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Effect of Rhythmical Disturbances on Repetitive Assembly Work

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EFFECT OF RHYTHMICAL DISTURBANCES ON REPETIVE ASSEMBLY WORK

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

Head, Mechanical Engineering Department Date

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RH

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

The field of industrial engineering has been traditionally based on the desire to produce more goods for less money. This goal has been accomplished by a variety of methods, including improved methods, monetary incentives, and nonmonetary incentives. In the modern industry all of these may be used.

Studies to isolate the effects of such types of incentives frequently, although not exclusively, have been conducted on highly repetitive tasks. This occurs for a number of reasons:

1. The simple task reduces the variability of the output both in quality and quantity.
2. Any given number of cycles will take less time since the time per cycle is shorter.
3. The learning curve quickly reaches the first plateau.
4. The work tends to have a simple rhythm which can be used to standardize the results. This rhythm itself has been defined as a series of cycles of motions accompanied by a feeling of grouping, that is, perceived as a series of distinct, separated cycles. Barnes (1), Watkins (2), and Burtt (3), in fact, have concluded the following:

1. Rhythm makes the task easier and more enjoyable.
2. The worker is physiologically attuned to rhythm.
3. There is a fundamental economy in rhythmical performance because a repetition of the act is obtained without an external repetition of the impulse.

Other factors tend to work against an absolute rhythm. Davis (4) studied the effects of productivity to determine what factors accounted for typical decrements in productivity and what changes in work habits appeared to cause decreases in production. Observations were collected over a period of six months on two experienced women operators engaged in semiskilled, light assembly work. He concluded that the work decrement in operations which are flexible in performance are largely the result of personal delays, rather than the product of fumbling, errors and slowing up. Personal delays consume about 24 percent of the work day and are consistent in pattern and vary negligibly from day to day. This finding was at variance with the theory at that time, although it is widely accepted now.

Dudley (5) reported on an analysis of work decrement factors in a repetitive industrial operation for six months. The normal work methods of two girls performing assembly work were studied to determine the effects of fatigue on daily production, rate of work, changes in methods, and delays. The results were:

1. No significant difference in production per day in the week.
2. P.M. production lower than A.M. production by 13 percent.
3. No significant change in method.
4. Delays were 50 to 55 percent higher in P.M. than in A.M.

Broadbent and Little (6) conducted experiments in a film-producing plant on the effect of noise on the worker's performance. They measured the worker's efficiency in terms of work rate, breakage, stoppages and downtime, maintenance requirements, employee turnover and absenteeism. Performance data were extracted from records of 26 week periods. Noise levels were varied during the experiment. The authors concluded that the rate of work was not improved by noise reduction except perhaps by a general morale factor. However noise effects did combine with other environmental effects, such as low illumination, to decrease the rate of work.

Although noise does not affect the work rate, background music which is rhythmical in nature does affect production. Smith (7) studied the effect of music during rest periods and lunch (rather than during work) on the performance of key-punch operators. He found no significant differences in the number of cards punched or punching errors. In a post-experimental questionnaire, he found that the key-punch operators were highly positive in their attitudes towards the music program. Seventy-five percent requested that the music hours be increased; 90 percent reported that they were happier on the music days; and 50 percent believed that the music had helped their work output.

Poock and Weiner (8) studied the effect of various auditory environments on a simple visual monitoring task. The authors tested the effect of preferred music, non-preferred music, and a meaningful conversational background against a control of white noise. The monitoring task selected was the detection of an abnormally large deflection of a voltmeter needle which made 50 regular rightward deflections per minute. A detection was regarded as a response within 2.5 seconds after presentation of a signal. All other responses were counted as commissive errors. Experiments were conducted on 75 subjects with the percentage of signals detected and number of commissive errors made as variables. They came to the conclusion that the best performing group was that with the conversational background. They suggested that persons working at less than mental effort may find such background as a way of relieving monotony during mechanical tasks.

Conte (9) studied the effect of paced audio rhythm upon repetitive tasks. He demonstrated that production can be regularized as well as increased through an external audio-pacing device. This demonstration implies that a worker's natural rhythm is not as productive as an outside-induced audio rhythm.

Bills and Sharpin (10) tested the effect on mental fatigue under automatically controlled rates of work. They assumed that fatigue is normally more rapid in physical rather than mental work. This fact is attributed to the usual fixed speed of the former, in contrast to the voluntary rate of mental work. To check this view, they tested 30 subjects in naming colors for 5 to 15 minute periods. Each time interval was fixed as a block. Fatigue was measured by frequency and duration of blocks at a given speed. They found that less fatigue occurred when the pace was rigidly applied than when it was determined voluntarily. These results are exactly opposite to the hypothesis tested.

Duker (11) studied the effect of tempo on quality and quantity of output while adding simple figures and while making paper bows according to a definite pattern. The experiment was conducted on 3 subjects for 10 minute intervals under two different conditions over a period of 16 days. He came to these conclusions:

1. Rhythm increases efficiency both quantitatively and qualitatively.
2. Rhythm is beneficial, however, only if it is adjusted to an individual's own speed. Any tempo which is too fast or too slow for a particular person is detrimental to his efficiency.
3. A well-adjusted tempo gives the worker a pleasant feeling.
4. Rhythmic work takes less effort than free work.
5. The greater efficiency during the rhythmic work results because of the saving of psychic energy.

Rebentisch (12) demonstrated that work can be regulated rhythmically in two ways:

1. Through continuous timing as in assembly belt.
2. Through periodical accents, as in rowing. The type and extent of the work are dependent upon such factors as the nature of the task,

The magnitude of movements involved, the length of work period and the personality and individual tempo of the worker. He made two conclusions:

1. That if the movements are irregular, there will be an initial detrimental effect from an externally induced rhythm and consequently a greater beneficial effect.
2. That the extent of output increases as a result of rhythm.

Gemelli and Galli (13) conducted industrial experiments involving conveyor belts in comparing the value of voluntary pace and conveyor-controlled pace. They concluded that there are two classes of workers: A majority prefer a conveyor-controlled pace, and a smaller group prefer voluntary pace. The former class of men find that the induced outside audio-rhythm is less fatiguing and affords them greater mental freedom.

Bruker (14) investigated the speed of the conveyor belt on the performance of 30 factory girls in a laboratory experiment with sorting and assembling operations. The sorting test involved the separation of six different kinds of nuts, with the belt moving continuously at different rates including a stop-and-go pattern. The major conclusions were these:

1. Stop-and-go operation of the belt is more efficient in terms of both production and agreeableness of work.
2. Right-handed workers perform best when the direction of motion is from left to right.

3. Whether the workers follow the belt or remain stationary is not important.
4. Individual differences make the optimum speed of the conveyor, with certain limits, a matter of individual preference.

Conrad (15) conducted a series of experiments dealing with the work paced by a conveyor. He compared the output results for the same task when the operator was rigidly paced so that the parts could go by the operator unprocessed, when the queues were allowed to build up, and other important conditions. Rigid pacing means that the parts are rigidly attached to the conveyors. Results of these experiments showed that the critical determinant of output was the time that the part was available to the operators. Thus, when the operator was rigidly paced, the time available was minimized and so was productivity. When the time available was maximum, the net output was also maximum.

Hunt (16) examined the situation of a conveyor by a waiting line model. He assumed Poisson arrival rate of parts and service and calculated the maximum possible utilization of the line for different cases of banking limitations and different number of stages or stations. He found that there is a considerable improvement in the utilization as the allowable bank increases. This finding agrees with Conrad's conclusions that the time available is critical.

Buffa (17) conducted additional studies on subjects paced by the conveyor. He came to the conclusion that time available taken by itself does not have any effect on the work-cycle time, but the overall productivity is affected by the time-available criterion, according to Conrad and Hunt, because parts may go by unprocessed, and this criterion does not have any effect on the internal elements or average work-cycle time. He also demonstrated that the time available, in combination with rate of feed, reduces the average work-cycle times as the imposed cycle time is reduced.

The distinction between a paced operation and one that is unpaced is not always as clear as one might suppose. Some workers, even on repetitive tasks, are free to decide precisely when they shall perform the next operation, and others must adapt their working pace to suit the speed of the machine or conveyor which is feeding them or which they must feed.

In most voluntary repetitive operations, the worker tries to develop a natural rhythm of his own. In other situations the worker must accept the rhythm of the machine as is suggested by machine-controlled cycles or conveyor-supplied work cycles. In these situations, the worker is subjected to pacing since he must finish the cycle before the next part reaches him on the conveyor belt. If an audio-pacing rhythm is imposed, the operator may work to such a pacing device.

Buffa, Conrad and Hunt state that the time the parts are available is critical when an operator is paced by a conveyor belt. They do not indicate how long the part should be available before it is critical. Experimentation should be carried out to determine when the availability of the part becomes critical.

Further, previous investigations have dealt with the problem of singular pacing devices. In many industrial situations, the effect of neighboring machines may be to introduce a conflicting pace. Therefore, it is proposed to investigate whether a subject doing simulated repetitive assembly work in which a major component is brought on a conveyor will be influenced by an external audio rhythm.

CHAPTER II

METHODS AND PROCEDURE

The purpose of the experiment is to find the effect of an external audio pacing device on subjects doing repetitive assembly work.

The repetitive task selected was the placing of wooden pegs in a pegboard. The design of pegs and boards was very similar to those designed by Barnes (1). Detailed descriptions of the task method is given in 'Appendix A' and the design of the work station, boards and pegs are given in 'Appendix B'. A pictorial view of the work place is shown in Figure 2-1.

The boards were supplied from the left by the conveyor. The full boards were deposited to the right. The two pacing devices used in the experiment were the conveyor and the metronome. The metronome provided the paced audio rhythm.

For the test, nine subjects were chosen. All subjects were male students from the Mechanical Engineering Department of South Dakota State University. Their ages are between 22 and 28 years.

In order to eliminate the effect of practice, the subjects were divided into three groups of three each. The first group followed the sequence of unpaced, audio-conveyor and conveyor-only pacing. The second group followed the sequence of conveyor-only, unpaced and audio-conveyor and the third group followed the audio-conveyor, conveyor-only and unpaced sequence.

Figure 2-1. A Pictorial View of the Work Place.

The number or cycles of practice for the experiment was determined from a preliminary test as explained in 'Appendix C'. The details of the number of cycles of practice for the three groups under the three conditions of the experiment are given in Table 2-1. A ten minute break was given for all the subjects after completing each condition of the experiment and a five minute break after completing thirty cycles of practice for the first condition of the experiment only.

While working with the unpaced condition, the subjects were instructed to work at a pace which they normally establish themselves throughout the day. The complete instructions for the subjects are given in 'Appendix D'. While working with the audio-conveyor paced condition, the number of beats of metronome was adjusted to sixty beats per minute. At sixty beats per minute, a subject following the audio-beat could not complete the task before the next board arrived on the conveyor, which could be approximated with a rhythm of 80 beats per minute. The time each board was available to the subjects was 0.127 minutes, or the time that a board would travel 9 inches along the conveyor. The determination of this time period is explained in 'Appendix E'. Finally, when working with the conveyor-only paced condition, only the area to reach the boards acted as a pacing device. The time available is the same as for the audio-conveyor paced condition.

The instructions and experimental procedure for all the three groups were exactly the same except that the different sequence is

TABLE 2-1

DETAILS OF THE NUMBER OF CYCLES OF PRACTICE

GROUP NUMBER	CONDITION OF THE EXPERIMENT		
	I UNPACED:	II AUDIO-CONVEYOR:	III CONVEYOR-ONLY:
GROUP I	60 cycles of practice with a 5 minute break after 30 cycles and timed for additional 30 cycles after practice. A 10 minute break after completion.	30 cycles of practice and timed for additional 30 cycles after practice. A 10 minute break after completion.	30 cycles of practice and timed for additional 30 cycles after practice.
GROUP II	CONVEYOR-ONLY: 60 cycles of practice with a 5 minute break after 30 cycles and timed for additional 30 cycles after practice. A 10 minute break after completion.	UNPACED: 30 cycles of practice and timed for additional 30 cycles after practice. A 10 minute break after completion.	AUDIO-CONVEYOR: 30 cycles of practice and timed for additional 30 cycles after practice.
GROUP III	AUDIO-CONVEYOR: 60 cycles of practice with a 5 minute break after 30 cycles and timed for additional 30 cycles after practice. A 10 minute break after completion.	CONVEYOR-ONLY: 30 cycles of practice and timed for additional 30 cycles after practice. A 10 minute break after completion.	UNPACED: 30 cycles of practice and timed for additional 30 cycles after practice.

changed. The subjects were timed for all the cycles of the experiment including the practice run, hence they were not aware that the criterion measure was only the mean of the last thirty cycles. A standard snap back type of time study watch was used throughout the experiment.

CHAPTER III

RESULTS AND DISCUSSION

In order to complete the study it was necessary to secure information on the pacing effects of conveyors prior to its use in combination with other pacing devices. In this preliminary experiment the critical length of time available during which the subject would be allowed to reach for the arriving part on the conveyor belt was determined. In the main experiment the effect of an external audio-rhythm on the mean cycle time of repetitive assembly work when conveyor paced was examined.

The preliminary experiment was conducted on three subjects in accordance with the procedure on page 10. The criterion of critical pacing was when the subjects missed one out of thirty while working unpaced. This occurred when the board was available for .127 minutes concurrently with the end of the cycle. This, of course, was translated into a distance along the conveyor belt for purposes of the experiment. Earlier investigations had suggested that the time available would become critical at some point. As the standard deviation of the experimental data in 'Appendix F' is .0085 minutes, this is a broader limit than the $\pm 3\sigma$ limits a worker might be expected to have under paced conditions.

For the main study in which various pacing devices were used, nine subjects performed in accordance to the procedure on page 10. The study was designed to eliminate the learning effects by providing practice and by changing the order of various treatments. The criterion measures were the mean cycle times for the individual treatment combinations. The mean cycle times for each individual treatment combinations are given in Table 3-1. A typical data sheet is shown in 'Appendix F'. Since a difference between subjects is to be expected, the subjects were grouped to determine whether or not the sequence of the experiment had any effect.

The results of the analysis of variance test for groups and treatments are given in Table 3-2. The calculations are in 'Appendix G'. It was found that the three groups were not significantly different at the 5 percent level of confidence. Hence, the order of performing the task did not affect the criterion measures for the different treatments. It was also found that the differences between the treatments were significant at the 5 percent level of confidence, or that there is a difference between the effects of the various treatments on the criterion measure.

Having found a significant difference between the treatments, it is common to determine whether the significance was due to a single treatment or to more than one treatment. Because there was not a significant difference between the three groups, the nine subjects may be considered to come from a single homogeneous population. Hence,

TABLE 3-1

MEAN CYCLE TIMES FOR ALL SUBJECTS

GROUP I				GROUP II				GROUP III			
Subject	Unpaced	Audio-conveyor	Conveyor-only	Subject	Unpaced	Audio-conveyor	Conveyor-only	Subject	Unpaced	Audio-conveyor	Conveyor-only
1	.554	.478	.464	4	.541	.480	.476	7	.569	.485	.481
2	.571	.490	.484	5	.560	.486	.485	8	.552	.463	.457
3	.576	.496	.492	6	.549	.474	.464	9	.559	.474	.469

TABLE 3-2

ANALYSIS OF VARIANCE

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Treatments	2	.039853	.019926	193.46
Groups	2	.000643	.000321	3.12
Treatments x Groups Interaction	4	.000273	.000068	
Sampling Error	18	.002002	.000112	
Combined Error	22	.002275	.000103	
Total	26	.042771		

F_{cr} .05, 2, 22 = 3.44

Reject null hypothesis between treatments and fail to reject null hypothesis between groups.

a "t" test with treatments vs subjects can be applied. Sample calculations are in 'Appendix H'.

Significance was not found between the criterion measures of the audio-conveyor and conveyor-only paced conditions at the 5 percent level of confidence. Therefore, the test failed to reject the null hypothesis that the criterion values were not significantly different. Failure to reject the null hypothesis means that either the treatments did not affect the criterion scores differently or that the test was not powerful enough to detect what difference is actually there.

A visual inspection of the criterion measures show that the mean cycle time for the conveyor-only pacing is less for all subjects tested than the mean cycle time of the audio-conveyor pacing.

If there is no significant difference between the conveyor-only paced and the audio-conveyor paced treatments, then the difference should be expected between the unpaced and the other two. Because of the failure to reject the null hypothesis, it is possible to combine the audio-conveyor paced and the conveyor-only paced treatments. The difference between the unpaced and combined paced treatments was significant at the 5 percent level of confidence, and the null hypothesis was rejected.

Most of the subjects indicated that they had a decided preference to work according to the rhythm of the audio beats in the early practice run. This might have been expected since the audio beats provided an accent for each movement. However, this pace was too slow to finish the cycle in the allotted time, and they were forced to change their pace to keep up with the conveyor. Generally a conveyor is a poorer pacing device since it provides the accent only once each cycle rather than for the individual hand movements. This implies again that the audio beats had an effect on at least some of the subjects, even though the cycle times were not significantly different. It could be anticipated that a conflict was created within the worker, although measurement of such conflict is very difficult if not impossible.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

The study was conducted to test the influence of an external audio-rhythm on subjects doing repetitive assembly work with a major component arriving from a conveyor being at fixed intervals. A sample of nine subjects was drawn from the population of male graduate students in the Mechanical Engineering Department. They were all between the ages of 22 and 28.

1. An analysis of variance of groups and treatments was made. A statistical test was carried out with 3 subjects per group. The differences were found to be significant between treatments and not significant between groups. From this finding it can be concluded that
    - (a) The order of performing the task did not affect the mean cycle times for the different treatments.
    - (b) There was a difference between two or more of the pacings comprising the treatments.
2. A subsequent series of "t" tests were conducted to determine the source of the significant difference found in the analysis of variance. The conclusions are:
    - (a) There was no difference between the mean cycle time of subjects doing assembly task in the conveyor paced situation and audio-conveyor paced situation.

(b) A difference exists in the performance of subjects between unpaced and the paced situations.

The following recommendations are made:

1. In many industries, the noise produced by the neighboring machines are rhythmical in nature. If the rhythm of such machines is slower than the job under consideration, conveyor-pacing may improve the output over an unpaced workplace.
2. Although the time for the conveyor-only paced portion was less for all nine subjects, the statistical 't' test was not significant. This finding indicates that further experimentation might be of value using more subjects, a louder audio beat, and different ratios of beat frequency to mean cycle time.
3. Ability of the subjects to follow an internal beat that differs from an external beat may have a higher cost to the worker. Any additional experimentation should include, if possible, a determination of the additional fatigue involved in the conflict situation.

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APPENDIX A

DETAILED TASK METHOD

The subjects were instructed to fill up the board with pegs by simultaneous symmetrical motion by using both hands. The subjects were instructed to simultaneously grasp one peg in each hand from the two separate bins and insert them in the top two center holes. They were instructed to fill the two center rows first and then the other rows and finally the two outermost rows. The fundamental motions involved in the entire assembly operation for both hands are listed below.

LEFT HAND			RIGHT HAND
NAME OF MOTION	SYMBOL	SYMBOL	NAME OF MOTION
TRANSPORT EMPTY: Reach for next board.	TE_1	TE_1	TRANSPORT EMPTY: Reach for completed board.
GRASP Close thumb and fingers on the board.	G	G	GRASP Close thumb and fingers on the board.
TRANSPORT LOADED: Slide board from the conveyor onto the work place.	TL	TL	TRANSPORT LOADED: Slide the full board to the right.
		TE_2	TRANSPORT EMPTY: Reach for next board.
		G	GRASP Close thumb and fingers on the board.

POSITION (IN TRANSIT) Board is positioned between guides as it is transported to the center of work place.	P	P	POSITION (IN TRANSIT) Board is positioned between guides as it is transported to the center of work place.
POSITION: Board is positioned between guides in the center of work place.	P	P	POSITION: Board is positioned between guides in the center of work place.
TRANSPORT EMPTY: Reach for pin.	TE_3	TE_3	TRANSPORT EMPTY: Reach for pin.
SELECT: Select one pin from among those in the box. The eyes aid the hand in searching for a particular pin.	St	St	SELECT: Select one pin from among those in the box. The eyes aid the hand in searching for a particular pin.
GRASP Close thumb and fingers around the pin selected.	G	G	GRASP Close thumb and fingers around the pin selected.
TRANSPORT LOADED: Carry pin from bin to hole in the board into which it will be inserted.	TL	TL	TRANSPORT LOADED: Carry pin from bin to hole in the board into which it will be inserted.
POSITION (IN TRANSIT) Pin is turned to vertical position as it is transported to the board.	P	P	POSITION (IN TRANSIT) Pin is turned to vertical position as it is transported to the board.
POSITION: Pin is lined up directly over the hole in the board into which it is to be inserted.	P	P	POSITION: Pin is lined up directly over the hole in the board into which it is to be inserted.

ASSEMBLE: Insert pin into hole in the board.	A	A	ASSEMBLE: Insert pin into hole in the board.
RELEASE LOAD: Open fingers and let go of pin.	RL	RL	RELEASE LOAD: Open fingers and let go of pin.

Repeat from transport empty (TE_3) 15 times to fill the board, then return to first.

APPENDIX B

DETAILS OF WORK STATION

A detailed drawing of the work place is shown in Figure B-1 and that of the pegs and board in Figure B-2. A wooden plank is fastened to the left of the work table supported by side planks. Two pulleys 3.0" in diameter made of steel are mounted on the ends of the plank and a belt runs on these two pulleys and the plank. A motor running at $7\frac{1}{2}$ RPM drives the belt.

Guides are provided at the top of the work table so as to facilitate the easy positioning of boards. To the right of the work table is the drop disposal, where the pins drop into a metal U shaped frame fastened to the bottom of the work table and drop into a metal tray at the back. The boards and pegs are all made of wood.

Computations of the Center to Center distance between Boards and total Length of Belt:

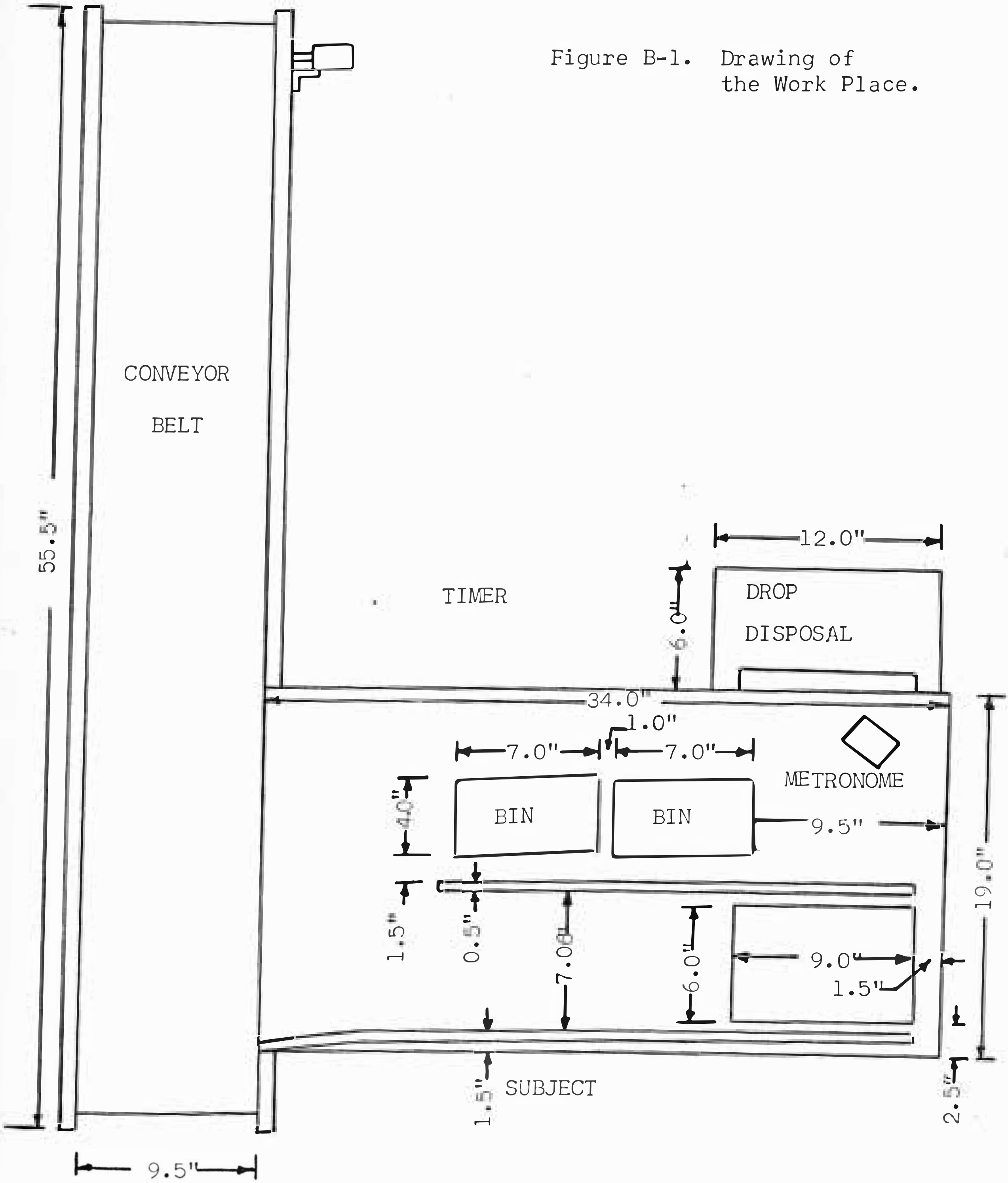
D = Diameter of pulley = 3.0".

N = Speed of motor = $7\frac{1}{2}$ RPM.

S = Belt speed $= \frac{\pi D N}{12}$

$$= \frac{\pi \times 3.0 \times 7.5}{12} = 5.90 \text{ fPM}$$

Figure B-1. Drawing of the Work Place.



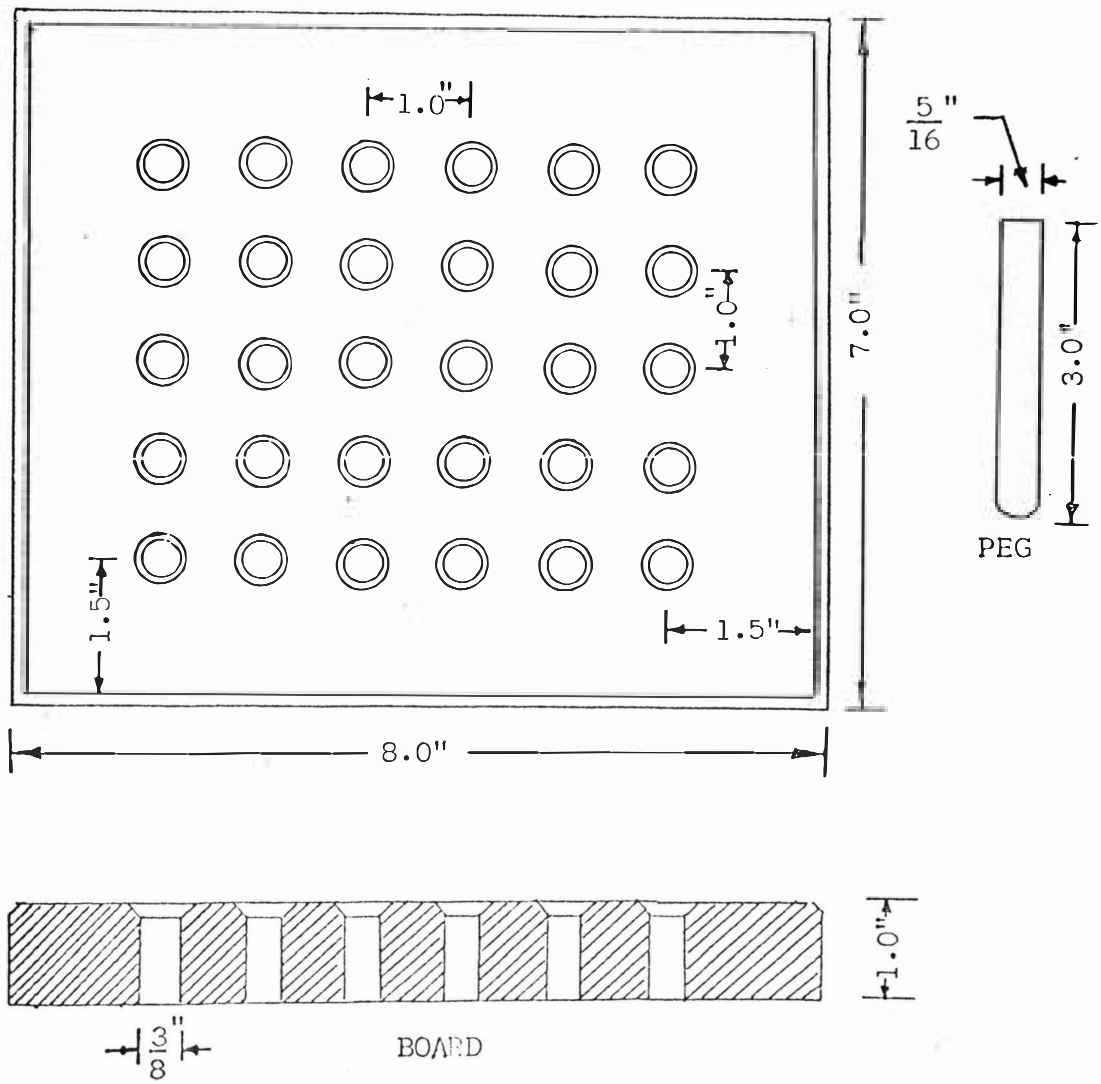


Figure B-2. Drawing of Boards and Pegs.

X = Center to center distance between boards.

P = Center to center distance between pulleys.

$$\text{Imposed cycle time} = \frac{\text{center to center distance between boards}}{\text{belt speed}}$$

$$= \frac{X}{S}$$

Assuming an imposed cycle time of .49 minutes

$X = (S \times .49)$

$= (5.90) \times (.49)$

$= 2.89'$

The distance of 2.89' is marked along the side edge of the plank on which the conveyor moves.

APPENDIX C

DETERMINATION OF THE NUMBER OF CYCLES OF PRACTICE

The purpose of this experiment is to determine the optimum number of cycles of practice.

The task selected was the placing of wooden pegs in the pegboard. In this condition of the experiment the full belt length was available to the subjects for selecting the next board. The audio pacing device was set in such a manner that it gave a rhythm to the subjects. The number of beats of metronome was adjusted to 80 beats per minute. The subjects were instructed to pick up one peg on one beat and to insert it on the next. In case he missed the beat due to fumbling, he was instructed to drop that beat and get back into rhythm as soon as possible.

Experiments were conducted on two subjects from the Mechanical Engineering Department of South Dakota State University. Their ages were respectively 25 and 26. They were timed for 100 cycles with a 5 minute break after 50 cycles. Both of them were timed during the afternoon. The mean of every 10 cycles was determined for each subject. A curve of the mean time for every 10 cycles vs the number of cycles for both subjects is shown in Figures C-1 and C-2 respectively.

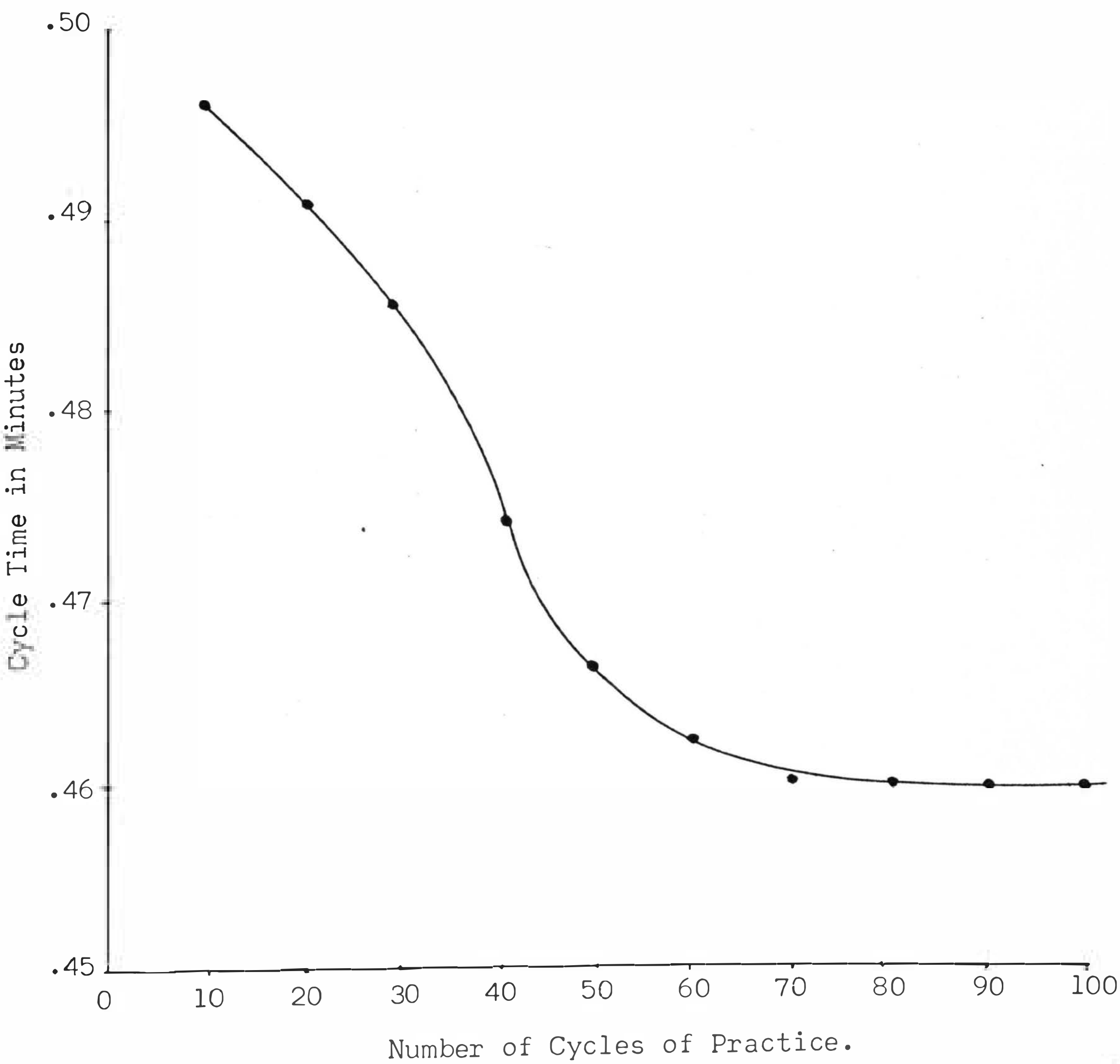


Figure C-1. Learning Curve for Subject 1.

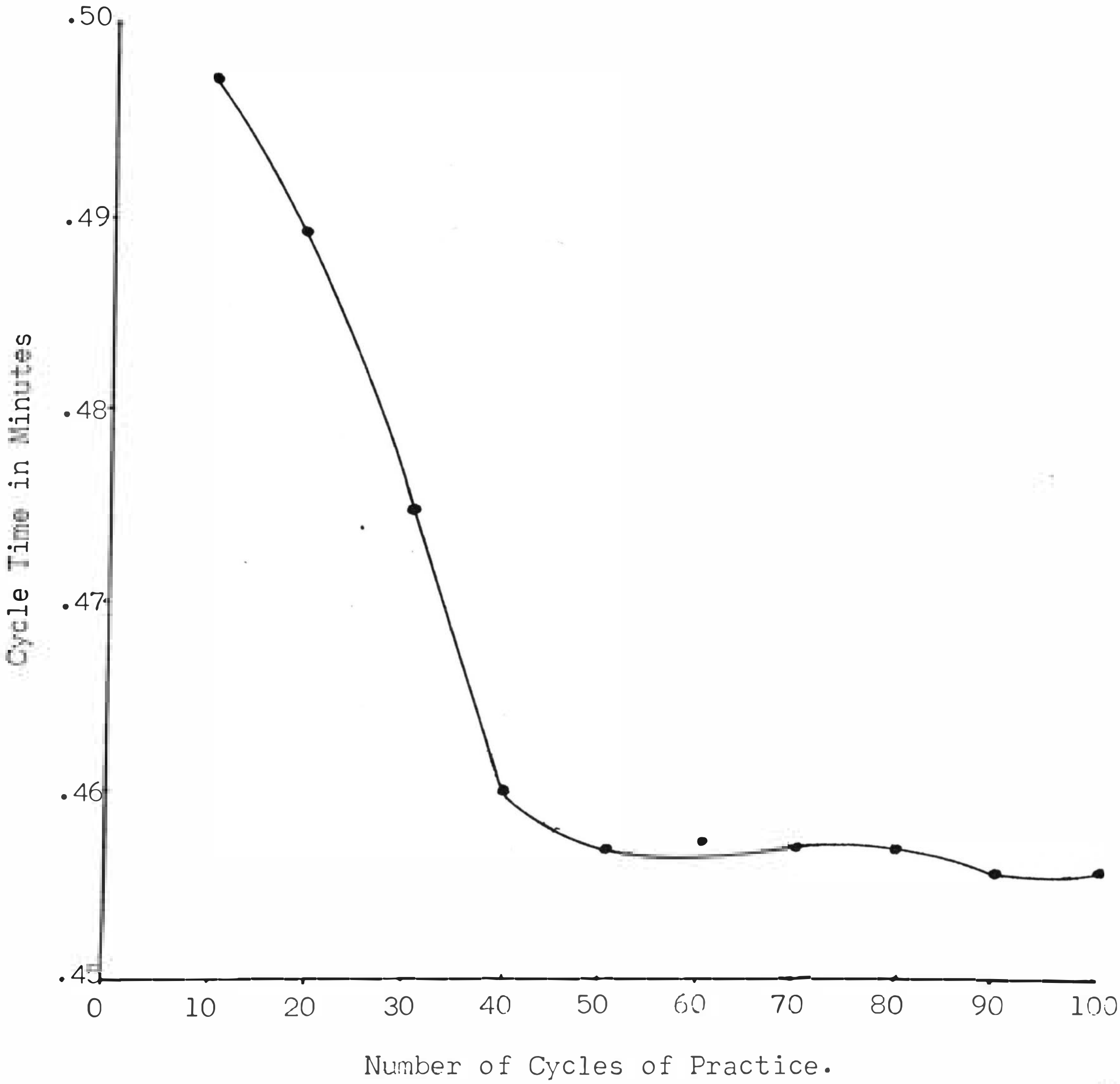


Figure C-2. Learning Curve for Subject 2.

From the learning curves of both the subjects, it can be concluded that the time to complete the job becomes fairly constant after 60 cycles of practice. Therefore, it can be concluded that since the task is repetitive in nature, it is only necessary to have 60 cycles of practice for the first time and for any subsequent change in the condition of the experiment 30 cycles of practice would be adequate.

APPENDIX D

DETAILED INSTRUCTIONS

The following material listed below is read to each subject before doing the experiment:

"The purpose of the experiment is to find out the effect of the audio-rhythm produced by a metronome clock when you are paced by a conveyor.

In order to see the effect we want you to do a simple assembly job. The job consists of placing of pins into a series of boards under three conditions. In each the parts will approach the work place on a conveyor belt at what is a reasonable pace. In the unpaced condition, you will not be paced in that you can slide the board from the belt at any point you wish. In the conveyor-only paced condition, the area of the belt that is available to you is highly restricted, so that you will need to work with regularity to fill all of the boards. In the last paced condition, an external audio rhythm will be superimposed on the restricted conveyor feed.

In all the cases we would like you to fill all of the boards if you can.

You are given 60 cycles of practice for the first condition of experiment with a 5 minute break after 30 cycles. You will be timed for additional 30 cycles after the 60 cycles of practice. A 10 minute break will be given after the first condition. You will be given 30 cycles of practice for the second condition and timed for additional 30 cycles after the practice. Finally, a 10 minute break is given again and you are given 30 cycles of practice for the third condition and thus timed for the final 30 cycles."

The specific instructions are: "While working with unpaced condition:

1. You are required to slide the board from the conveyor and position it between guides with your left hand.
2. Now reach with both hands into the bin.
3. Pick up one pin in each hand and insert it in the top two center holes.
4. Finish the center rows first and then the outer rows and finally the two outermost rows.
5. You slide the board to the right with your right hand, with the left hand reaching to the other board being fed by the conveyor.
6. Repeat steps (1-4) until told to stop.
7. You can contact the board anywhere in the Region AB as shown in Figure D-1.
8. If the front edge of the board crosses B, do not use board, but wait until next board comes in the Region AB and start again.
9. Work at a rate which you would feel could be followed for an entire day."

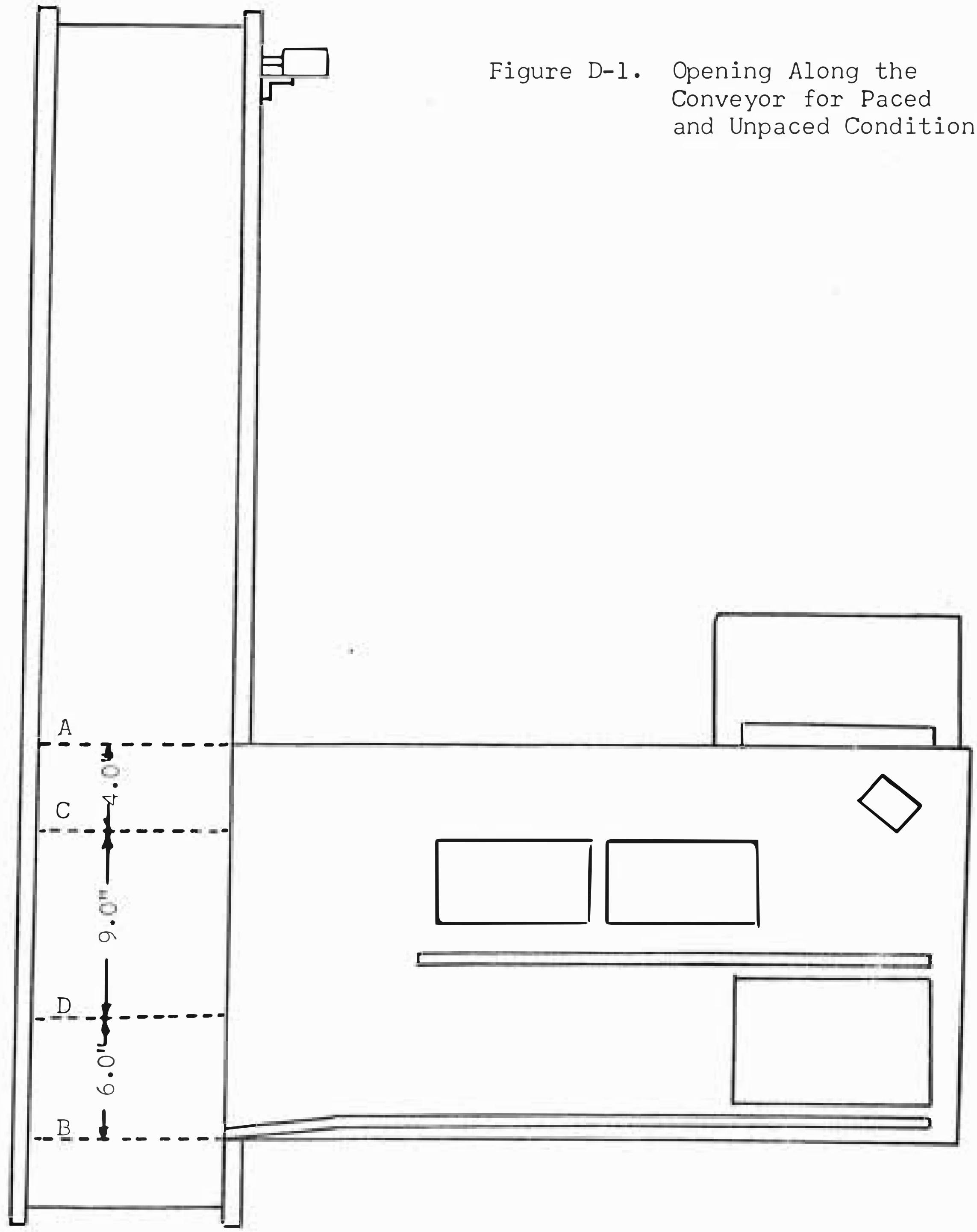


Figure D-1. Opening Along the Conveyor for Paced and Unpaced Conditions.

While working with conveyor-only pacing,

5. Steps (1-4) are repeated.

In addition, the subjects were told:

6. "The region from which you slide the board from the conveyor is restricted. You are required to slide the board from the conveyor when the leading edge is in the Region CD as shown in Figure D-1.

7. In case the front edge of the board crosses D, wait until the front edge of the next board crosses C, and then slide the board from the conveyor.

8. In case you finish the board before the front edge of the next board reaches C, wait until it crosses C and then start."

Finally, while working with the audio-conveyor pacing,

5. Steps (1-8) are repeated.

In addition, the subjects were told:

6. "You have a metronome clock which is giving a rhythm."

APPENDIX E

DETERMINATION OF THE CRITICAL TIME AVAILABLE

The purpose of this preliminary experiment was to find the critical time available for the next board, or translated in terms of distance, the size of the critical opening along the conveyor within which the subjects were allowed to reach the boards before the boards went by unprocessed.

The task consists in filling the pegboards with pegs with the boards being fed by the conveyor. The audio-rhythm was provided by the metronome clock. The number of beats of metronome was adjusted to 80 beats per minute.

Experiments were conducted on three subjects who are students of the Mechanical Engineering Department of South Dakota State University. The time available and hence the opening along the conveyor which the subjects were allowed to use to reach the boards was varied in steps. The variable of the experiment was the number of boards missed in the last 30 cycles. The time available was said to be critical when the subjects missed one board in the last 30 cycles.

The experiment was conducted in three stages with the number of cycles of practice of 60 cycles for the first stage and 30 cycles for subsequent changes. In each case the subjects were timed for additional 30 cycles after practice. Hence, the subjects were not aware when they were timed for the last 30 cycles.

In stage 1, the time the next board was available to the subjects was .21 minutes. Translated in terms of distance, the opening along the conveyor which the subjects were allowed to use to reach the boards was restricted to 15", which is the distance AB as shown in Figure E-1. The subjects were allowed to use the board only if the front edge of the board was in the Region AB. A board was said to be missed when the front edge crossed A. It was found that none of the subjects missed any boards during the last 30 cycles in which the experiment was conducted.

In stage 2, the time the next board was available to the subjects was reduced to .156 minutes. Translated in terms of distance, the opening along the conveyor which the subjects were allowed to use to reach the boards was reduced to 11", which is the distance CD as shown in Figure E-2. The subjects were instructed to use the board only if the front edge of the board was in the Region CD. Again the boards were said to be missed if the front edge crossed D. It was found that none of the subjects missed any boards during the last 30 cycles.

In the final stage the time the next board was available to the subjects was reduced to .127 minutes. Translated in terms of distance the opening along the conveyor which the subjects were allowed to use to reach the boards was restricted to 9.0", which in the distance EF as shown in Figure E-3. The subjects were instructed to use the boards only if the front edge was in the Region EF. A board was said to be missed if it crossed F. It was found that each of the subjects missed one board in the last 30 cycles.

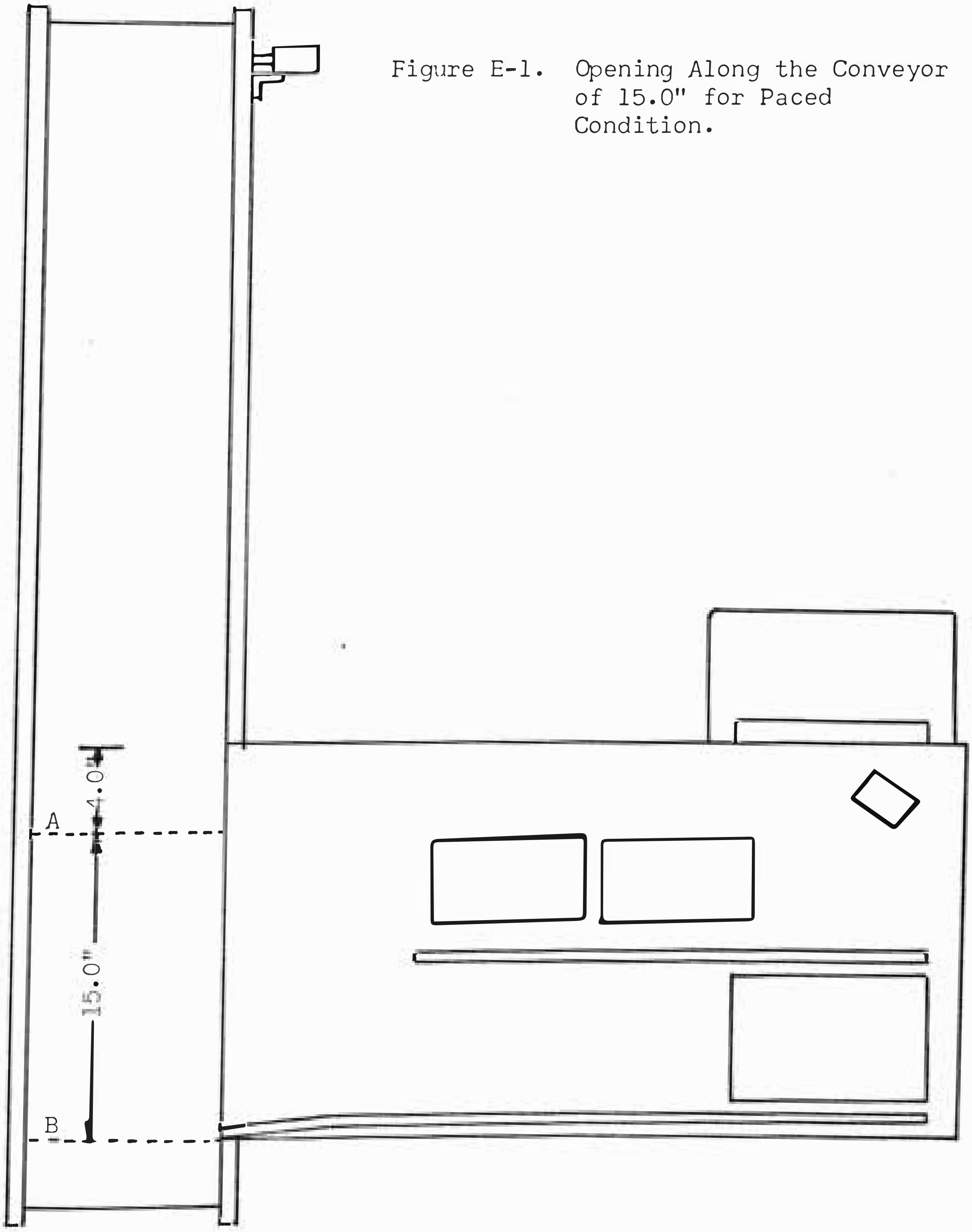


Figure E-1. Opening Along the Conveyor of 15.0" for Paced Condition.

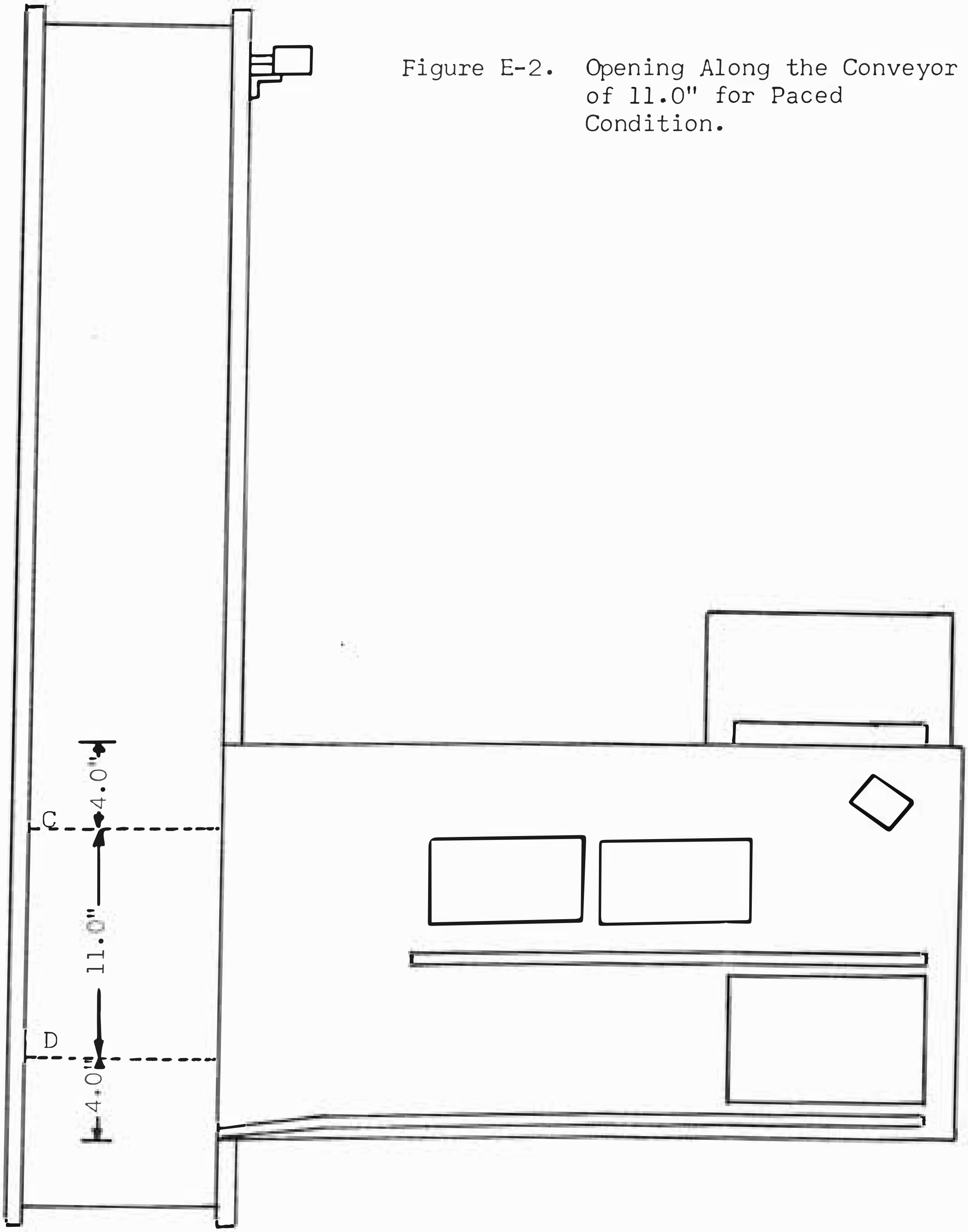


Figure E-2. Opening Along the Conveyor of 11.0" for Paced Condition.

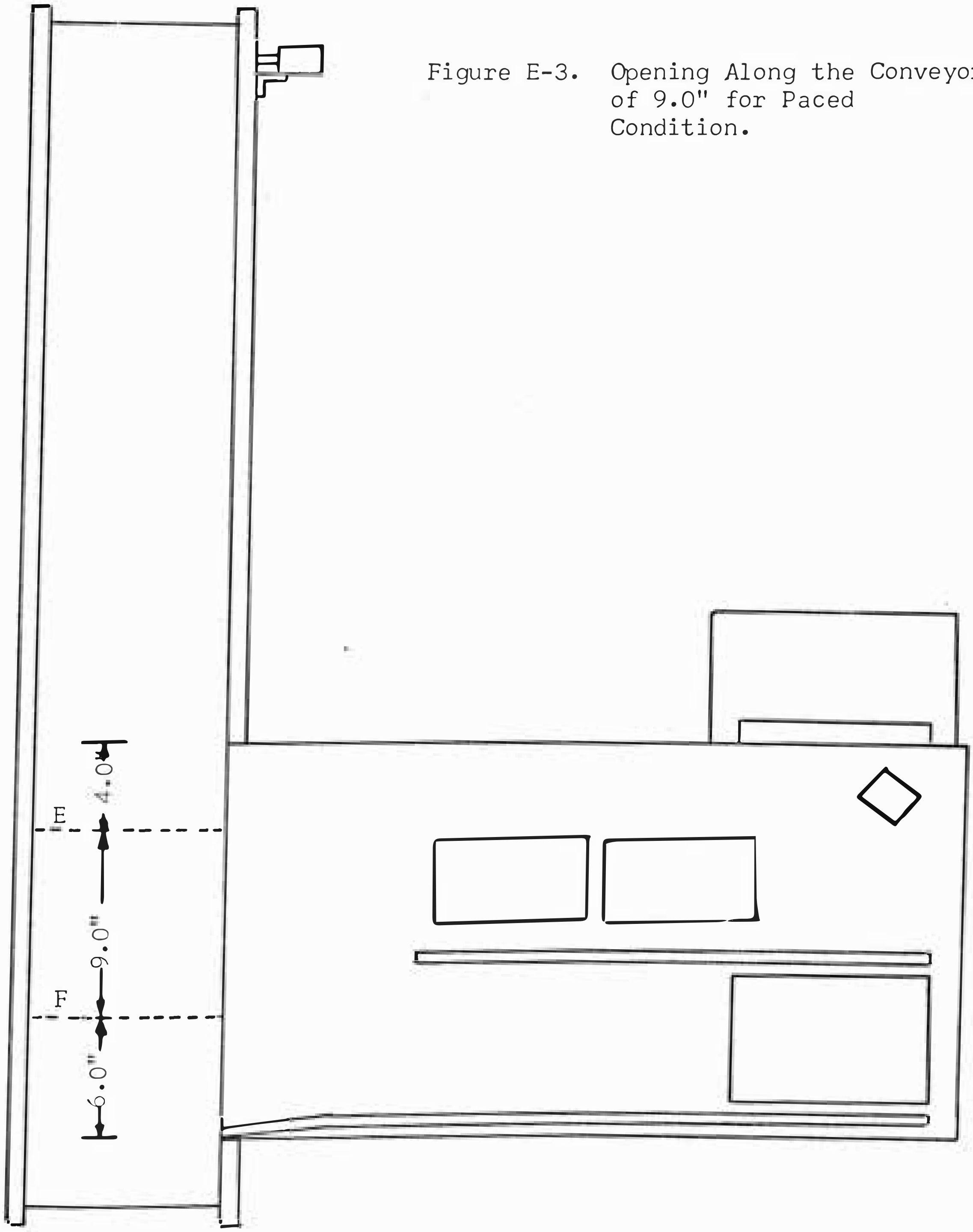


Figure E-3. Opening Along the Conveyor of 9.0" for Paced Condition.

It was therefore concluded that the time available had become critical and that the desired value was .127 minutes. Translated in terms of distance, the opening along the conveyor which the subjects were allowed to use to reach the boards was 9.0".

APPENDIX F

TYPICAL RAW DATA SHEET

Condition of Experiment: Audio-conveyor

Sequence followed: Audio-conveyor, conveyor-only, unpaced

Name: Kim | Date: Nov. 22, 1969

Time at Start: 3:15 P.M. | Time at Finish: 4:15 P.M.

Cycle Number	Cycle time in Mins.	Cycle Number	Cycle time in Mins.	Cycle Number	Cycle time in Mins.	Cycle Time	Cycle time in Mins.
1	.49	26	.48	50	.49	15	.48
2	.51	27	.48	51	.48	16	.49
3	.50	28	.48	52	.49	17	.48
4	.50	29	.49	53	.49	18	.49
5	.49	30	.49	54	.47	19	.48
6	.51		5 min. rest	55	.48	20	.50
7	.48	31	.49	56	.50	21	.49
8	.47	32	.49	57	.49	22	.48
9	.49	33	.50	58	.48	23	.50
10	.49	34	.49	59	.49	24	.48
11	.49	35	.48	60	.49	25	.48
12	.48	36	.49	1	.49	26	.48
13	.50	37	.49	2	.48	27	.49
14	.50	38	.48	3	.50	28	.50
15	.49	39	.49	4	.48	29	.48
16	.48	40	.48	5	.47	30	.47
17	.48	41	.48	6	.50		
18	.47	42	.49	7	.48		
19	.48	43	.50	8	.49		
20	.49	44	.48	9	.48		
21	.48	45	.48	10	.49		
22	.48	46	.48	11	.49		
23	.50	47	.48	12	.47		
24	.49	48	.49	13	.50		
25	.49	49	.48	14	.48		

APPENDIX G

ANALYSIS OF VARIANCE

A test of the hypothesis that there is no significant difference between the three groups and between the three treatments.

H_{01}: There is no difference between the three groups.

H_{A1}: There is difference between the three groups.

H_{02}: There is no difference between the three treatments.

H_{A2}: There is difference between the three treatments.

Level of significance chosen: $\alpha = .05$

Test statistic: F.

Critical Region:

Reject H_{01} when,

$$F_{CAL} \geq F_{.05,\ 2,\ 22}$$

$$F_{CAL} \geq 3.44^{*}$$

Reject H_{02} when,

$$F_{CAL} \geq F_{.05,\ 2,\ 22}$$

$$\geq 3.44$$

The data are shown in Table G-1.

---

*Tabulated values of 'F' are taken from Table A-6 of reference 18.

TABLE G-1

EXPERIMENTAL DATA FOR ANALYSIS OF VARIANCE

Groups	Subjects in Group	Treatments			Group Totals	
		Unpaced	Audio-Conveyor	Conveyor-only	$X_{i..}$	X^2_{iJK}
Group 1	1 2 3	.554 .571 .576	.478 .490 .496	.464 .484 .492	4.605	2.310949
Group 2	4 5 6	.541 .560 .549	.480 .486 .474	.476 .485 .464	4.515	2.276051
Group 3	7 8 9	.569 .552 .559	.485 .463 .474	.481 .457 .469	4.509	2.275387
Treatments	$X_{.J.}$	5.031	4.326	4.272	13.629	
Totals	X^2_{iJK}	2.813361	2.080142	2.028884		6.922387

Computations:

Correction term "C" = $X^2\ldots/_{rtS}$

$r = 3,\ t = 3,\ S = 3$

$$C = \frac{(13.629)^2}{3x3x3}$$

$$= \frac{185.749641}{27}$$

$$= 6.879616$$

$$\text{Total SS} = \sum_{i,J,K} X^2_{iJK} - C$$

$$= (2.813361 + 2.080142 + 2.028884) - (6.879616)$$

$$= 6.922387 - 6.879616$$

$$= .042771$$

$$\text{Treatments SS} = \frac{\sum_J X^2_{.J.}}{tS} - C$$

$$= \frac{5.031^2 + 4.326^2 + 4.272^2}{3x3} - 6.879616$$

$$= \frac{62.275221}{9} - 6.879616$$

$$= 6.919469 - 6.879616$$

$$= .039853$$

$$\text{Groups SS} = \frac{\sum_{i} X^2_{i..}}{rS} - C$$

$$= \frac{4.605^2 + 4.515^2 + 4.509^2}{3x3} - 6.879616$$

$$= \frac{61.922331}{9} - 6.879616$$

$$= 6.880259 - 6.879616$$

$$= .000643$$

Treatments x Groups
Interaction

$$= \frac{\sum_{i\,J} X^2_{iJ.}}{S} - C - \underset{SS}{\text{Treatments}} - \underset{SS}{\text{Groups}}$$

$$= \frac{1.701^2 + 1.464^2 + ... + 1.407^2}{3} - 6.879616$$

$$- .039853 - .000643$$

$$= \frac{20.761155}{3} - 6.879616 - .039853 - .000643$$

$$= 6.920385 - 6.879616 - .039853 - .000643$$

$$= .000273$$

$$\text{Sampling Error} = \underset{SS}{\text{Total}} - \left(\underset{SS}{\text{Treatments}} + \underset{SS}{\text{Group}} + \underset{\text{Interaction}}{\text{Treatments x Groups}}\right)$$

$$= .042771 - (.039853 + .000643 + .000273)$$

$$= .042771 - .040769$$

$$= .002002$$

Combined Error = Treatments x Groups Interaction + Sampling Error

= .000273 + .002002

= .002275

Df for Groups = 2, Df for treatments = 2

Df for Treatments x Groups Interaction: 2 x 2 = 4

Df for Sampling Error = 18

Df for Combined Error = 22

Total Df = 26

$$\text{MS value for Groups} = \frac{\text{Groups SS}}{\text{Groups Df}}$$

$$= \frac{.000643}{2}$$

$$= .000321$$

$$\text{MS value for Treatments} = \frac{\text{Treatments SS}}{\text{Treatments Df}}$$

$$= \frac{.039853}{2}$$

$$= .019926$$

$$\text{MS value for Treatments x Groups Interaction} = \frac{\text{Treatments x Groups Interaction}}{\text{Treatments x Groups Interaction Df}}$$

$$= \frac{.000273}{4}$$

$$= .000068$$

$$\text{MS value for Sampling Error} = \frac{\text{Sampling Error SS}}{\text{Sampling Error Df}}$$

$$= \frac{.002002}{18}$$

$$= .000112$$

$$\text{MS value for Combined Error} = \frac{\text{Combined Error SS}}{\text{Combined Error Df}}$$

$$= \frac{.002275}{22}$$

$$= .000103$$

1. For H_{01}:

$$F = \frac{\text{Groups MS}}{\text{Combined Error MS}}$$

$$= \frac{.000321}{.000103}$$

$$F_{CAL} < F_{cr};\ .05,\ 2,\ 22\ (3.44)$$

Hence, fail to reject H_{01} that there is no difference between the three groups.

2. For H_{02}:

$$F_{CAL} = \frac{\text{Treatments MS}}{\text{Combined Error MS}}$$

$$= \frac{.019926}{.000103}$$

$$= 193.46 \text{ (significant)}$$

$$F_{CAL} > F_{cr},\ .05,\ 2,\ 22\ (3.44)$$

Hence, reject H_{02} that there is no difference between the three treatments.

APPENDIX H

STATISTICAL "t" TEST

A test of the hypothesis that there is no significant difference of subjects between the audio-conveyor and conveyor-only paced treatments.

H_0: There is no significant difference between the audio-conveyor and conveyor-only paced treatments.

H_A : There is significant difference between the audio-conveyor and conveyor-only paced treatments.

Chosen level of significance: $\alpha = .05$.

Test Statistic: "t"

Critical Region:

Reject H_0 when,

$$t_{CAL} \geq t_{.05} \text{ at 16 df}$$

$$t_{CAL} \geq 2.120*$$

The data are shown in Table H-1.

Computations:

$$\sum x_1^2 = \sum X_1^2 - \frac{(\sum X_1)^2}{n}$$

*Tabulated values of "t" are taken from Table A-3 of reference 18.

TABLE H-1

EXPERIMENTAL DATA FOR "t" TEST

Subject	Treatments	
	Audio-Conveyor	Conveyor-Only
1	.478	.464
2	.490	.484
3	.496	.492
4	.480	.476
5	.486	.485
6	.474	.464
7	.485	.481
8	.463	.457
9	.474	.469
X	4.326	4.272
X^2	2.080142	2.028884
$\bar{x}$	.480666	.474666

$$= 2.080142 - \frac{(4.326)^2}{9}$$

$$= 2.080142 - \frac{18.714276}{9}$$

$$= .000778 = (n_1 - 1)\ S_1^2$$

$$\sum x_2^2 = \sum X_2^2 - \frac{(\sum X_2)^2}{n}$$

$$= 2.028884 - \frac{(4.272)^2}{9}$$

$$= 2.028884 - \frac{18.249984}{9}$$

$$= .001108 = (n_2 - 1)\ S_2^2$$

$$S^2 = \frac{\sum x_1^2 + \sum x_2^2}{2(n-1)}$$

$$= \frac{.001886}{16}$$

$$= .000117$$

$$Df = 2(n-1) = 16$$

$$S_{\bar{d}} = \sqrt{\frac{2S^2}{n}}$$

$$= \frac{2 \times .000117}{9}$$

$$= .005099$$

$$t = \frac{\bar{d}}{S_{\bar{d}}}$$

$$= \frac{.480666 - .474666}{.005099}$$

$$= \frac{.006000}{.005099}$$

$$= 1.176701 \quad (t_{.05} = 2.120)$$

Since, $t_{CAL} < t_{cr,\ .05}$ at 16 df

Do not reject H_0 that there is no significant difference between the audio-conveyor and conveyor-only paced treatments.