.R.D.) were not significant in Phase III, it was



(a) Cycle of variants



(b) Mean reaction time (milliseconds) after 4 cycles
(seat height constant at 10 inches)

Fig. 6. Pattern of variants and results for three variables for Phase III.

Table 5

Mean reaction time (milliseconds) on ten trials in Phase III

Subjects	Points 1	2	3	4	5	6	7	8	9	10	Average
L.W.	297	322	334	338	325	296*	320	340**	328	318	322
T.P.	289*	327	327	366**	331	292	330	329	317	324	323
E.B.	281	299	309	301	301	281*	299	301	306	314**	299
H.S.	287*	321	327	329**	319	288	321	324	312	326	316
Average	288	317	324	333	319	289	317	323	316	320	315

*Subject's minimum mean time for his or her ten points (row minimum).

**Subject's maximum mean time for his or her ten points (row maximum).

Table 6

Consolidated main effects and 95 per cent error limits (Phase III)

Cycle No.	Cumulative Effects α	β	S.R.D.	$\alpha \times \beta$	α x SRD	β x SRD	95% Error Limits
2	10.00*	-2.50	10.50*	-2.50	6.50	-5.00	±8.60
3	7.00	0.00	4.50	-3.00	4.50	-4.50	±8.17
4	5.75*	0.75	3.75	-1.75	4.25	-4.75	±5.72

*Significant effect.

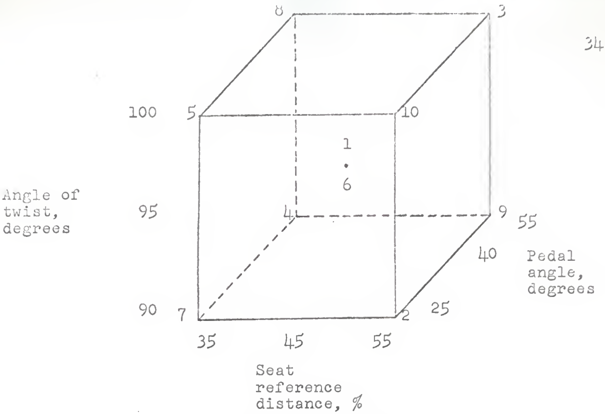
decided to lower the values of β to a range which was most suitable to the subjects; 90-95-100.

The new values of the variables selected are shown in the Fig. 7 (a). The mean reaction times for the ten points after completion of Phase IV are shown in Fig. 7 (b). Reaction times for the four subjects are summarized in Table 7. Cumulative effects and 95 per cent error limits for various effects in Phase IV are summarized in Table 8. The average response was 329 milliseconds and the error was $\pm$11.39.

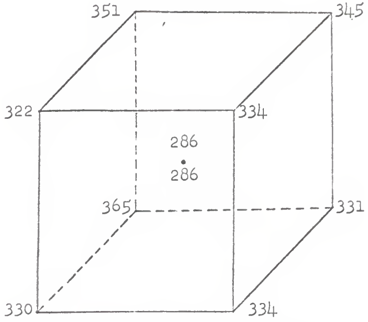
As seen from the Table 8, the main effect of α had a significant effect on the reaction times. A change of 30 degrees in α changed the response 18 milliseconds or a slope upward of 0.6 millisecond per degree from 25 degrees. Although the response of 330 at 25 degrees was better than 348 at 55 degrees, both were higher than the response at 30 and 35 degrees in previous Phases or the 286 for 40 degrees in this Phase. Angle of twist, β was not significant. The S.R.D. response, when 35 per cent was contrasted against 55 per cent, was not significant. Only the α x S.R.D. interaction effect was significant.

The search was terminated after Phase IV, as the feasible surface had been scanned. The minimum reaction time was 270 milliseconds for point 1 (α = 35 degrees, β = 105 degrees, S.R.D. = 50 per cent) in Phase II.

Since β was never significant in the range 90 to 115 degrees, its effect was ignored and the overall results for α and S.R.D. for all the four Phases is shown in Fig. 8. The common points of the four Phases showed some learning as the number of



(a) Cycle of variants.



(b) Mean reaction time (milliseconds) after 4 cycles (seat height constant at 10 inches)

Fig. 7. Pattern of variants and results for three variables for Phase IV.

Table 7

Mean reaction time (milliseconds) of ten trials in Phase IV

Subjects	Points										Average
	1	2	3	4	5	6	7	8	9	10	
E.B.	277*	308	306	319**	305	279	300	318	304	316	303
L.W.	283*	329	340	350**	328	292	322	337	322	314	322
T.P.	300	359	388	389	331	296*	373	418**	355	376	359
H.S.	284	340	345	404**	323	279*	327	333	343	330	331
Average	286	334	345	365	322	286	330	351	331	334	329

*Subject's minimum mean time for his or her ten points (row minimum).

**Subject's maximum mean time for his or her ten points (row maximum).

Table 8

Consolidated main effects and 95 per cent error limits (Phase IV)

Cycle	Cumulative Effects						95% Error
No.	α	β	S.R.D.	$\alpha \times \beta$	α x SRD	β x SRD	Limits
2	9.25*	1.25	4.75	0.25	7.75	-2.25	± 7.85
3	15.75*	3.75	6.25	7.75	13.25*	-6.75	±12.53
4	18.00*	-2.00	6.00	2.00	14.00*	-9.00	±11.39

*Significant effect.

trials increased. The learning curve for the dual-function pedal is shown in Fig. 9. For direct comparison the reaction times of each Phase were reduced to Phase IV as their reference base, by multiplying by a certain correction factor obtained from Fig. 9. The multiplying factor was obtained by taking each point of the different phase (Fig. 8) as 100 per cent and then finding what per cent the fourth phase point was of the 100 per cent. The multiplying factor for each phase is given in Appendix III. Adjusted points for all the four phases are shown in Fig. 10. The appearance of the response surface showing its contours is shown in Fig. 11. The times shown in Fig. 11 are the adjusted average reaction times at different conditions.

Comparison of Dual-Function Pedal with Conventional Brake-Accelerator System

Twelve reaction times (highest and the lowest eliminated) of the same four subjects were taken on the conventional brake-accelerator system. The seat height was fixed at 10 inches. S.R.D. was fixed according to the subject's own convenience. The mean reaction time for these subjects on dual-function pedal at the best condition ($\alpha = 35^{\circ}$, $\beta = 105^{\circ}$, S.R.D. was fixed according to the subject's own convenience) was found to be 270 milliseconds. This showed that there was a saving in reaction time of 249 milliseconds by using the dual-function pedal.

Twelve reaction times (highest and the lowest eliminated) were taken on the dual-function pedal and twelve times (highest and lowest eliminated) on a conventional brake-accelerator system for each of the 50 subjects of 16 to 67 years of age (average

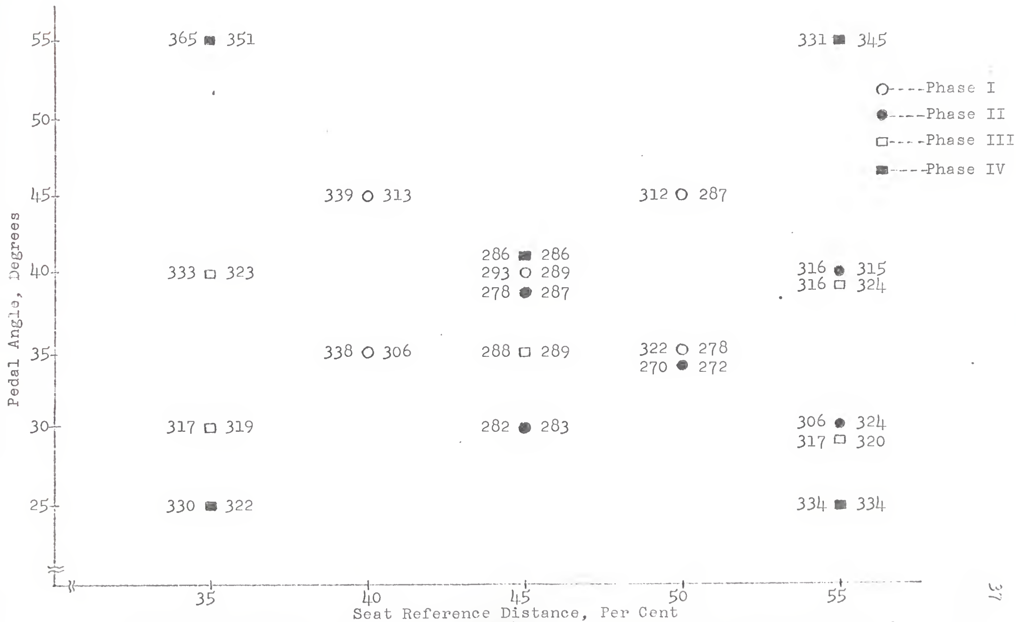


Fig. 8. Reaction times (milliseconds) after ignoring the effect of angle of twist, for Phases I to IV.

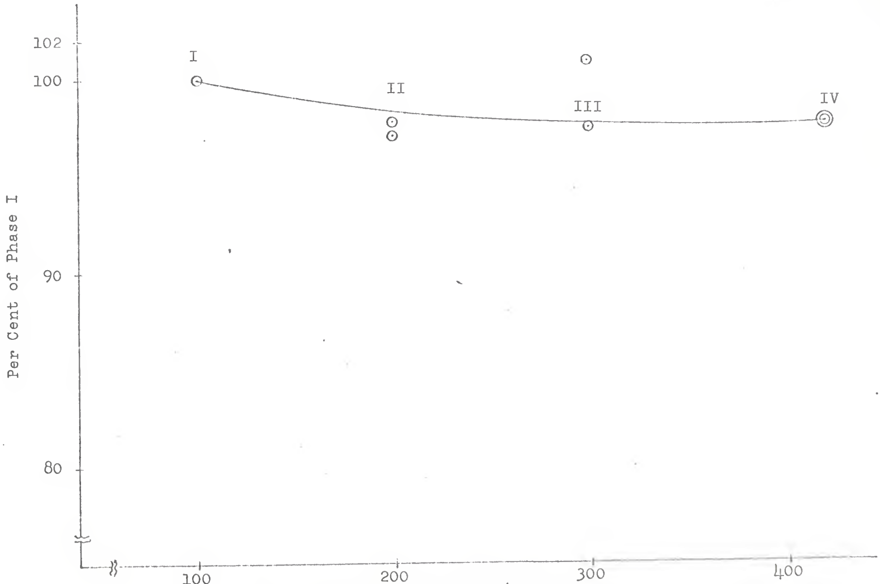


Fig. 9. Learning effect for dual-function pedal in experiment nine.

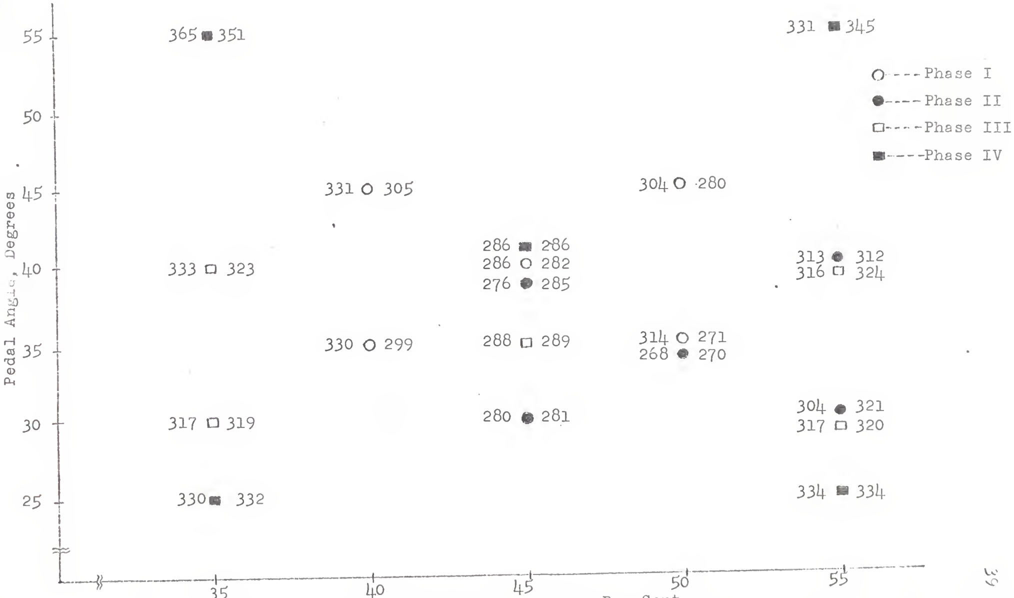


Fig. 10. Reaction times (milliseconds) after ignoring the effects of angle of twist, with respect to Phase IV as base, for Phase I to IV.

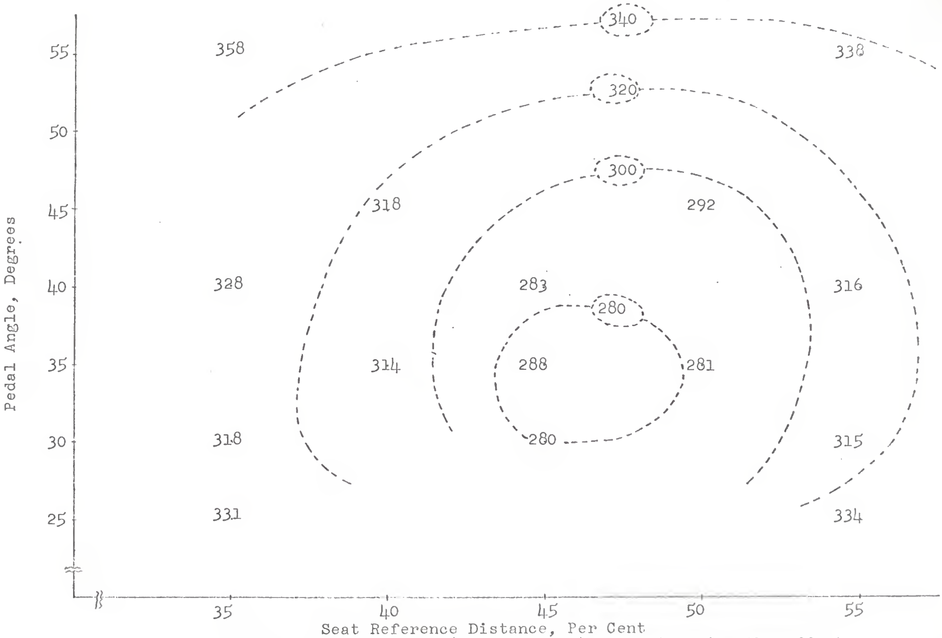


Fig. 11. Average reaction times (milliseconds) after ignoring the effect of angle of twist, with respect to Phase IV.

age: 30 years), from Engineering Open House (March 15, 1969) at Kansas State University. Before the trials on dual-function pedal and conventional system were taken, each subject was given a small amount of instructions (about a minute) explaining the procedure to be followed. No practice was given to the subjects.

For showing the direct comparison between dual-function pedal and conventional brake-accelerator system, the histograms for reaction times (500 in each case) in both the systems were drawn on the same sheet (Fig. 12). On the dual-function pedal the average time was 280 milliseconds (Table 10), and conventional brake-accelerator system averaged 470 milliseconds (Table 11). Thus there was a saving in reaction time of 190 milliseconds by using the dual-function pedal. This saving in time was achieved with small amount of instructions (about a minute) and without practice given to the subjects. Figure 12 shows that 90 per cent of the time, the reaction time for dual-function pedal would be 350 milliseconds and for conventional brake-accelerator system would be 650 milliseconds.

For determining the effect of age on reaction time, a graph (Fig. 13) of age versus reaction time was plotted. It showed that in case of a dual-function pedal age has very little effect on the reaction time, but in case of the conventional brake-accelerator system the reaction time goes on increasing appreciably with respect to age. This means that older people can be well adjusted on the dual-function pedal system using the criterion of reaction time. The saving for a 60-year-old subject would be predicted to be 260 milliseconds; this is compatible with 249 milliseconds made by the four subjects.

Table 9

Mean reaction time (milliseconds) of ten trials on conventional brake-accelerator system

Subjects	Trials											
	1	2	3	4	5	6	7	8	9	10	Total	Average
W.L.	610	580	570	620	560	590	630**	540*	600	550	5850	585
T.P.	520*	530	560**	535	520	550	530	535	560	540	5380	538
E.B.	520**	480	500	480	465	475	495	455*	510	515	4895	489
H.S.	480	450	490**	440*	465	480	460	445	475	460	4645	464
											2077	519

*Subject's minimum time out of ten trials.

**Subject's maximum time out of ten trials.

Table 10

Mean reaction time (milliseconds) of ten trials on dual-function pedal

Subjects No.	Trials 1	2	3	4	5	6	7	8	9	10	Total	Average	Age
1	275	280	300	260	250	230	260	265	275	315	2710	271	19
2	330	340	290	265	330	305	340	300	290	270	3060	306	18
3	250	255	260	275	240	280	230	250	235	290	2565	256	18
4	300	250	280	310	280	275	300	305	280	310	2890	289	39
5	330	290	290	300	310	280	260	310	290	300	2960	296	38
6	310	330	310	350	325	380	370	320	300	300	3295	329	67
7	300	290	310	280	290	290	300	250	265	280	2855	285	18
8	270	280	275	270	255	260	250	245	240	300	2645	264	20
9	210	220	230	200	210	220	210	210	200	200	2110	211	30
10	270	300	300	265	300	245	300	300	245	290	2815	281	19
11	300	310	280	330	290	300	280	260	310	300	2960	296	18
12	240	290	250	250	260	265	280	255	245	220	2555	255	57
13	280	270	265	280	290	230	285	270	240	270	2680	268	33
14	280	295	260	290	260	295	270	285	305	245	2785	278	35
15	310	280	250	300	305	310	270	295	330	270	2920	292	52
16	290	260	370	300	260	310	295	245	265	275	2870	287	41
17	310	300	330	310	315	295	310	290	310	315	3085	308	65
18	305	320	335	310	300	305	300	295	315	335	3120	312	60
19	290	285	275	305	265	310	255	270	295	300	2850	285	20
20	260	260	265	250	235	285	280	270	265	255	2625	262	21
21	270	305	290	275	310	290	300	270	270	280	2860	286	20
22	300	270	260	265	260	290	310	285	290	250	2780	278	16
23	290	285	300	285	280	280	285	320	300	270	2895	289	18
24	310	280	305	280	330	300	290	270	320	295	2980	298	43
25	250	245	260	290	300	275	280	260	260	300	2720	270	17

Table 10 (Continued)

Subjects No.	Trials 1	2	3	4	5	6	7	8	9	10	Total	Average	Age
26	275	270	245	295	275	280	290	255	270	250	2705	270	21
27	310	290	305	335	300	335	310	315	330	295	3125	312	43
28	315	310	315	290	250	265	265	300	260	295	2865	286	26
29	280	240	290	255	260	310	240	235	290	250	2650	265	16
30	300	295	265	315	280	265	250	300	300	255	2825	282	20
31	230	250	220	250	230	225	235	225	225	250	2340	234	28
32	265	300	260	290	265	290	290	310	275	300	2845	284	17
33	305	270	280	260	265	295	295	300	235	300	2805	280	45
34	290	280	300	310	295	280	310	295	300	300	2960	296	46
35	300	280	310	300	300	250	295	310	330	280	2955	295	27
36	240	230	230	210	220	225	240	230	230	210	2265	226	21
37	290	280	300	305	270	265	300	265	285	240	2800	280	43
38	300	270	275	260	260	290	275	260	265	265	2720	272	21
39	300	285	280	285	280	270	320	265	240	280	2805	280	20
40	280	295	240	275	290	260	250	290	280	265	2725	272	25
41	300	275	295	295	300	290	290	260	275	290	2870	287	18
42	290	280	305	290	275	280	250	270	270	265	2775	277	22
43	270	305	240	310	290	295	275	275	270	265	2795	279	23
44	290	260	275	280	285	295	255	250	305	270	2765	276	20
45	290	285	295	270	285	260	250	250	280	300	2765	276	20
46	280	265	300	245	290	320	310	315	290	285	2900	290	61
47	275	270	280	280	300	260	300	250	290	270	2775	277	19
48	320	285	295	315	330	305	300	270	305	300	3025	302	69
49	275	290	305	260	295	280	290	260	285	295	2835	283	18
50	260	240	245	255	240	240	245	300	245	230	2500	250	22
											139985	280	

Table 11

Mean reaction time (milliseconds) of ten trials on conventional system

Subjects	Trials												
No.	1	2	3	4	5	6	7	8	9	10	Total	Average	Age
1	480	450	450	450	460	450	440	445	460	440	4525	452	19
2	580	530	550	560	600	610	590	600	590	560	5770	577	18
3	420	410	400	400	420	420	420	390	420	410	4110	411	18
4	500	480	485	490	490	450	480	450	460	445	4730	473	39
5	580	530	500	520	510	500	500	520	500	450	5110	511	38
6	550	640	580	600	580	530	640	550	560	650	5880	588	67
7	510	500	630	570	680	590	570	540	550	580	5720	572	18
8	460	460	650	460	450	490	420	430	420	440	4480	448	20
9	410	450	420	370	350	355	320	380	350	340	3745	374	30
10	450	450	480	510	530	490	525	470	445	505	4855	485	19
11	510	460	440	450	440	440	430	440	415	420	4445	444	18
12	580	550	560	510	510	550	520	560	540	560	5440	544	57
13	580	560	570	520	500	595	560	580	550	510	5525	552	33
14	540	500	490	510	535	550	510	500	480	500	5115	511	35
15	510	460	470	460	500	410	400	480	500	450	4640	464	52
16	530	525	520	500	500	490	520	550	460	450	5045	504	41
17	560	580	550	570	590	520	560	570	560	480	5540	554	65
18	570	700	610	610	560	600	600	550	750	550	6100	610	60
19	415	390	405	405	410	390	395	445	430	450	4135	413	20
20	420	410	400	400	400	400	395	420	400	395	4040	404	21
21	400	410	395	420	400	395	340	405	390	400	3955	395	20
22	500	490	460	490	500	470	480	500	450	490	4830	483	16
23	455	450	555	430	450	440	455	450	470	540	4695	469	18
24	540	500	450	430	470	440	500	450	430	450	4660	466	43
25	470	460	480	460	450	480	455	440	440	520	4655	465	17

Table 11 (Continued)

Subjects	Trials												
No.	1	2	3	4	5	6	7	8	9	10	Total	Average	Age
26	420	400	410	420	380	420	430	420	380	390	4070	407	21
27	650	495	540	500	640	490	500	460	500	490	5265	526	43
28	440	420	435	435	400	420	425	415	410	410	4210	421	26
29	500	470	450	435	460	450	450	430	430	450	4525	452	16
30	460	450	425	420	400	425	440	420	440	435	4315	431	20
31	440	430	425	460	450	425	410	420	405	390	4255	425	28
32	470	490	430	480	410	450	420	435	520	480	4585	458	17
33	430	450	450	435	470	435	435	470	440	460	4475	447	45
34	450	440	445	440	420	410	440	415	410	430	4300	430	46
35	460	435	440	450	420	490	450	420	425	405	4395	439	27
36	360	360	340	370	360	380	350	370	350	370	3610	361	21
37	580	610	430	455	550	405	430	400	470	405	4735	473	43
38	450	470	430	430	450	425	440	440	440	440	4415	441	21
39	450	460	440	430	470	420	475	450	440	490	4525	452	20
40	475	460	440	440	460	480	490	440	425	410	4520	452	25
41	490	470	500	430	400	460	440	450	420	410	4470	447	18
42	490	460	500	460	510	500	460	490	420	440	4730	473	22
43	450	480	410	480	430	440	420	480	410	400	4400	440	23
44	490	410	415	430	520	410	425	410	430	425	4365	436	20
45	440	445	410	415	420	410	410	395	380	390	4115	411	20
46	540	490	460	510	480	460	510	450	440	440	4780	478	61
47	510	450	430	450	570	590	470	590	440	460	4960	496	19
48	610	530	540	540	520	515	530	500	540	510	5335	533	69
49	650	600	570	640	550	540	515	530	680	550	5825	582	18
50	450	440	405	425	415	455	405	410	405	435	4245	428	22
											235170	470	

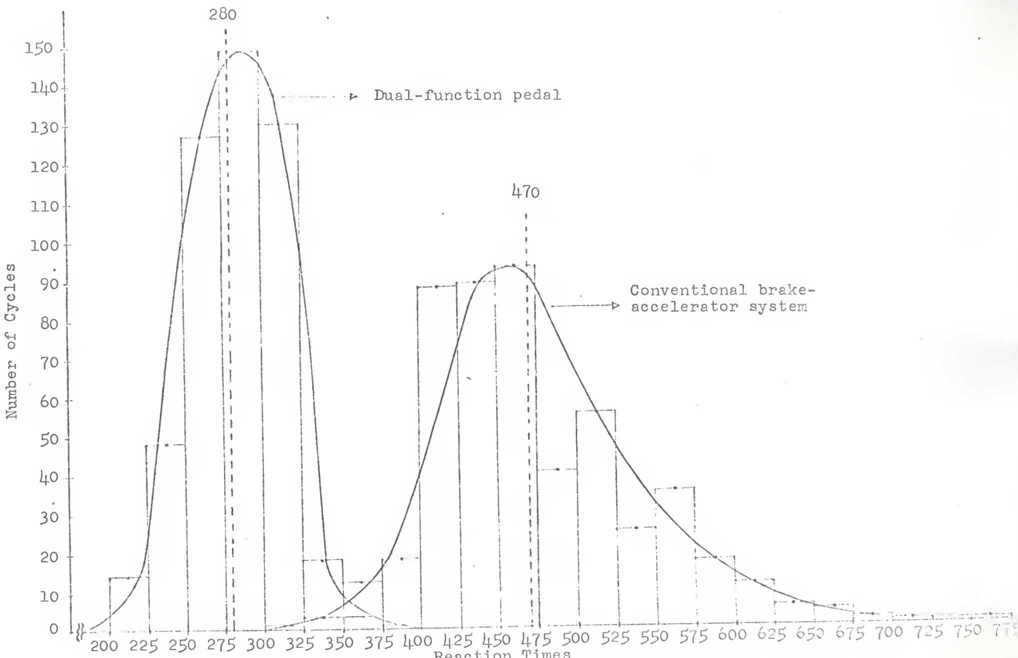


Fig. 12. Histograms for the two types of controls, each having 500 reaction times.

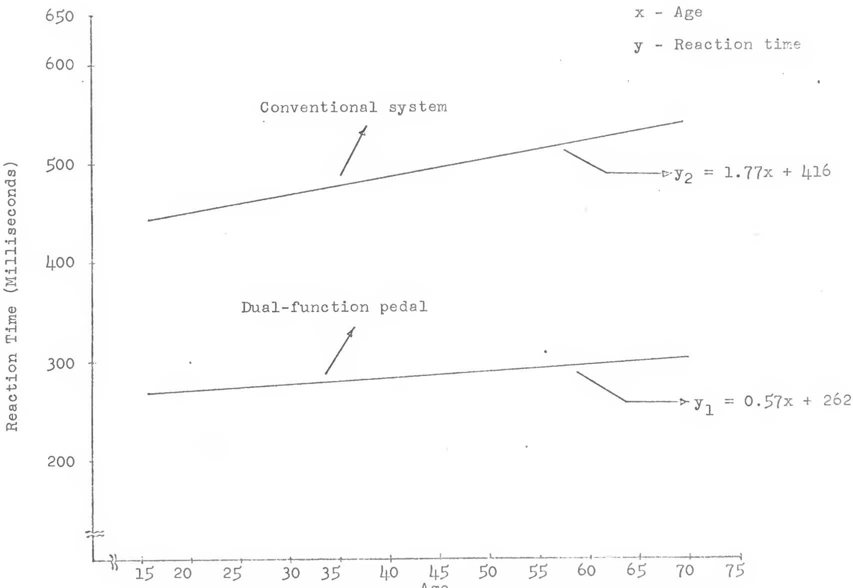


Fig. 13. The effect of age versus reaction time for the two types of controls.

DISCUSSION

Figure 11 shows the optimum range for selecting the variables of α and S.R.D. It indicated that optimum value for S.R.D. seems to lie between 45 to 50 per cent of the subject's height; the optimum value of pedal angle is between 30 to 40 degrees. Selection of values beyond this region would increase the reaction time.

It was found that S.R.D. was significant in Phase I when 40 per cent was compared versus 50 per cent, and in Phase II when 45 per cent was compared versus 55 per cent of the subject's height. But in Phases III and IV, S.R.D. was not significant in both the Phases when 35 per cent was compared versus 55 per cent of the subject's height. Figure 11 indicates that when we consider the points at S.R.D. of 35 per cent and 55 per cent, we come out of the optimum range (bottom of the valley) and approach toward higher levels of nearly the same magnitude on both sides of the valley. These values of the S.R.D. nearly provide the same reaction times. Thus S.R.D. was not significant after Phases I and II.

Another possible reason for S.R.D. being insignificant in Phase III was observed by the author during the period when the experiment was in progress. The reaction time varied with the same subject at a particular condition, that is, if the subject was used for this experiment at different times of the day (i.e., morning, afternoon, evening). This kind of instance was observed in Phase III. At the end of the second cycle (Phase III) the main effect of S.R.D. was significant for the first two subjects, but was made insignificant by the third subject (third cycle) who was the only subject used in the morning in that particular phase. This ultimately resulted in making S.R.D. insignificant at the end of Phase III (consisting of four cycles).

This kind of situation indicated that a subject's reaction time also depends upon the time of the day when subject is used for this experiment. In other words, it can be said that one is more active in the morning and is likely to show a low reaction time than in the afternoon or evening when one is tired due to the day's hard work and does not have the proper intention to work.

After completion of all the four phases, it was observed that subject T.P. (sex: female, height: 5'4", age: 60 years), who showed low average reaction times in Phases I and II, had sufficiently higher average reaction times in Phases III and IV. She was especially poor at S.R.D. of 55 per cent. This kind of situation indicated that shorter people do not feel comfortable if S.R.D. is increased beyond 50 per cent, and are prone to give higher reaction times. On the other hand, taller people may feel comfortable if S.R.D. is increased beyond 50 per cent to some extent. It is obvious that the reverse is true if we approach below S.R.D. of 40 per cent. Thus, in general, S.R.D. value should be selected from 40 to 50 per cent of the subject's height.

Contrary to the expectation of the author, angle of twist (within the range 90 to 115 degrees) did not have a significant effect on the reaction time. However, the minimum reaction times were observed at the conditions when angle of twist was 105 and 107 1/2 degrees.

Contrary to the expectation of the author, the mean reaction time at the best condition of the older subjects (average age, 60 years) used in this experiment was less than that of young students (average age, 23 years) used in experiment eight (Sathaye, 1969). This might be due to the fact that older subjects had nearly 10 times more driving experience than young students.

Another possible design of a dual-function pedal could have a larger size plate (2' x 1') for the pedal. This plate size would cover the same area in the new system which the brake and accelerator already occupy in the conventional system. A person thinking he was actuating a conventional system would lift his foot and move it to the left. A wide pedal would accommodate even this type of error. In this kind of arrangement the operator would be at liberty to use either foot for applying brake or accelerator.

The information given above provides a fairly wide working range to select the values of pedal angle, S.R.D., and angle of twist on criteria of more mechanical nature.

CONCLUSION

There is no definite optimum design since reaction time is more or less the same over a certain range of the values of the variable. The above discussion provides a conclusion which is significant for the designers. It says that to obtain minimum reaction time along with comfortable situation for the operator, the values of the variables considered in this experiment can be taken as given below.

The optimum pedal angle is between 30 to 40 degrees. The optimum seat reference distance can lie between 45 to 50 per cent of the subject's height. Beyond this region a change in S.R.D. of one per cent will increase reaction time approximately 7 milliseconds per per cent. A change in pedal angle of one degree will increase reaction time 4 milliseconds per degree. Minimum reaction time can be obtained when the angle of twist is between 105 to 107.5 degrees.

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APPENDICES

APPENDIX I

DATA RECORDING SHEET

Name: ____________________ Phase: ____________

Height: ____________________ Cycle: ____________

Yrs. of Driving Exp. ________ Date: ____________

Sequence											
Conditions											
Trials	1	2	3	4	5	6	7	8	9	10	Average
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
Total											
Average											

APPENDIX II

THREE-VARIABLE EVOLUTIONARY OPERATION PROGRAM CALCULATION WORK SHEET

BLOCK I

Project Dual-Function Pedal
Cycle $n = 1$
Phase 4

Response Reaction Time (Milliseconds)

	Operating Conditions	(1)	(2)	(3)	(4)	(5)	Calculation of Standard Deviation	
		Calculation of Averages						
(i)	Previous Sum for Block I						Previous Sum s (all blocks)	=
(ii)	Previous Average for Block I						Previous Average s (all blocks)	=
(iii)	New Observations for Block I	277	308	306	319	305	New s = Range x $f_{k,n}$	=
(iv)	Differences (ii) less (iii)						Range	=
(v)	New Sums for Block I	277	308	306	319	305	New Sum s (all blocks)	=
(vi)	New Averages for Block I	277	308	306	319	305	New Average s $\frac{(\text{New Sum s})}{(2n - 3)}$	=

Calculations of Effects

$E_1 = (A - BC)$ Effect $= 1/2(\overline{y}_3 + \overline{y}_4 - \overline{y}_2 - \overline{y}_5) = 6.0$

$E_2 = (B - AC)$ Effect $= 1/2(\overline{y}_3 + \overline{y}_5 - \overline{y}_2 - \overline{y}_4) = -8.0$

$E_3 = (-C + AB)$ Effect $= 1/2(\overline{y}_2 + \overline{y}_3 - \overline{y}_4 - \overline{y}_5) = -5.0$

$E_4 =$ Change in Mean Effect $= 1/5(\overline{y}_2 + \overline{y}_3 + \overline{y}_4 + \overline{y}_5 - 4\overline{y}_1) = 26.0$

APPENDIX II

THREE-VARIABLE EVOLUTIONARY OPERATION PROGRAM CALCULATION WORK SHEET

BLOCK II

Project Dual-Function Pedal
Cycle $n = 1$
Phase 4

Response Reaction Time (Milliseconds)

		Calculation of Averages				
		(6)	(7)	(8)	(9)	(10)
(i)	Previous Sum for Block II					
(ii)	Previous Average for Block II					
(iii)	New Observations for Block II	279	300	318	304	316
(iv)	Differences (ii) less (iii)					
(v)	New Sums for Block II	279	300	318	304	316
(vi)	New Averages for Block II	279	300	318	304	316

Calculation of Standard Deviation

Previous Sum s (all blocks) =
Previous Averages (all blocks) =
New s Range x $f_{k,n}$ =
Range =
New Sum s (all blocks) =
New Average s $\frac{(\text{New Sum s})}{(2n - 2)}$ =

Calculation of Effects

E_5 = (A + BC) Effect = $1/2(\bar{y}_8 + \bar{y}_9 - \bar{y}_7 - \bar{y}_{10}) = 3.0$

E_6 = (B + AC) Effect = $1/2(\bar{y}_8 + \bar{y}_{10} - \bar{y}_7 - \bar{y}_9) = 15.0$

E_7 = (C + AB) Effect = $1/2(\bar{y}_7 + \bar{y}_8 - \bar{y}_9 - \bar{y}_{10}) = -1.0$

E_8 = Change in Mean Effect = $1/5(\bar{y}_7 + \bar{y}_8 + \bar{y}_9 + \bar{y}_{10} - 4\bar{y}_6) = 24.4$

α A = $1/2(E_5 + E_1) = 4.5$

β B = $1/2(E_6 + E_2) = 3.5$

SRD C = $1/2(E_7 - E_3) = 2.0$

$\alpha \times \beta$ AB = $1/2(E_7 + E_8) = -3.0$

$\alpha \times$ SRD AC = $1/2(E_6 - E_2) = 11.5$

$\beta \times$ SRD BC = $1/2(E_5 - E_1) = -1.5$

Calculations of Error Limits

For New Averages $\frac{2}{\sqrt{n}}\sigma$ =

For New Effects $.71 \frac{2}{\sqrt{n}}\sigma$ =

For Change in Mean $.63 \frac{2}{\sqrt{n}}\sigma$ =

Change in Mean Effect

$1/2(E_8 + E_4) = 25.2$

APPENDIX II

THREE-VARIABLE EVOLUTIONARY OPERATION PROGRAM CALCULATION WORK SHEET

BLOCK I

Project Dual-Function Pedal
Cycle $n = 2$
Phase 4

Response Reaction Time (Milliseconds)

	Operating Conditions	(1)	(2)	(3)	(4)	(5)	Calculation of Standard Deviation	
		Calculation of Averages						
(i)	Previous Sum for Block I	277	308	306	319	305	Previous Sum s (all blocks)	=
(ii)	Previous Average for Block I	277	308	306	319	305	Previous Average s (all blocks)	=
(iii)	New Observations for Block I	283	329	340	350	328	New s = Range x $f_{k,n}$	= 8.4
(iv)	Differences (ii) less (iii)	- 6	-21	-34	-31	-23	Range	= 28.0
(v)	New Sums for Block I	560	637	646	669	633	New Sum s (all blocks)	= 8.4
(vi)	New Averages for Block I	280	318	323	334	316	New Average s $\frac{\text{(New Sum s)}}{(2n - 3)}$	= 8.4

Calculations of Effects

E_1 = (A - BC) Effect = $1/2(\bar{y}_3 + \bar{y}_4 - \bar{y}_2 - \bar{y}_5) = 11.5$

E_2 = (B - AC) Effect = $1/2(\bar{y}_3 + \bar{y}_5 - \bar{y}_2 - \bar{y}_4) = -6.5$

E_3 = (-C + AB) Effect = $1/2(\bar{y}_2 + \bar{y}_3 - \bar{y}_4 - \bar{y}_5) = -4.5$

E_4 = Change in Mean Effect = $1/5(\bar{y}_2 + \bar{y}_3 + \bar{y}_4 + \bar{y}_5 - 4\bar{y}_1) = 34.2$

APPENDIX II

THREE-VARIABLE EVOLUTIONARY OPERATION PROGRAM CALCULATION WORK SHEET

BLOCK II

Project Dual-Function Pedal
Cycle $n = 2$
Phase 4

Response Reaction Time (Milliseconds)

		Calculation of Averages					Calculation of Standard Deviation	
		(6)	(7)	(8)	(9)	(10)		
(i)	Previous Sum for Block II	279	300	318	304	316	Previous Sum s (all blocks)	= 8.4
(ii)	Previous Average for Block II	279	300	318	304	316	Previous Averages (all blocks)	= 8.4
(iii)	New Observations for Block II	292	322	337	322	314	New Range x $f_{k,n}$	= 7.2
(iv)	Differences (ii) less (iii)	-13	-22	-19	-18	2	Range	= 24.0
(v)	New Sums for Block II	571	622	655	626	630	New Sum s (all blocks)	= 15.6
(vi)	New Averages for Block II	285	311	327	313	315	New Average s $\dfrac{\text{(New Sum s)}}{(2n - 2)}$	= 7.8

Calculation of Effects

E_5 = (A + BC) Effect = $1/2(\bar{y}_8 + \bar{y}_9 - \bar{y}_7 - \bar{y}_{10}) = 7.0$

E_6 = (B + AC) Effect = $1/2(\bar{y}_8 + \bar{y}_{10} - \bar{y}_7 - \bar{y}_9) = 9.0$

E_7 = (C + AB) Effect =$1/2 (\bar{y}_7 + \bar{y}_8 - \bar{y}_9 - \bar{y}_{10}) = 5.0$

E_8 = Change in Mean Effect = $1/5(\bar{y}_7 + \bar{y}_8 + \bar{y}_9 + \bar{y}_{10} - 4\bar{y}_6) = 25.3$

Calculations of Error Limits

For New Averages $\frac{2}{\sqrt{n}}\sigma$ = ± 11.06

For New Effects $.71 \frac{2}{\sqrt{n}}\sigma$ = ± 7.85

For Change in Mean $.63 \frac{2}{\sqrt{n}}\sigma$ = ± 6.96

α A = $1/2(E_5 + E_1) = 9.25$

β B = $1/2(E_6 + E_2) = 1.25$

SRD C = $1/2(E_7 - E_3) = 4.75$

$\alpha \times \beta$ AB = $1/2(E_7 + E_3) = 0.25$

α x SRD AC = $1/2(E_6 - E_2) = 7.75$

β x SRD BC = $1/2(E_5 - E_1) = -2.25$

Change in Mean Effect

$1/2(E_8 + E_4) = 29.75$

APPENDIX II

THREE-VARIABLE EVOLUTIONARY OPERATION PROGRAM CALCULATION WORK SHEET

BLOCK I

Project Dual-Function Pedal
Cycle $n = 3$
Phase 4

Response Reaction Time (Milliseconds)

	Operating Conditions	(1)	(2)	(3)	(4)	(5)	Calculation of Standard Deviation	
		Calculation of Averages						
(i)	Previous Sum for Block I	560	637	646	669	633	Previous Sum s (all blocks)	= 15.6
(ii)	Previous Average for Block I	280	318	323	334	316	Previous Average s (all blocks)	= 7.8
(iii)	New Observations for Block I	300	359	388	389	331	New s = Range x $f_{k,n}$	= 17.5
(iv)	Differences (ii) less (iii)	-20	-41	-65	-55	-15	Range	= 50.0
(v)	New Sums for Block I	860	996	1034	1058	964	New Sum s (all blocks)	= 33.1
(vi)	New Averages for Block I	287	332	345	353	321	New Average s $\frac{\text{(New Sum s)}}{(2n - 3)}$	= 11.03

Calculations of Effects

E_1 = (A - BC) Effect = $1/2(\bar{y}_3 + \bar{y}_4 - \bar{y}_2 - \bar{y}_5) = 22.5$

E_2 = (B - AC) Effect = $1/2(\bar{y}_3 + \bar{y}_5 - \bar{y}_2 - \bar{y}_4) = -9.5$

E_3 = (-C + AB) Effect = $1/2(\bar{y}_2 + \bar{y}_3 - \bar{y}_4 - \bar{y}_5) = 1.5$

E_4 = Change in Mean Effect = $1/5(\bar{y}_2 + \bar{y}_3 + \bar{y}_4 + \bar{y}_5 - 4\bar{y}_1) = 40.6$

APPENDIX II

THREE-VARIABLE EVOLUTIONARY OPERATION PROGRAM CALCULATION WORK SHEET

BLOCK II

Project Dual-Function Pedal
Cycle $n = 3$
Phase 4

Response Reaction Time (Milliseconds)

		Calculation of Averages (6)	(7)	(8)	(9)	(10)	Calculation of Standard Deviation	
(i)	Previous Sum for Block II	571	622	655	626	630	Previous Sum s (all blocks)	= 33.1
(ii)	Previous Average for Block II	285	311	327	313	315	Previous Averages (all blocks)	= 11.03
(iii)	New Observations for Block II	296	373	418	355	376	New s Range x $f_{k,n}$	= 28.0
(iv)	Differences (ii) less (iii)	-11	-62	-91	-42	-61	Range	= 80.0
(v)	New Sums for Block II	867	995	1073	981	1006	New Sum s (all blocks)	= 61.1
(vi)	New Averages for Block II	289	332	358	327	335	New Average s $\frac{\text{(New Sum s)}}{(2n - 2)}$	= 15.27

Calculation of Effects

E_5 = (A + BC) Effect = $1/2(\bar{y}_8 + \bar{y}_9 - \bar{y}_7 - \bar{y}_{10}) = 9.0$

E_6 = (B + AC) Effect = $1/2(\bar{y}_8 + \bar{y}_{10} - \bar{y}_7 - \bar{y}_9) = 17.0$

E_7 = (C + AB) Effect = $1/2(\bar{y}_7 + \bar{y}_8 - \bar{y}_9 - \bar{y}_{10}) = 14.0$

E_8 = Change in Mean Effect = $1/5(\bar{y}_7 + \bar{y}_8 + \bar{y}_9 + \bar{y}_{10} - 4\bar{y}_6) = 39.2$

Calculations of Error Limits

For New Averages $\frac{2}{\sqrt{n}}\sigma = \pm 17.65$

For New Effects $.71 \frac{2}{\sqrt{n}}\sigma = \pm 12.53$

For Change in Mean $.63 \frac{2}{\sqrt{n}}\sigma = \pm 11.12$

α A = $1/2(E_5 + E_1) = 15.75$

β B = $1/2(E_6 + E_2) = 3.75$

SRD C = $1/2(E_7 - E_3) = 6.25$

$\alpha \times \beta$ AB = $1/2(E_7 + E_3) = 7.75$

α x SRD AC = $1/2(E_6 - E_2) = 13.25$

β x SRD BC = $1/2(E_5 - E_1) = -6.75$

Change in Mean Effect

$1/2(E_8 + E_4) = 39.9$

APPENDIX II

THREE-VARIABLE EVOLUTIONARY OPERATION PROGRAM CALCULATION WORK SHEET

BLOCK I

Project Dual-Function Pedal
Cycle $n = 4$
Phase 4

Response Reaction Time (Milliseconds)

	Operating Conditions	(1)	(2)	(3)	(4)	(5)	Calculation of Standard Deviation	
		Calculation of Averages						
(i)	Previous Sum for Block I	860	996	1034	1058	964	Previous Sum s (all blocks)	= 61.1
(ii)	Previous Average for Block I	287	332	345	353	321	Previous Average s (all blocks)	= 15.27
(iii)	New Observations for Block I	284	340	345	404	323	New s = Range x $f_{k,n}$	= 19.98
(iv)	Differences (ii) less (iii)	3	-8	0	-51	-2	Range	= 54.0
(v)	New Sums for Block I	1144	1336	1379	1462	1287	New Sum s (all blocks)	= 81.08
(vi)	New Averages for Block I	286	334	345	365	322	New Average s $\frac{\text{(New Sum s)}}{(2n - 3)}$	= 16.21

Calculations of Effects

$E_1 = (A - BC)$ Effect $= 1/2(\bar{y}_3 + \bar{y}_4 - \bar{y}_2 - \bar{y}_5) = 27.0$

$E_2 = (B - AC)$ Effect $= 1/2(\bar{y}_3 + \bar{y}_5 - \bar{y}_2 - \bar{y}_4) = -16.0$

$E_3 = (-C + AB)$ Effect $= 1/2(\bar{y}_2 + \bar{y}_3 - \bar{y}_4 - \bar{y}_5) = -4.0$

E_4 = Change in Mean Effect $= 1/5(\bar{y}_2 + \bar{y}_3 + \bar{y}_4 + \bar{y}_5 - 4\bar{y}_1) = 44.4$

APPENDIX II

THREE-VARIABLE EVOLUTIONARY OPERATION PROGRAM CALCULATION WORK SHEET

BLOCK II

Project Dual-Function Pedal
Cycle $n = 4$
Phase 4

Response Reaction Time (Milliseconds)

		Calculation of Averages					Calculation of Standard Deviation	
		(6)	(7)	(8)	(9)	(10)		
(i)	Previous Sum for Block II	867	995	1073	981	1006	Previous Sum s (all blocks)	= 81.08
(ii)	Previous Average for Block II	289	332	358	327	335	Previous Averages (all blocks)	= 16.21
(iii)	New Observations for Block II	279	327	333	343	330	New s Range x $f_{k,n}$	= 15.17
(iv)	Differences (ii) less (iii)	10	5	25	-16	5	Range	= 41.0
(v)	New Sums for Block II	1146	1322	1406	1324	1336	New Sum s (all blocks)	= 96.25
(vi)	New Averages for Block II	286	330	351	331	334	New Average s $\frac{\text{(New Sum s)}}{(2n - 2)}$	= 16.04

Calculation of Effects

E_5 = (A + BC) Effect = $1/2(\bar{y}_8 + \bar{y}_9 - \bar{y}_7 - \bar{y}_{10}) = 9.0$

E_6 = (B + AC) Effect = $1/2(\bar{y}_8 + \bar{y}_{10} - \bar{y}_7 - \bar{y}_9) = 12.0$

E_7. = (C + AB) Effect = $1/2(\bar{y}_7 + \bar{y}_8 - \bar{y}_9 - \bar{y}_{10}) = 8.0$

E_8 = Change in Mean Effect = $1/5(\bar{y}_7 + \bar{y}_8 + \bar{y}_9 + \bar{y}_{10} - 4\bar{y}_6) = 40.4$

Calculations of Error Limits

For New Averages $\frac{2}{\sqrt{n}}\sigma = \pm 16.04$

For New Effects $.71 \frac{2}{\sqrt{n}}\sigma = \pm 11.39$

For Change in Mean $.63 \frac{2}{\sqrt{n}}\sigma = \pm 10.10$

α A = $1/2(E_5 + E_1) = 18.0$

β B = $1/2(E_6 + E_2) = -2.0$

SRD C = $1/2(E_7 - E_3) = 6.0$

$\alpha \times \beta$ AB = $1/2(E_7 + E_3) = 2.0$

$\alpha \times$ SRD AC = $1/2(E_6 - E_2) = 14.0$

$\beta \times$ SRD BC = $1/2(E_5 - E_1) = -9.0$

Change in Mean Effect

$1/2(E_8 + E_4) = 42.2$

APPENDIX III

(A)

Calculations for Points in Fig. 9

1. Common points to Phases I and II

   (a) S.R.D. = 50%, $\alpha = 35^{\circ}$, $\beta = 105^{\circ}$ (point 10 for Phase I, point 1 for Phase II).

   (1) 270/278 = .971 or 97.1% of Phase I.

   (b) S.R.D. = 50%, $\alpha = 35^{\circ}$, $\beta = 105^{\circ}$ (point 10 for Phase I, point 6 for Phase II).

   (1) 272/278 = .978 or 97.8% of Phase I.

2. Common points to Phases II and III

   (a) S.R.D. = 55%, $\alpha = 30^{\circ}$, $\beta = 100^{\circ}$ (point 2 for Phase II, Point 2 for Phase III).

   (1) 317/306 = .1036 or 103.6% of Phase II.

   (2) $$\frac{103.6(97.1 + 97.8)/2}{100} = 100.9\% \text{ of Phase I.}$$

   (b) S.R.D. = 55%, $\alpha = 40^{\circ}$, $\beta = 100^{\circ}$ (point 9 for Phase II, point 9 for Phase III).

   (1) 316/316 = 1.0 or 100% of Phase II.

   $$\frac{100(97.1 + 97.8)/2}{100} = 97.45\% \text{ of Phase I}$$

3. Common points to Phases I and IV

   (a) S.R.D. = 45%, $\alpha = 40^{\circ}$, $\beta = 95^{\circ}$ (points 1, 6 for Phase I, points 1,6 for Phase IV).

   (1) $$\frac{(286 + 286)/2}{(293 + 293)/2} = .976 \text{ or } 97.6\% \text{ of Phase I}$$

(B)

Correction Factor for Adjusting all Phases to Phase I Using Curve of Fig. 9.

The learning factor was determined by considering each point of different phase (Fig. 9) as 100% and finding what per cent the fourth phase point was of the 100%.

Phase I

Considering the points I and IV of Fig. 9, it was concluded that IV is 97.6% of I.

$$\text{Correction factor} = \frac{0.976}{100} \times 100 = 0.976$$

Hence the mean reaction times of Phase I were multiplied by 0.976 for direct comparison.

Phase II

Considering the points II and IV,

$$\text{Correction factor} = \frac{0.976}{0.984} \times 100 = 0.992$$

Hence the mean reaction times of Phase II were multiplied by 0.992 for direct comparison.

Phase III

Considering the points III and IV,

$$\text{Correction factor} = \frac{0.976}{0.977} \times 100 = 0.999$$

Hence the mean reaction times of Phase III were multiplied by 0.999 for direct comparison.

Phase IV

This phase being the base, mean reaction times remained unchanged.

DESIGN CONSIDERATIONS OF A
DUAL-FUNCTION PEDAL

by

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Manhattan, Kansas

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The effect of varying three parameters in the design of a dual-function pedal was determined. The experiment was conducted under partially simulated driving conditions.

A reaction time of 270 milliseconds was found for the optimum design; the conventional brake-accelerator system requires 519 milliseconds for the four experimental subjects. For fifty Engineering Open House visitors, the dual-function pedal required 280 milliseconds and the conventional system 470 milliseconds.

The optimum pedal angle is between 30 to 40 degrees. The optimum seat reference distance is estimated between 45 to 50 per cent of the subject's height. Beyond this region a change of one per cent in S.R.D. will increase reaction time approximately 7 milliseconds per per cent. A change in pedal angle of one degree will increase reaction time about 4 milliseconds per degree. The angle of twist, when varied between 90 to 115 degrees did not have a significant effect on the reaction time. Negative angles (less than 90 degrees) increased the reaction time.