AN INVESTIGATION OF BELT SPEEDS AND DENSITIES USED IN MANUAL QUALITY PICKING OF SMALL OBJECTS

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By

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ABSTRACT

The aim of this thesis was to provide a more refined basis for the selection of optimum conditions to be used in the manual quality picking of small objects. This investigation was part of a research project begun at the Georgia Institute of Technology in 1950 under the direction of Dr. J. J. Moder, Jr.

In specific terms, the following is the objective of this thesis: To determine if there are belt speeds common to the three rates of flow of objects at which optimum picking rates, and high quality of pickouts are obtained.

The data used was obtained from six experimental subjects selected from a total of twenty volunteer students at the Georgia Institute of Technology. The experiments were conducted in the laboratory of the School of Industrial Engineering, utilizing a specially constructed picking conveyor. The objects used were Great Northern beans containing three per cent (by weight) Pinto beans which represented the defective objects.

A factorial mixed model experiment was employed to test the effect of the following independent variables upon the operators' performance:

1. Six operators
2. Three flow rates
3. Four densities
4. Three replications

while the succeeding independent variables were held constant:

1. Operator position
2. Picking method
3. Damage content
4. Illumination
5. Work - surface height
6. Operator posture
7. Operator pace

The following dependent variables were used to measure the operators' performance:

1. Net picking rate
2. Per cent of good objects in the pickouts

From a statistical and graphical analysis of the experimental data the following conclusions were drawn:

1. Picking conditions for optimum net picking rate.—

   A maximum number of picked defective objects for all operators was obtained for each flow rate at a belt speed of 50 ± 2 feet per minute. At this belt speed, the net picking rates of the individual operators deviated by less than two pickouts per minute from their maximum rates. At these optimum belt speeds, a drop in the picking rate of defective objects was observed as the flow rate increased (higher densities).

2. Picking conditions for optimum quality of pickouts.—

   A maximum picking quality for all operators was obtained for each flow rate at a belt speed of 32 ± 2 feet per minute. At this belt speed, the per cent of good objects in the pickouts of the individual operators deviated by less than one per cent from their maximum quality. At these optimum belt speeds, a drop in the picking quality was observed as the flow rate increased (higher densities).

CHAPTER I

INTRODUCTION

General.--It is a recognized industrial fact that the cost of labor in America accounts for a high percentage of the total cost of most manufactured products. A large segment of our national economy is composed of the agricultural products processing industry.

In the Southern United States, the peanut processing industry stands out as an example of an industry where a large annual labor expense is incurred in the buying and marketing of its products. It is within this industry, particularly that part dealing with edible products, that the problem of manual quality picking is of considerable importance. In processing peanuts for the edible market, damaged objects and foreign material are hand quality picked to reduce the relative damage content of a given lot of product to acceptable levels. This "quality picking accounts for approximately half of the total labor costs and about one-fifth of the total processing costs in shelling farmer's stock peanuts." (1)*

There are two obvious solutions to the high costs of the quality picking operation. One of these is to further mechanize the picking operation through the use of various electro-mechanical devises now on the market. The other solution is to learn everything we can about the hand picking operation and then adjust all the factors involved to their most economical level of performance for the process conditions prevailing at any given time.

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*Numbers in parentheses identify references listed in Bibliography.

Of the two approaches to the problem the former has been discussed in considerable detail by Moder and Penny (2), with reference to the peanut processing industry, while the latter has been the subject of investigations by Calhoun (3), Zimmer (4), and Wright (5). Moder (6) found that for companies of a certain size, electronic devices were quite feasible; whereas, for the smaller concerns, manual quality picking was still preferable.

For ease of understanding, all further references to manual quality picking will be specifically related to the peanut processing industry. Because of similar equipment, techniques, and labor, it is felt that the results of this study may be applied generally to manual quality picking operations throughout the food processing industry where small objects such as nuts, peas and beans, are hand quality picked.

Statement of the Problem.--Moder and Penny (7) made an extensive survey of the peanut processing industry. Among other things brought out in their report was a recommendation for a thorough analysis of the costly manual quality picking operation. Calhoun (8) made an exploratory study of those factors which seem most likely to affect manual quality picking. Zimmer (9) made a detailed investigation of those factors which Calhoun found significant. Wright (10) made a detailed investigation based on some of the recommendations made by Calhoun and Zimmer. This thesis aims to base its experimentation upon the results of these earlier studies and is an attempt to provide a more refined basis for the selection of optimum manual quality picking conditions.

CHAPTER II

PRESENT STATUS OF THE PROBLEM

This chapter is divided into three major sections. First, a brief description of the manual quality picking operation, and the means by which it was measured during this study, is presented. The second section is concerned with a discussion of previous research done at the Georgia Institute of Technology on manual quality picking of small objects. The last section presents those factors affecting operator performance which were considered in the course of this investigation.

Description of the Manual Quality Picking Operation

Manual quality picking is essentially an inspection operation. It requires the operator to make a continuous series of mental acceptance or rejection-type decisions.

In general terms the operation of manual quality picking is as follows: The objects to be quality picked are presented to the operator by means of a continuous moving conveyor belt. Upon this belt are placed the products which are to be inspected for defectives. The defectives are dispersed at random among the vast mass of good products. The damaged objects are to be recognized and picked by the operator. They move within his reach and are to be placed aside. The operator is not expected to pick out all he can see, but only as many as he can pick from his own position. Also, it is expected that the operators will mistakenly pick out some good object instead of defective.

There are two means of measuring operator performance which are used throughout this thesis. The first of these is the number of picked defective objects per minute which is found by the following formula:

Total Number of Pickouts Per Minute (or Total Picking Rate) Less the Number of Good Objects Picked Per Minute (or Picking Errors) = Number of Picked Defective Objects Per Minute (or Net Picking Rate)

The other measure used to evaluate operator performance is the picking quality which is the per cent of good objects (non-defective) in the total pickouts. A high per cent of good objects denotes poor operator performance, while a high picking quality denotes a low per cent of good objects.

Previous Research at Georgia Institute of Technology

Overall Project.--In 1950, a project was begun under the auspices of the Engineering Experiment Station, Georgia Institute of Technology and the Agricultural Experiment Station of the University of Georgia. This project directed by J. J. Moder and N. M. Penny was completed, and a report, Industrial Engineering and Economic Studies of Peanut Marketing, was published in December, 1954 (11).

The above report has formed the basis for further research by Calhoun (12), Zimmer (13), and Wright (14). This thesis is a continuation of the work begun by Calhoun, although certain portions are based upon the work of Zimmer and Wright.

Calhoun's Work.--In order to explore the subject of manual quality picking of small objects, it was necessary first to develop a criteria and an independent measure of this criteria. Furthermore, this criteria had to be analyzed statistically in order to establish the true sources of variance.

Calhoun (15) assumed the following factors to be the most important in the hand quality picking operations:

1. Operator
2. Method
3. Position
4. Belt Speed
5. Damage-Density
6. Belt Loading
7. Replication

He used the total picking rate and the per cent of good objects in the pickouts as a measure of his criteria (16). Other factors such as illumination, work-surface height, etc., were considered but they were felt to be of minor importance in his study (17). He reached the following conclusions (18):

1. Operators demonstrated statistically significant differences in both picking rate and quality of picking.

2. The use of a low belt loading with the operator stationed at the side of the picking table, and using the "pick and throw" method, resulted in a higher picking rate and fewer good objects in the pickouts.

3. An increase in belt speed adversely affected the number of picking errors.

4. All of the variables investigated had an effect upon both the picking rate and the number of picking errors made.

His conclusions were subject to the following limitations (19):

1. Only four operators were used.

2. Only belt speeds of 15 f.p.m. and 30 f.p.m. were investigated.

3. The lowest belt loading that was investigated was 33.3 per cent density.

4. The runs lasted only two minutes each.

Calhoun (20) recommended that further study of manual quality picking be directed toward:

1. The use of larger number of operators selected at random.

2. The investigation of lower belt loadings.

3. Belt speeds both higher and lower than the ones he used.

4. Damage-Density levels lower than the ones investigated in his study.

Zimmer's Work.--Zimmer (21) saw the need for further study and set forth the following objectives:

1. To select tests which discriminate between aptitude characteristics of successful and unsuccessful hand quality pickers.

2. To determine an index of correlation between test performance and an operator's picking rate.

3. To develop density-belt speed combinations which result in optimum picking rates and high picking quality for:

    a. A constant rate of flow of 7.75 pounds of objects per minute.

    b. Damage contents of two and four per cent.

    c. Operators grouped into classes according to their scores of selected aptitude tests.

Zimmer studied the operation of hand quality picking in detail. From his investigation he determined aptitude characteristics which the job required. He, therefore, selected a battery of tests which he assumed would be predictors of job success in hand quality picking (22). Following Calhoun's recommendations concerning belt loading and belt speed, Zimmer chose several combinations of belt speed and density to give a constant rate of flow (23). He used belt speeds both above and below those used by Calhoun. He did the same thing with the density. The rate of flow was fixed at a level which would keep the operators continuously supplied with defectives.

Zimmer's (24) conclusions were as follows:

1. The test battery which he had selected did discriminate between the operators whose aptitude scores fell in the upper quartile and those whose scores fell in the middle two quartiles.

2. An index of correlation between the scores and the battery of tests and the operator's picking rates of defective objects was found to be .877. This index is significant at the .001 probability level of linear correlation coefficients.

3. Optimum picking rates and a high picking quality, for a flow rate of 7.75 pounds of objects per minute, were found to result for a density of 22 per cent and a belt speed of 46 feet per minute for all operators and both damage contents.

4. He also found from his results that the high damage content consistently resulted in higher picking rates of defective objects and better picking quality than the low damage content.

Zimmer (25) recommended that further investigation be directed towards different flow rates, particularly higher rates.

Wright's Work.--Wright (26) saw the need for further investigation using the optimum conditions of the previous studies and set forth the following objectives:

1. To determine if the picking method affected the net picking rate when other factors were at optimum levels.

2. To determine if the picking position affected the net picking rate when other factors were at optimum levels.

3. To determine if there was any relationship between an operator's performance and his dominant hand.

4. To validate the use of certain aptitude tests to predict job success in manual quality picking.

Wright's (27) conclusions were as follows:

1. The two "pick and throw" methods proved to have statistically significant greater net picking rate than the "roll" method. However, the "roll" method had a better picking quality rate than either of the other methods.

2. None of the picking positions had a significant effect upon either the net picking rate or picking quality.

3. Left-handed operators picked as well at all positions as right-handed operators.

4. He also found that the Purdue Pegboard Test score was not a valid predictor of an operator's net picking rate for his particular group of subjects.

Factors Which Affect Operator Performance

Attack of the Problem.--A first consideration of the problem may indicate its treatment by a conventional motion and time study technique. However, valid objections to such an analysis of the problem were raised by Malcolm and DeGarmo (28) in a study of visual inspection of products for surface characteristics in grading operations. For two major reasons usual work measurement methods are of questionable value in determining optimum work and labor requirements for grading operations as the operation is currently performed:

1. The task cannot be standardized because the defective objects are randomly spaced and are haphazardly presented to the inspector's visual field.

2. The measurement of visual-reaction-decision time on the part of an inspector would be difficult, if not impossible, by the method suggested because grading involves subjective, internal work that is not observable by outward physical indicators.

The logical attack to the problem is the determination of significant factors, involved in the picking operation, through experimental investigation. Once these factors and their relative magnitude are known the optimum picking conditions for specific industrial situations can be established.

The above method of attack is the same as that used by Calhoun (29), Zimmer (30), and Wright (31). The factors explored in this investigation are those which they proved to have a significant effect on the operators' picking rate. Each factor will be discussed separately.

Operator.--A significant difference in the picking rates of the operators were found in each of the investigations made by Calhoun, Zimmer, and Wright. Calhoun (32) found a difference of 14.2 per cent in the picking rate between his fastest and slowest operators. Zimmer (33) found a difference of 19.8 per cent between his fastest and slowest operators. Wright (34) found differences of 26.6 and 21.1 per cent in the picking rates between the fastest and the slowest operators in the two replications of his study.

Zimmer felt that previous research justified an attempt to devise aptitude testing procedures for the selection of operators best suited for quality picking. He states that the visual-reaction-decision time and the manipulative skill are the two principal factors which account for the large differences in operator picking rates (35).

Pace.--In analyzing experimental data it is of vital importance that these data are collected under precisely known conditions; in any experiment in which the human element is a source of variation this factor is important. It is difficult, if not impossible, to measure operator pace precisely. Therefore, the experimenter can only use the relative measures of normal and maximum pace. Calhoun (36) had all his operators work at their normal pace. Wadsworth meanwhile found that performing a task at a very fast speed results in less variation in time (inconsistency) than at a lower speed (37). Zimmer and Wright, therefore, required their operators to work at a brisk pace (38 and 39).

Fatigue.—This is another source of operator variation which is difficult to measure either in the absolute or relative terms. With proper working conditions and rest pauses used in this study it is felt that the effect of fatigue upon the investigated manual picking operation is likely to be so small that it could be omitted as a significant factor.

Work-Surface Height.—This factor was standardized by Calhoun (40) at approximately three inches below the elbow as recommended by Barnes (41) and Ellis (42). Considering the work done by Barnes and Ellis, it is felt that optimum results will be obtained by continuing this standard.

Illumination.—The intensity of illumination at the work place affects the time required for seeing. There must be enough illumination on the work place so that the operator's maximum visual impression time is less than the time the object is within his field of vision (43). Marks (44) recommends for inspection work an illumination level between 30 and 100-foot candles at the work surface. McCormick (45) found that a level of illumination beyond 50-foot candles will not have a significant effect upon performance of a motor task. It is felt, however, that in order to use the results of the previous studies in manual quality picking an illumination level of 65-foot candles as used by Calhoun (46) and Zimmer (47) will be regarded as satisfactory.

Picking Position.—This is determined by the operator's position in relation to the picking belt and the direction of flow of objects as follows:

1. Right Side Position - The operator stands facing perpendicularly to the conveyor with the objects moving from left to right across his field of vision.

2. Left Side Position - The operator stands facing perpendicularly to the conveyor with the objects moving from right to left across his field of vision.

3. End Position - The operator stands at the end of the conveyor with the objects moving towards his field of vision.

Wright (48) investigated the three positions and found that there was no significant difference between any of the three positions. Calhoun (49) found in his factory experiments with experienced operators that half of his subjects had better picking rates with the right side position, the other half had a higher rate with the end position. The average increase in the picking rate of the operators favoring the side position was 3.7 per cent, while the average increase of the group favoring the end position was only 1.2 per cent, based upon the grand average picking rate of all operators. Calhoun's results are backed by a study by Kephart and Besnard (50) on visual differentiation of moving objects. These investigators found that the actual discrimination of moving objects is much easier when these objects are viewed from the side rather than when they are viewed coming towards the subject. Zimmer accepted Calhoun's findings and used the side (right) position only (51). In view of these findings it was regarded satisfactory to use the side position in this investigation.

Picking Method.--There are two picking methods which are in use today, the most common picking method found in the peanut processing industry is termed the "roll" method. In this picking method the operator picks the object with thumbs and fore-fingers on both hands, rotates the hand and releases the objects into the palms of the hands. These motions are repeated until the hands are full and then the objects are tossed aside.

In the second method, the damaged objects are picked with the fingers of both hands as described above and are then immediately thrown into a container with a simple wrist movement. This method is called the "pick and throw" method. There is no restriction upon grasping more than one object at a time if the objects are adjacent to each other.

Calhoun (52) found for the "pick and throw" method a significantly higher picking rate than with the "roll" method. The difference was 6.7 pickouts per minute; however, this method resulted in a slight decrease in picking quality. Wright (53) also found this method to be superior to the "roll" method, resulting in 4.7 and 5.2 pickouts per minute better for replications one and two respectively, and again a small decrease in the picking quality.

Wright (54) tested the above two methods and a modification of the "pick and throw" method. This new method required that the defectives be disposed of one at a time. He found no significant difference between the two "pick and throw" methods (55); however, the "pick and throw" method with no restriction upon grasping more than one object at a time if the objects are adjacent to each other, was slightly superior in overall performance.

It is felt that optimum results will be obtained by continuing the use of the "pick and throw" method that Wright found to be slightly superior.

<u>Rate of Flow of Objects</u>.—One measure of the rate of flow is the weight of objects passing an operator per unit of time. Zimmer (56) established this factor in the following manner:

Rate of Flow (lbs/min) =

Belt Speed (ft/min) x Belt Width (ft)

x Relative Density of Objects on Belt

$$\frac{\text{Weight of Objects/Square feet amount of objects actually on the belt}}{\text{Weight of Objects/Square feet for 100 per cent coverage of the belt}}$$

x Weight of Objects (lbs/square feet with 100 per cent coverage)

The density of objects on the belt is the ratio of the actual weight of objects per unit area of the belt over an experimentally derived weight of objects per unit area representing 100 per cent density. This 100 per cent density is established by weighing the objects on a unit area of the belt, placed so that there is no more room for additional objects without their having to rest on top of others.

Using a constant rate of flow and a fixed belt width, Zimmer (57) determined four combinations of density and belt speed which he used in his investigation. These density-belt speed combinations ranged from 100 per cent and 10 feet per minute to 10 per cent and 100 feet per minute.

Zimmer's (58) results showed that the density-belt speed factor had the greatest effect on the picking rate. The second combination of 25 per cent density and 40 feet per minute was found to be the best of the combinations tested. This level resulted in a 5.4 per cent higher picking rate than the next best combination.

From his experimental data Zimmer graphically determined optimum levels of density and belt speed combinations at 21.8 per cent and 46 feet per minute (59). These findings, however, were for one rate of flow only (7.75 lbs/min).

Moder (60) found in laboratory tests that the belt speed when varied between 10 and 60 feet per minute, did not appreciably affect the picking rate when a sufficient number of objects was delivered to keep the operator busy. On the other hand, Calhoun realized in factory experiments that the operators reacted differently to a change in the belt speed. His study was limited to the investigation of only two different belt speeds, a fact which makes it impossible to determine exactly which belt speed results in optimum picking rates.

Calhoun investigated the density and the damage content of the objects as one combined variable with constant products. The results showed that the lowest of the three investigated levels, which had a density of 33.3 per cent and a damage content of 4 per cent, did more than any other factor to improve the picking rate (61).

With a constant rate of flow and fixed experimental conditions (belt width and weight of objects) it is possible to arrive at an infinite number of different density-belt speed combinations. The reason for this becomes obvious by examining the rate of flow formula; an increase in belt speed, for instance, has to result in a decrease of the objects in the belt and vice versa.

Damage Content.--This factor is the percentage, figured on a weight basis, of the objects in question that are visibly damaged. Moder (62) found in his studies that the average damage contents of Spanish-type and Runner-type peanuts of the crops of 1949 and 1952 ranged from 0.80 per cent to 3.76 per cent, based on unshelled peanuts. Calhoun (63) found his highest investigated level on 4 per cent damage content to be the most favorable one for an optimum picking rate. Zimmer (64) utilized damage content as an independent variable in his study. He found that the high (4 per cent) damage content consistently resulted in a higher picking rate and a better picking quality than did the low (2 per cent) damage content for all conditions; however, his optimum density-belt speed combination was about the same for both damage contents. The grand average differences between the high and the low damage contents for both picking rate and picking quality were 7.8 per cent and 18.6 per cent respectively (65). Wright (66) used a damage content of 4 per cent in his investigations.

Since Zimmer found about the same optimum density-belt speed combinations for the two damage contents in his investigation, a 3 per cent damage content will be regarded satisfactory in this experiment.

Summary.--In this chapter, the manual quality picking operation was described. Those factors which influence manual quality picking were discussed. A review was given of previous investigations since the results and limitations of these earlier studies form the basis and indicate the direction for this study.

CHAPTER III

OBJECTIVE

The purpose of this thesis is to study the effects of:

1. Operators
2. Density
3. Belt speed

on the:

1. Net picking rate
2. Per cent of good objects in the pickouts

in the operation of manual quality picking of small objects.

The specific objective of this thesis is as follows:

> To determine if there are belt speeds common to three rates of flow of objects at which optimum picking rates and high quality of pickouts are obtained.

For assurance that the results sought for the above objectives are not the results caused by random variations of individual performance, the following null hypotheses are to be tested at various probability levels which are set forth in Chapter VI.

1. That the average picking rates of the operators are not statistically different.
2. That there is no significant difference in the picking rates for each of the tested rates of flow due to an effect of the tested densities.
3. That there is no significant difference in the picking rates of the tested densities due to an effect of the tested rates of flow.

A factorial mixed model experiment is to be employed to test the above hypotheses.

CHAPTER IV

EXPERIMENTAL DESIGN

In this chapter a brief description is given of the experimental subjects and the manner of their selection, and of apparatus and objects used for the control of the factors under investigation.

Subjects.--Six white male experimental subjects were used in this investigation. Their ages varied from 19 to 24 years. All were right-handed and possessed no eye trouble or obvious physical defects. The subjects were not skilled in work of this type. These six subjects were selected from a group of twenty volunteer students. Because of the time required for experimentation and training in quality picking of small objects, the subjects were selected on the basis of their availability to work two three-hour periods and one four-hour period within a span of five days. This time was required from each experimental subject during the running of the experiments.

Tests for Selection.--Zimmer (67) found that the test battery which he had selected did discriminate between operators whose aptitude scores fell in the upper quartile and those whose scores fell in the middle two quartiles. Wright's (68) results indicate that three of the four tests used by Zimmer were not valid predictors of an operator's net picking rate for his particular group of experimental subjects.

A study of the relation between vision and accuracy of inspection made by Tiffin (69) shows that successful passing a battery of visual screening tests does not predict success in the detection of different types of defects for visual inspection. Perhaps this may be explained by the fact that an individual has compensated by a handicap in one respect (visual) by developing greater than average skill for another aspect of the job where vision is not essential (70). It was therefore regarded to be satisfactory not to use any visual or manual tests in the selection of the operators.

Apparatus.--The experimental apparatus used in this investigation was essentially the same as that which Calhoun (71) designed and constructed. The picking table consists of four component parts: the frame, the belt carrier, hopper and feed control, and the drive.

Frame: This component, constructed of galvanized iron pipe, supports the other parts of the apparatus. The details of the frame construction may be seen in Fig. 8, Appendix I.

Belt carrier: The belt carrier forms the picking table. This consisted of side rails, cross supports, platform, pulleys and an endless belt for conveying the objects. Mounted at one end of the belt carrier were the hopper and feed control, and the drive.

Hopper and feed control: A hopper, with a feed control as an integral part, is constructed of galvanized sheet steel and is supported by a welded angle iron frame. The frame is designed for adjusting the hopper laterally and horizontally. A twelve inch brush in front of the hopper opening gives an even flow, while a vertically adjustable aluminum gate regulates, in connection with the belt speed, the rate of flow of the objects onto the belt (See Figs. 9 and 10, Appendix I). Wright (72) added a horizontal baffle in the neck of the hopper, so that the pressure of the objects upon the belt would be independent of the level of objects in the hopper. This baffle was wide enough to support most of the objects, yet narrow enough to allow an unobstructed flow of material to the belt. The gate is calibrated against a marker which is fastened to the hopper in order that each density level can be quickly established. For the calibration of the gate see Appendix III.

Drive: A variable speed fluid coupled drive, with a 3/4 HP electric motor furnishes power through a "V" belt to drive the belt (See Figure 10, Appendix I).

Objects.--Great Northern beans were used as the small objects to be picked in this investigation. Because of their hardness, shape, and resistance to wear and decay, these beans were considered to be suitable in the experiments. These beans are representative of many edible products that are hand-quality picked, such as peanuts, pecans, and coffee beans.

Pinto beans were used to represent the damaged objects. These beans are very similar to Great Northern beans. They differ largely in their color. Whereas the Great Northern beans are solid white, Pinto beans are speckled brown.

The Pinto beans were mixed with the Great Northern beans to form a lot with a 3 per cent (by weight) damage content.

CHAPTER V

EXPERIMENTAL PROCEDURE

In this chapter an outline is given of the factors and their levels studied in this investigation. The overall experimental conditions are discussed, together with the experimental plan and operator time table.

Variable Factors.--The following variables were investigated at the indicated levels:

1. Operator - Six
2. Flow rate - Three

    Flow rate 1 - 10.0 pounds per minute
    Flow rate 2 - 13.5 pounds per minute
    Flow rate 3 - 17.0 pounds per minute

3. Density - Four

    Density 1 - 100 per cent
    Density 2 - 75 per cent
    Density 3 - 50 per cent
    Density 4 - 25 per cent

The product of density-belt speed is a measure of the flow rate of the objects upon the belt. Four combinations of density-belt speed were studied for each of the flow rates. These density-belt speed combinations are listed on the following page. For the derivation of the rate of flow, a belt width of one foot and an experimentally derived weight of the objects of 351 grams per square foot (See Appendix III) representing 100 per cent density, were used. Figure 1 clearly shows the relationship of density and belt speed combinations for each flow rate investigated.

Density (per cent)	Belt Speed in Feet Per Minute at Flow Rates of		
	10.0 Lbs./Min.	13.5 Lbs./Min.	17.0 Lbs./Min.
100	12.9	17.4	21.9
75	17.2	23.2	29.3
50	25.8	34.8	43.9
25	51.7	69.7	87.8

4. Replication - Three

The complete experiment was run three times. However, each replication was analyzed separately in order to remove the variance due to the operator's practice between replications.

Constant Factors.--The following factors were standardized throughout the experiments:

1. Position--Side position with the belt moving from the operator's right to left.

2. Method--The "pick and throw" method with no restriction upon grasping more than one object at a time if they are adjacent to each other.

3. Damage content--3 per cent.

4. Illumination--65-foot candles.

5. Work-surface height--41.5 inches. This was measured from the floor to the top of the pickout tray. This height was below the elbow of all operators.

6. Operator posture--Standing.

7. Operator pace--Brisk.

General Conditions.--The experiments were conducted in the Laboratory of the School of Industrial Engineering, Georgia Institute of Technology. The experimental data was gathered over the period June 27 to July 21, 1956, and during the hours between 10:00 a.m. and 6:00 p.m.

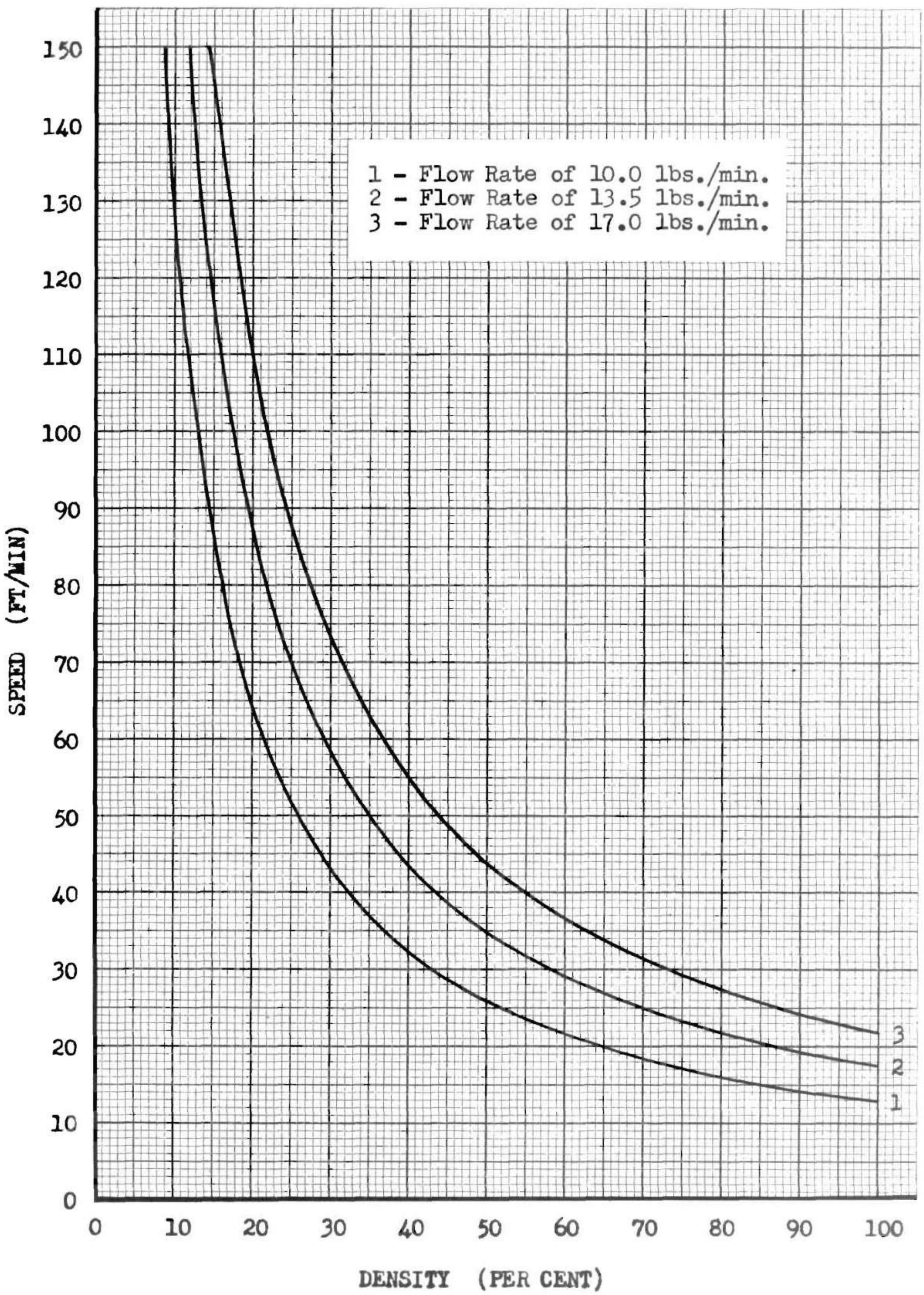

Figure 1. Flow Rates versus Density and Belt Speed Combinations

The laboratory, where the experiments were conducted, was well-ventilated and adequately lighted. Temperature and humidity levels were comfortable throughout the experiments. In addition to the normal lighting within the room, a supplementary light fixture was suspended five feet above the picking table, providing the desired illumination of 65-foot candles at the working surface.

Experimental Plan.--The experimental plan was prepared prior to the actual conduct of the experiment. Because of the few operators used and their limited availability of the subjects, it was felt that more meaningful data would result from a partially non-randomized plan.

The sequence of testing the four density levels was assigned from a table of random numbers. This process was repeated during each flow rate tested by each operator in each replication.

The sequence for testing the flow rates was organized as balanced designs made up of Latin Squares. There were six permutations of the flow rates, and six operators; consequently, the operators were balanced against orders. For this design, a sequence of testing the flow rates was set up in which a different permutation was used by each operator during each replication. From Table 10, Appendix II, it can be seen that each flow rate is tested twice in every position (sequence) in each replication; also that each flow rate appeared once and only once in each sequence location of the three replications performed by each operator.

The subjects participated in the experiments on a non-financial, voluntary basis which amply proved their interest in the study. All the subjects appeared to be amply motivated and exhibited considerable interest in the conduct and outcome of the experiments.

The conduct of an experiment for one operator is described below:

The operators had previously been acquainted with the purpose of the experiment. The method to be used was described and demonstrated. The operator was then put through a one-hour learning session in order to become familiar with the picking operation (a fifteen-minute practice period was given at the beginning of the second and third replications). During this learning session, he picked at the four density levels with speeds equal to and higher (25 per cent higher than the belt speeds for the high flow rate) than those used in the experimental conditions. At the end of the familiarization session a coffee break of fifteen minutes long, being timed by a decimal-minute stop watch, was taken, as were the record runs of three minutes long. The desired belt speed was set by means of a tachometer. The lot of beans was placed into the hopper and once again the belt speed was checked. After the run, the receptacle with the pickouts was removed from the apron of the table and the number of defectives and the number of good objects in the pick-outs were counted and recorded. The pickouts were then thoroughly mixed with the original lot, and the hopper was refilled as needed for the next run.

The operator was sitting and resting during the counting and recording of the pickouts, and during the adjustment of the belt speed and density. The total elapsed time between runs varied from five to eight minutes.

Operator Schedule.--The time when the operators could work was largely determined by their class schedules. The only requirments imposed were that a complete replication was performed without interruption and only one replication was performed per day. The schedule of experimentation is shown below.

Operator	Replication	Date	Hour
1	1	June 27	11:00 a.m.
	2	June 28	11:00 a.m.
	3	June 29	11:00 a.m.
2	1	June 28	3:00 p.m.
	2	June 29	3:00 p.m.
	3	July 2	2:00 p.m.
3	1	July 4	12:00 p.m.
	2	July 6	4:00 p.m.
	3	July 7	4:00 p.m.
4	1	July 11	2:00 p.m.
	2	July 13	1:00 p.m.
	3	July 14	12:00 p.m.
5	1	July 12	4:00 p.m.
	2	July 13	3:00 p.m.
	3	July 16	2:00 p.m.
6	1	July 18	3:00 p.m.
	2	July 20	2:00 p.m.
	3	July 21	10:00 a.m.

Summary.--A description has been given of the variables tested at the chosen levels, and variables standardized in the experimentation. The general conditions, experimental plan, and the operator schedule has been discussed to give complete information regarding the experimental procedures.

CHAPTER VI

ANALYSIS OF RESULTS

The analysis of the experimental data was broken into three major parts. First, the individual results for each of the three replications are discussed together with tests of the hypotheses outlined in Chapter III. Second, the results are statistically and graphically analyzed in order to determine density-belt speed combinations that will result in optimum picking rates with high quality pickouts.

The number of picked defective objects per minute and the per cent good objects in the pickouts were the two dependent variables treated in the analysis. An economic study was made by Zimmer (73) to determine the effects of good objects in the total pickouts on the costs of the hand quality picking operation in the peanut processing industry. This study led to the conclusion that this effect is so small as to be negligible. The loss of value of the products by placing good objects in the pickouts amounted to $0.10 per operator per eight-hour working day. This figure, however, does not make allowances for the time lost in this operation, however, this is not necessary since the good objects were not considered in the picking rate analysis. Because of the relatively small value of the products being picked and the high picking labor costs, the picking rate was based on the <u>defective</u> picked objects per minute rather than the total objects per minute.

Comparison of Replications

In the preceding chapter it was pointed out that the subjects used in the experiment were unskilled in the picking operation. Furthermore, it was also pointed out that in order to check the stability of the results, each one of the replications was to be analyzed separately. The analysis of variance was the statistical tool employed in testing the number of picked defective objects per minute for each of the replications (74).

A necessary assumption for the test of significance in the analysis of variance is that the errors in the observations are from populations with common variances. A check on the stability of the subjects was made by studying the ranges of the experimental data from the three replications made on each set of operating conditions (independent variables). These ranges, when treated by statistical control chart techniques (75 and 76), showed excellent control at about the same level of variability for each subject.

In the analyses, all of the independent variables were appropriately classified as Model I and Model II variables (77). Model I variables, the densities and the flow rates, have a constant effect. The only variable that was treated as random, or Model II, was the group of operators. Model II variables allow a generalization of their effects upon the picking rate while the conclusions regarding Model I variables apply only to the fixed levels studied in the experiment. The model equation for the factorial experiment, analysis of variance tables for each of the replications, and sample calculations and results of the analyses of variance are given in Appendix III.

From the investigations by Zimmer (78) it was found that there was an increase in the proficiency of the subjects as they acquired skill in picking small objects, being more skilled during the second (last) replications of his experiment. Davies (79) in reference to the analysis of variance of a randomized block (replications in this case) experiment has the following to say:

> Though the variation between blocks may be of no direct interest, a large value of the mean square would mean that the subdivision into blocks had been effective in separating from the other comparisons a considerable amount of variation which, if included in the residual, would have made the experiment less sensitive. Knowledge that this variation exists may be used to improve the process; it may be possible to bring the overall performance of the process under investigation up to that of the best blocks if a reason for the variation can be found.

This investigation was not designed to study the rate of acquisition of skill of individual subjects in picking small objects, but rather to eliminate from the experimental results the variation between the replications. It is for this reason and those given by Davies that the replications were analyzed separately, rather than making analysis of variance for the pooled results for the three replications. The use of covariance analysis was not appropriate here because of the complex nature of the acquisition of skill which varies significantly from one subject to another.

Table 1 shows those factors which have a significant effect upon the picking rate and are denoted by three probability levels of .05, .01, and .001. The results of the analysis of variance for each of the replications, as indicated by this table, show a difference in the significance of main effects and interactions between replication 1 and those of replications 2 and 3. Also, the residual variance (i.e., the variation

Table 1. Summary of Significant Factors Influencing the Picking of Defective Objects

Factor	Degrees of Freedom	Mean Square Replication 1	Mean Square Replication 2	Mean Square Replication 3
Flow Rate	2	736.8 **	234.9	426.3
Density	3	946.3 *	1,579.1 **	832.8 *
Operator	5	14,571.4 ***	17,642.7 ***	22,064.4 ***
Flow Rate x Density	6	248.2	290.5 *	639.1 ***
Flow Rate x Operator	10	95.6	205.5 *	157.5
Density x Operator	15	237.7 *	224.1 *	197.5 *
Residual	30	117.1	91.3	93.7

* Significant at the .05 probability level
** Significant at the .01 probability level
*** Significant at the .001 probability level

not associated with any deliberate variation in the experimental conditions) for replication 1 was larger than those of replications 2 and 3 which showed a close resemblance.

The average picking rate per minute for replication 1 was 94.1. The picking rates for replications 2 and 3 were 98.4 and 100.8 respectively. This was undoubtedly caused by the operators becoming more proficient at the task as the experiment progressed. The literature does not record the learning time for this operation, but, evidently, the time alloted for familiarization was not sufficient to allow the operators to reach a flat portion of the learning curve before replication one. However, as Table 2 indicates, the change in the picking rate of defective objects per minute between replications 2 and 3 was largely the result of an increased proficiency in the quality of the pickouts since the total picking rates are almost the same.

Table 2. Averages of Total Picking Rate Per Minute, Picking Rate of Defective Objects Per Minute, and Observed Per Cent of Good Objects in Pickouts for Each of the Three Replications.

Averages of	Replication		
	1	2	3
Total Picking Rate Per Minute	99.6	104.0	104.2
Picking Rate of Defective Objects Per Minute	94.1	98.4	100.8
Observed Per Cent of Good Objects in Total Pickouts	5.7	5.2	3.3

Figures 2 and 3 show the observed performance curve in defective objects and in good objects in the pickouts. Each point on the curves represents the average of six operators over four three-minute runs for each operator. The broken lines for each three points represent the average for each of the replications, while the full line represents a curve drawn in by inspection for the performance of all the operators.

The difference between the results of the analysis of variance for the three replications needs an explanation. Two tests were made to check if each of the mean squares for the three replications in Table 1, were from populations with common variances. Table 3 shows the results of Cochran's test (80). These results indicate that there is no reason to believe, at the .05 probability level, that any of the mean squares are from different populations. Similar results were obtained using Bartlett's test (81).

Replication 1 shows the flow rate to be significant at the .01 probability level while replications 2 and 3 do not show any significance for this factor. Table 4 shows that the picking rate decreased as the flow rate increased. Figure 4 shows the average picking rates of defective objects versus density-belt speed combinations for the three flow rates of replication 1 and an average of replications 2 and 3. It can be seen from these curves that as the experiment progressed, the proficiency of the operators increased more at the flow rates with higher speeds (2 and 3) than at flow rate 1. It can be safely said that during the first replication there was a natural reluctance towards the higher speeds of flow rates 2 and 3; this was later overcome and was not observed

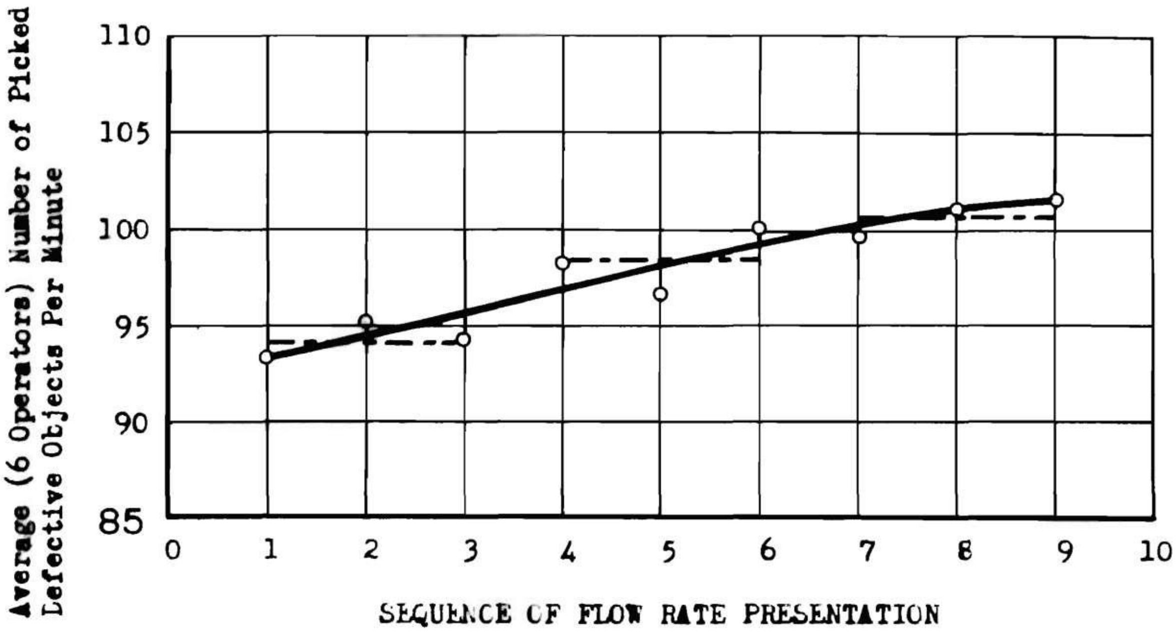

Figure 2. Observed Performance Curve in Picking Defective Objects

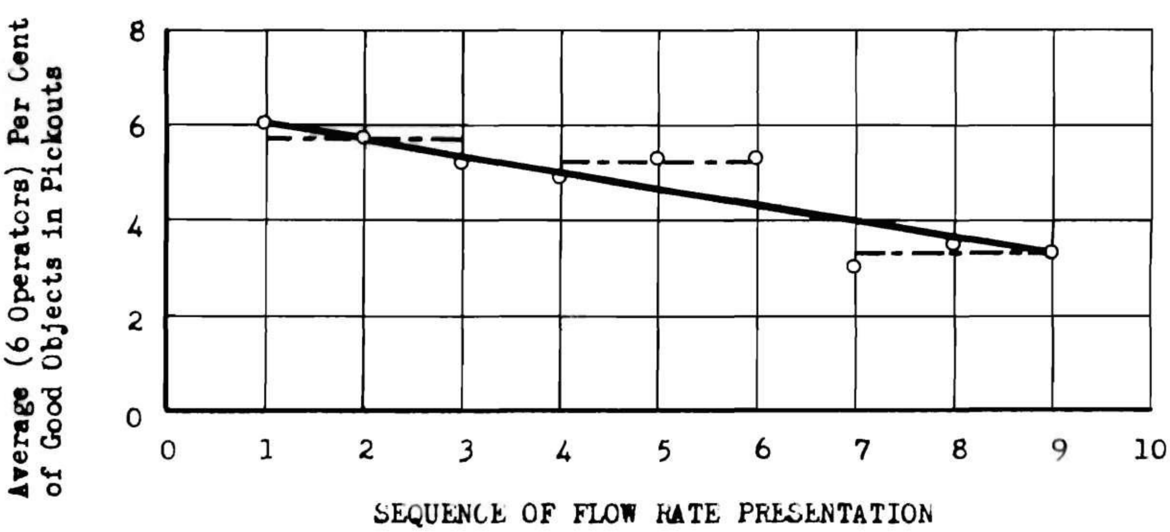

Figure 3. Observed Performance Curve in Picking Good Objects

Table 3. Cochran's Test for Homogeneity of Variances (at the .05 probability level)

Factor	Cochran's Statistic $S = \frac{\text{Largest } s^2}{\sum s_i^2}$	Degrees of Freedom n	Critical Value (.05 level)
Flow Rate	$\frac{737}{1,398} = .53$	2	.871
Density	$\frac{1,579}{3,348} = .47$	3	.798
Operator	$\frac{22,046}{54,260} = .40$	5	.707
Flow Rate x Density	$\frac{639}{1,178} = .54$	6	.677
Flow Rate x Operator	$\frac{206}{460} = .45$	10	.603
Density x Operator	$\frac{238}{660} = .36$	15	.556
Residual	$\frac{117}{302} = .39$	30	.488

Table 4. Significant Main Effects and Interactions of Replication 1 Expressed As a Per Cent of the Grand Average of All Operators of the Number of Picked Defective Objects Per Minute

Operator	Operator	Density 1	Density 2	Density 3	Density 4
1	87.8	82.9	88.4	89.4	90.6
2	93.1	92.4	94.1	92.1	94.0
3	95.0	94.5	94.7	98.6	92.1
4	106.8	100.6	104.3	111.1	111.2
5	121.8	116.5	117.7	123.4	129.3
6	95.5	91.9	98.8	96.1	95.3
Average	100.0	96.5	99.7	101.8	102.0
Flow Rate 1	101.9	-	-	-	-
Flow Rate 2	100.2	-	-	-	-
Flow Rate 3	97.9	-	-	-	-

Grand Average of All Operators = 94.1 picked defective objects per minute
- indicates factor is not significant

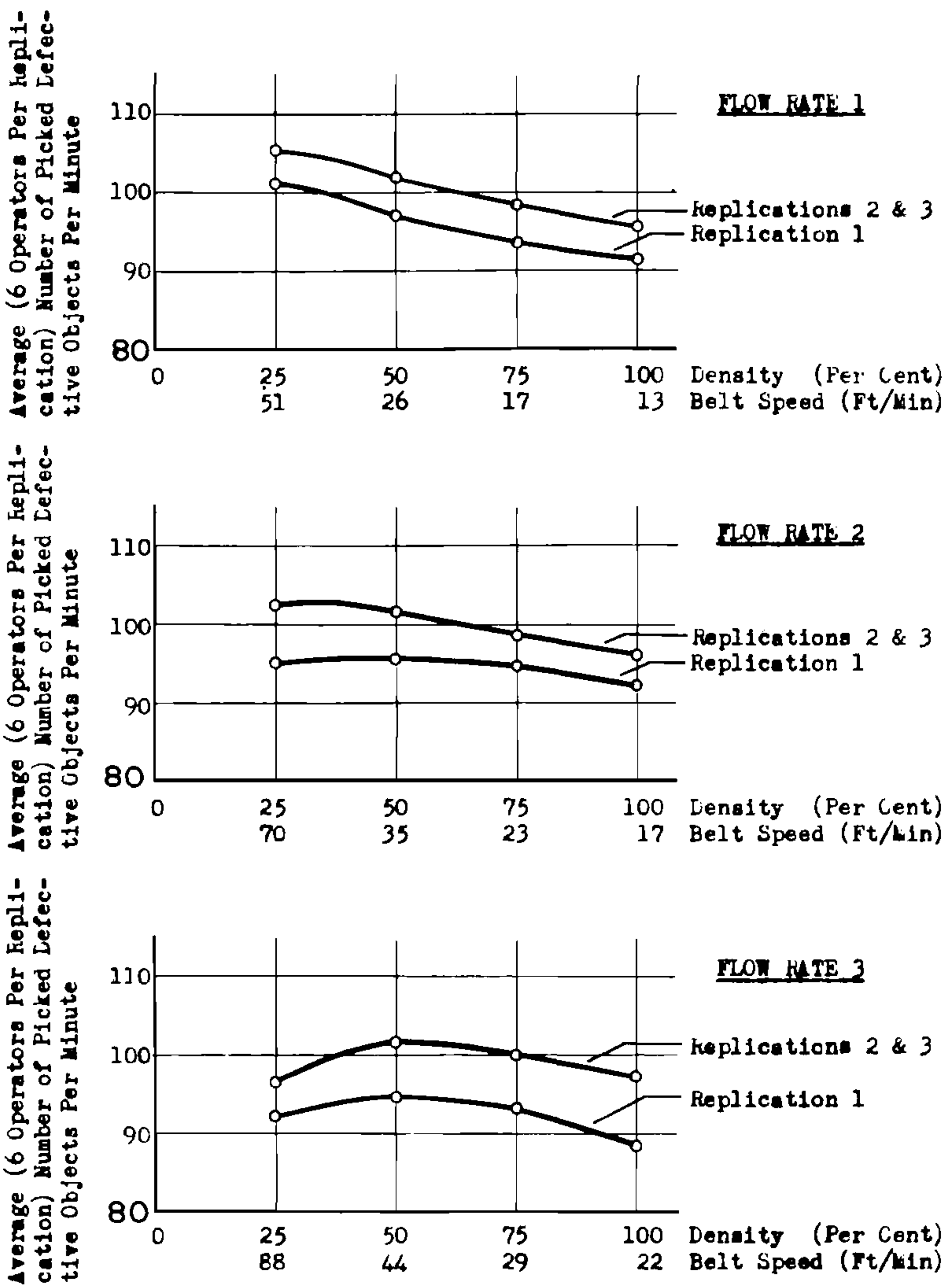

Figure 4. Average Picking Rates of Defective Objects versus Density-Belt Speed Combinations for Replications and Flow Rates

in the results of the analyses of variance of replications 2 and 3.

Because of the similarity of the results in the analyses of variance for replications 2 and 3, and their small difference in the picking rates of defective objects, it was decided to omit the experimental data of the first replication in the explanation regarding the grand average of all operators of the number of picked defective objects.*

Statistical Analysis of Picking Rate

The analysis of the experimental data is broken down into two parts corresponding to the dependent variables that were measured; the number of picked defective objects per minute, and the per cent of good objects in the total pickouts.

Number of Picked Defective Objects Per Minute

The factors found to affect the picking rate of defective objects were given in Table 1. The results of the analysis of variance for the last two replications, as indicated in this table, reject the three hypotheses stated in the objective of the experiments. Table 5 shows the significant main effects and interactions common to replications 2 and 3 as a per cent of the grand average of all operators of the number of picked defective objects per minute. The discussion below is in terms of these percentages. The grand average net picking rate for replications 2 and 3 combined was 99.6 defective per minute. Both the main effects and interactions follow in the order they appear in Table 1.

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*Omission of this replication did not change the optimum density-belt speed combinations for the grand average of all operators.

Density.--This variable had an effect, at the .01 probability level for replication 2 and at the .05 probability level for replication 3. The difference between the four density levels is not important when taken over the average of the three different flow rate levels, each having a different belt speed, since the interaction of density x flow rate proved to be significant. The differences between the four density levels will be presented in the density-flow rate interaction.

Operator.--Significance of the operators at the .001 probability level shows that individual large differences existed between the operators. Thus, the hypothesis that there is no significant difference between operator net picking rates due to operator differences is rejected. Table 5 indicates the relative rank of each operator. It also shows that there was a difference of 36.7 per cent in the picking rate between the best and least successful subject.

Flow Rate x Density.--This interaction was significant at the .05 probability level for replication 2 and at the .001 probability level for replication 3. Thus, the last two hypotheses outlined in Chapter III are rejected.

The first flow rate level and the fourth density level, with a density of 25 per cent and a belt speed of 52 feet per minute, was found to be the most favorable flow rate-density combination tested in the experiment. At this flow rate-density combination, an increase in the density or flow rate resulted in a lower picking rate. For this density level an increase in the belt speed to 70 feet per minute (for flow rate 2) resulted in a 8.9 per cent lower picking rate, and an increase at 89 feet per minute (for flow rate 3) resulted in a 12.9 per cent lower picking rate.

For this flow rate level (10.0 lbs./min.) an increase in the density from the first level to the third, second, and the first levels resulted in a lower picking rate of 3.4 per cent, 6.9 per cent and 9.8 per cent, respectively.

For the second flow rate level the picking rate was almost the same for the third and fourth density levels, with belt speeds of 35 and 70 feet per minute respectively. An increase in the density to the second and first levels resulted in a lower picking rate, listed in descending order of importance.

For the third flow rate level the third density level, with a density of 50 per cent and a belt speed of 44 feet per minute, had the highest picking rate. The second, first, and fourth density levels resulted in a lower picking rate, listed in descending order of importance.

A comparison of these results with the findings cited above by Moder that belt speeds between 10 and 60 feet per minute did not appreciably affect the picking rate; Zimmer's results of an optimum picking rate at a density-belt speed combination of 22 per cent and 46 feet per minute for a flow rate of 7.75 pounds per minute, and Calhoun's results that more pickouts were obtained at his lowest investigated density of 33 per cent, gives assurance that the density of the objects in the belt is the most critical factor influencing the picking rates of defective objects up to speeds of 60 feet per minute. However, for any given flow rate, there is a density-belt speed combination that determines the optimum picking rate. This optimum picking rate occurs at a density-belt speed combination having a belt speed slower than 60 feet per minute.

Table 5. Significant Main Effects and Interactions of Replications 2 and 3 Expressed As A Per Cent of The Grand Average of All Operators of The Number of Picked Defective Objects Per Minute

Operator	Operator	Density 1	Density 2	Density 3	Density 4
1	76.3	73.9	75.1	76.6	79.3
2	93.1	91.1	91.7	95.4	94.3
3	104.0	101.4	106.9	105.9	102.0
4	107.7	105.6	108.1	110.7	106.6
5	113.0	106.2	112.6	116.0	117.4
6	105.8	102.0	101.9	108.3	111.0
Average	100.0	96.7	99.4	102.2	101.8
Flow Rate 1	-	95.9	98.8	102.3	105.7
Flow Rate 2	-	96.5	99.0	102.1	102.8
Flow Rate 3	-	97.7	100.4	102.1	96.8

Grand Average of All Operators = 99.6 picked defective objects per minute - indicates factor is not significant

Density x Operator.—This interaction was significant at the .05 probability level in each of the replications. This interaction means that the operators performed better at different density levels. This interaction, however, is an average over the three different flow rates where each density level was performed at three different speeds. For this reason, Table 6 was constructed which shows that, in general, the operators had a higher picking rate at the fourth density level during the first flow rate level, a preference of either the third or fourth density levels for the second flow rate level and a preference of the third density level for the third flow rate level. This table offers evidence that the optimum performance of the operators was very similar for the four density levels when considered for each flow rate separately.

Corrected Per Cent of Good Objects in Pickouts

It was mentioned earlier in this chapter that the effect of the picking quality on the costs of the picking operation is practically negligible. It was regarded to be satisfactory, therefore, to present and discuss the experimental data in their relative magnitude as a per cent value of the grand average per cent of good objects in the pickouts. These per cent values are shown in Table 7. It should be emphasized that the values are relative terms based on the grand average per cent of the good objects in the pickouts of all operators of only 4.72 per cent. It would be misleading, therefore, to regard the data on actual per cent of the total pickouts.

The experimental factors are discussed in the order of their decreasing importance upon the picking quality.

Table 6. Experimental Factors Expressed As A Per Cent of The Grand Average of All Operators of The Number of Picked Defective Objects Per Minute

Operator	Operator		Density				Flow Rate		
			1	2	3	4	1	2	3
		F1	76.5	80.6	78.9	87.5	80.9		
1	79.9	F2	78.2	78.0	82.7	84.8		80.9	
		F3	75.7	79.7	80.4	76.5			78.0
		F1	91.8	91.1	93.2	96.7	93.2		
2	93.1	F2	90.1	91.9	93.5	94.8		92.6	
		F3	92.7	94.2	96.3	91.0			93.6
		F1	99.8	102.7	104.8	104.7	103.0		
3	101.1	F2	98.1	102.3	102.6	98.5		100.4	
		F3	99.6	103.9	103.3	93.3			100.0
		F1	104.7	104.9	112.1	112.9	108.6		
4	107.4	F2	103.9	108.6	110.6	105.2		107.1	
		F3	103.4	107.1	109.8	106.1			106.6
		F1	109.4	111.9	120.9	125.1	116.9		
5	115.9	F2	109.0	113.3	116.5	121.7		114.4	
		F3	110.4	117.4	117.7	116.9			115.6
		F1	95.9	102.4	105.8	110.7	103.7		
6	102.5	F2	102.7	102.5	104.9	108.1		104.6	
		F3	97.6	97.9	102.5	99.1			99.3
Average	100.0		96.6	99.5	102.0	101.9	101.0	100.1	98.8
Flow Rate 1			96.4	98.9	102.6	106.3			
Flow Rate 2			97.0	99.4	101.8	102.2			
Flow Rate 3			96.6	100.0	101.7	97.2			

Grand Average of All Operators and Replications = 97.8 picked defective objects per minute

Table 7. Experimental Factors Expressed As A Per Cent of The Grand Average Per Cent of Good Objects in The Pickouts

Operator	Operator		Density				Flow Rate		
			1	2	3	4	1	2	3
		F1	22	55	27	40	36		
1	48	F2	33	36	40	61		43	
		F3	40	33	64	124			66
		F1	167	120	113	155	139		
2	149	F2	114	128	96	138		119	
		F3	178	165	183	227			188
		F1	86	75	62	60	71		
3	98	F2	118	94	72	139		106	
		F3	119	91	135	124			117
		F1	152	131	112	143	134		
4	178	F2	161	169	166	193		172	
		F3	212	186	227	278			226
		F1	45	30	34	41	38		
5	35	F2	30	23	18	41		28	
		F3	32	40	46	42			40
		F1	58	70	70	75	69		
6	81	F2	90	57	64	79		73	
		F3	105	83	70	143			100
Average	100		101	90	91	117	82	92	126
Flow Rate 1			91	80	71	87			
Flow Rate 2			93	87	78	109			
Flow Rate 3			118	102	124	158			

Grand Average of All Operators = 4.72 per cent good objects in pickouts

Operator.--The greatest difference in the per cent of good objects in the pickouts was found to be present between the individual operators. This difference upon the average per cent of good objects in the pickouts was as great as 143 per cent between the operator having the highest picking quality and the one having the lowest quality.

Flow Rate.--Four operators showed their highest picking quality at the first flow rate level; two operators had their lowest picking quality at the third flow rate level.

There is a clear indication that the quality of the pickouts is dependent upon both the density and the belt speed. For any density level an increase in speed (a change from a low flow rate level to a high flow rate level) resulted in lower quality of the pickouts; however, there was a density-belt speed combination for each of the flow rates at which the picking quality was a maximum, usually the third density level.

Graphical Analysis of the Picking Rate

The graphical presentation of the results is given for two reasons. First, an interpretation of optimum conditions is simplified by interpolating the picking rate curves. Second, a graphical presentation shows more clearly fluctuations in the output curves.

The analysis of these results is broken into three parts. First, the graphical analysis of the number of picked defective objects per minute. Second, the graphical analysis of the per cent of good objects in the total pickouts. Third, the determination of density-belt speed combinations that will result in joint optimum picking rates and high quality of the pickouts.

Number of Picked Defective Objects Per Minute

Figure 4 shows curves for the number of picked defective objects per minute of the three flow rates in relation to their corresponding density-belt speed combinations. Figure 5 shows these same curves for the flow rates in relation to their corresponding belt speeds. It is very noticeable that the belt speed designates the optimum range of density-belt speed combinations for each of the flow rates investigated. The shaded column designated an optimum range of belt speeds of all the operators for the three investigated flow rates. This range was obtained from the individual operator picking rate curves shown in Figures 11 through 13, Appendix IV; the results are recorded for each flow rate in Table 19. This range designates the belt speeds common to the three flow rate levels at which the operator's picking rates varied within two defective objects from their maximum number of picked defective objects per minute. In this table the overlapping belt speeds indicate that the optimum range for all the operators common to the three flow rates was between a belt speed of 45 and 51 feet per minute. There is a clear indication that the corresponding densities for these belt speed ranges increase as the flow rate is increased. For this reason, no attempt was made in finding ranges of overlapping densities.

Per Cent of Good Objects in Pickouts

A range of belt speeds common to the three flow rate levels, at which the operators' picking quality varied within one per cent from their minimum per cent of picked good objects, was found. Figures 6 and 7 show curves for each flow rate presenting the per cent of picked good objects in relation to the density and to the belt speed. The shaded column in figure 7 designates an optimum range of belt speeds of all the operators for the three investigated flow rates. This range was obtained from individual curves for each operator and flow rate as shown in Figures 14 through 16, Appendix IV; the results are recorded for each flow rate in Table 20. In this table, the overlapping belt speeds indicate that the optimum range for all operators for the investigated flow rate levels was between 27 and 36 feet per minute.

Determination of Optimum Picking Rates

An overall survey of the experimental data can be gained by reference to the curves in Figures 4 through 7. These curves clearly show the optimum density-belt speed combinations for each flow rate for the grand average number of picked defective objects and the grand average per cent of good objects in the pickouts.*

An attempt was made in finding overlapping density-belt speed ranges from the curves of the grand average number of picked defective objects and the grand average per cent of good objects in the pickouts for each of the flow rates. Tables 8 and 9 show the overlapping ranges of densities and belt speeds, as well as the optimum density-belt speed combination for each flow rate for the highest number of picked defective objects per minute and the minimum per cent of good objects in the pickouts. These ranges designate the density-belt speed combinations for each flow rate at which the grand average picking rate varied within 1/2 defective object from the maximum number of picked defective objects per

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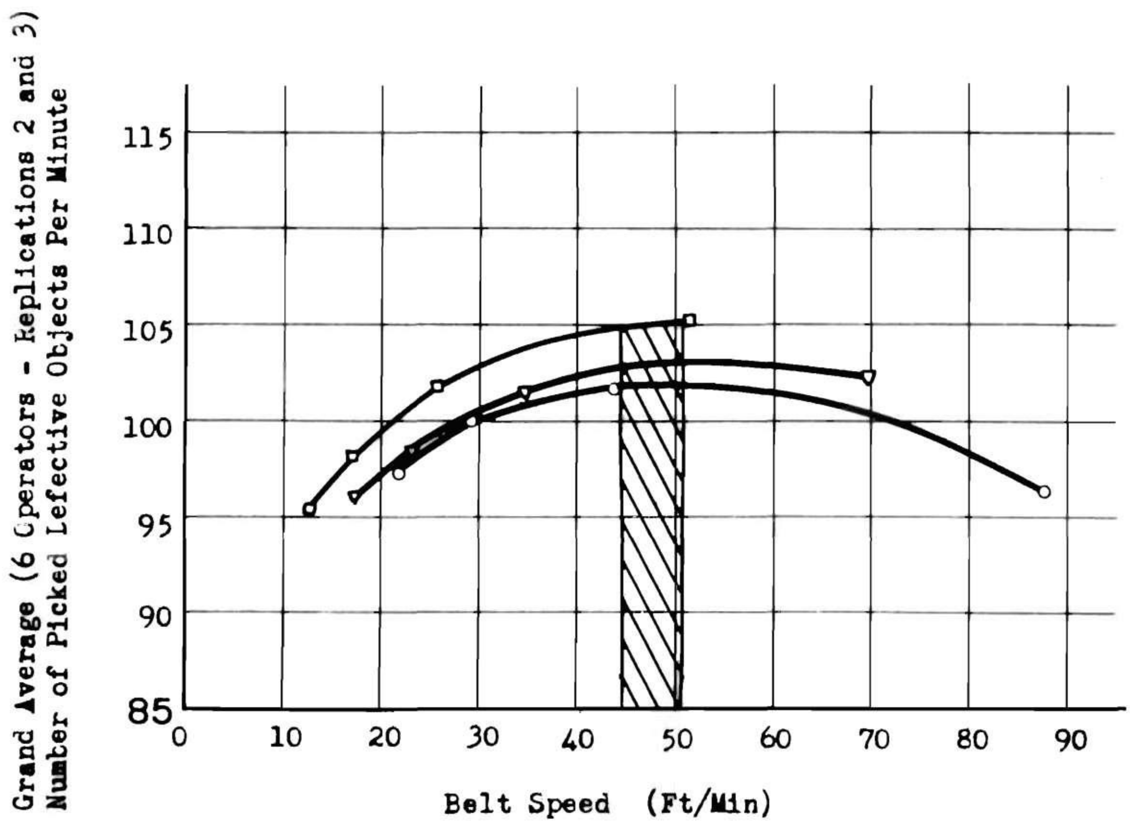
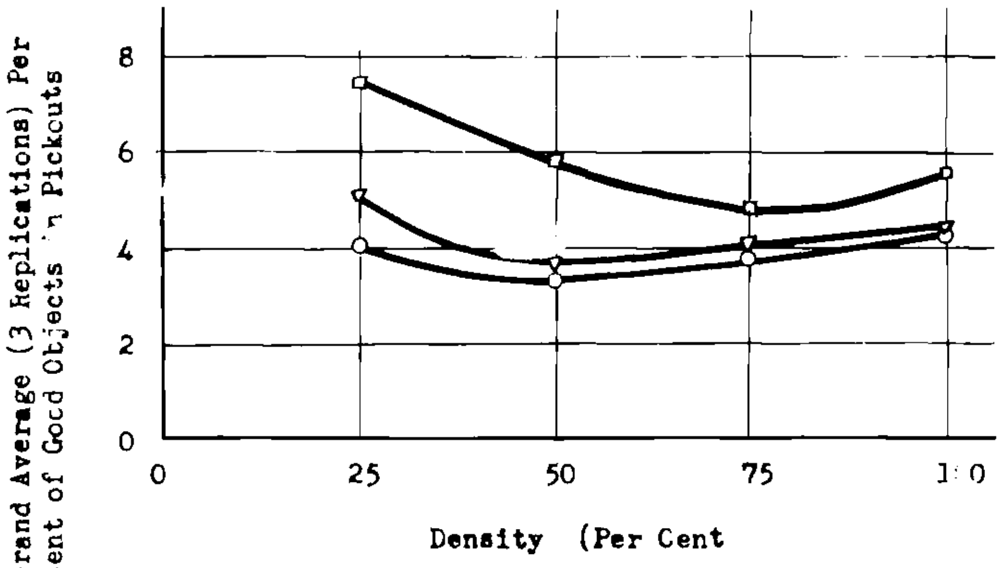
*See footnote on page 36.



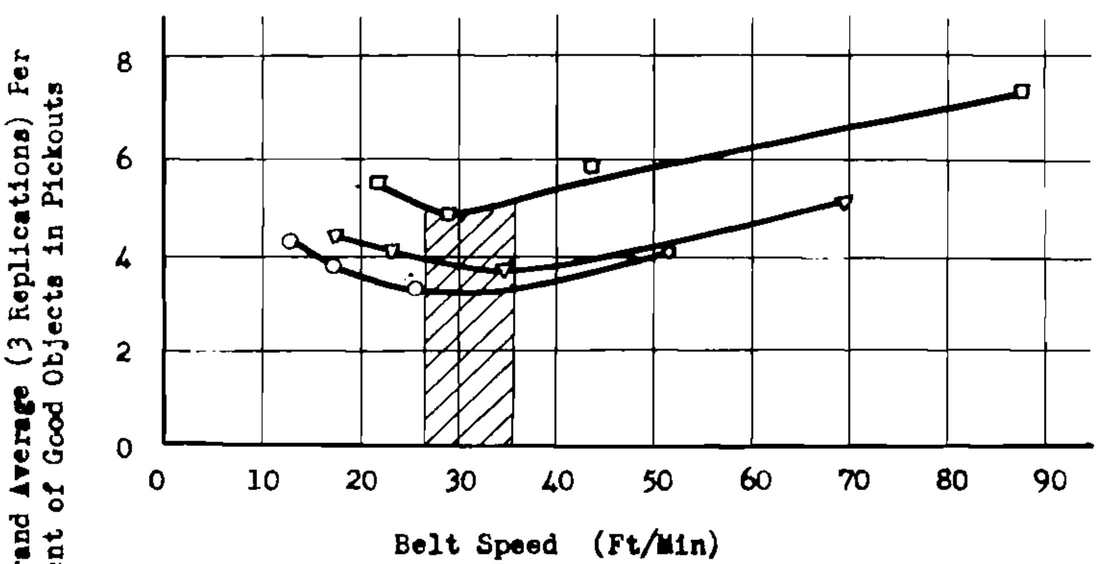
Key: ■ Flow Rate of 10.0 lbs. per minute
▽ Flow Rate of 13.5 lbs. per minute
○ Flow Rate of 17.0 lbs. per minute

Figure 5. Grand Average Picking Rate of Defective Objects versus Belt Speed for Flow Rates



Key: o Flow Rate 1; ▿ Flow Rate 2; □ Flow Rate 3

Figure 6. Grand Average Picking Quality Expressed in Per Cent versus Density for Each Flow Rate



Key: o Flow Rate 1; ▿ Flow Rate 2; □ Flow Rate 3

Figure 7. Grand Average Picking Quality Expressed in Per Cent versus Belt Speed for Each Flow Rate

minute and where the grand average picking quality varied within a one per cent from the minimum per cent of good objects in the pickouts.

Table 8 clearly shows that the optimum belt speed is approximately the same for all three flow rates. These speeds are centered around 50 feet per minute for the net picking rate, and around 32 feet per minute for the quality of the pickouts. Figures 5 and 7 show the curves from which tables 8 and 9 were constructed.

The overlapping belt speeds, for the grand average picking of defective objects and the grand average per cent of good objects in the pickouts, common to the three flow rates are also shown in Table 8. These ranges of belt speeds were found to be 42 to 52 feet per minute for the net picking rate, and 22 to 43 feet per minute for the per cent of good objects in the pickouts. The overlapping range of belt speeds, from the grand average curves, common to both factors was 42 to 43 feet per minute.

From Tables 8 and 19 it can be seen that for a maximum net picking rate a belt speed of 50 feet per minute is desirable, provided that the per cent of good objects in the pickouts of experienced operators is of negligible economic importance. However, if the per cent of good objects in the pickouts is found to be high among the operators and the cost of good objects in the pickouts is high, a belt speed of 32 feet per minute is desirable to obtain the maximum picking quality. It should be kept in mind that at these optimum speeds, lower densities, and thus, lower flow rates, will result in higher picking rates and picking quality. For the peanut processing industry, the established favorable belt speed for a high rate of picked defective objects will

Table 8. Ranges of Belt Speeds in Feet Per Minute for Maximum Number of Picked Defective Objects and for Minimum Per Cent of Good Objects in the Pickouts.

Condition	Belt Speeds for Flow Rates of 10.0 lbs./min.	13.5 lbs./min.	17.0 lbs./min.	Range Common to 10.0, 13.5, and 17.0 lbs./min.
Maximum Number of Picked Defective Objects Per Minute - 1/2 Obtained from Grand Average Curve*	41.0-52.0	42.0-61.0	37.0-58.0	42.0-52.0
Optimum Obtained from Grand Average Curve	52.0	50.0	48.0	
Minimum Per Cent of Good Objects in Pickouts + 1 Per Cent Obtained from Grand Average Curve	13.0-52.0	18.0-58.0	22.0-43.0	22.0-43.0
Optimum Obtained from Grand Average Curve	32.0	34.0	30.0	
Range Common to - 1/2 Defective Object Per Minute from Maximum Number of Picked Objects and Minimum Per Cent of Good Objects in the Pickouts + 1 Per Cent (Optimum Range)	41.0-52.0	42.0-58.0	37.0-43.0	42.0-43.0

*Replications 2 and 3 only. Omission of replication 1 did not change the optimum belt speed.

Table 9. Ranges of Densities in Per Cent for Maximum Number of Picked Defective Objects and for Minimum Per Cent of Good Objects in the Pickouts.

Condition	Densities for Flow Rates of 10.0 lbs./min.	13.5 lbs./min.	17.0 lbs./min.
Maximum Number of Picked Defective Objects Per Minute - 1/2 Obtained from Grand Average Curve*	32.0-25.0	41.0-29.0	60.0-38.0
Optimum Obtained from Grand Average Curve	25.0	35.0	46.0
Minimum Per Cent of Good Objects in Pickouts + 1 Per Cent Obtained from Grand Average Curve	100.0-25.0	100.0-30.0	100.0-51.0
Optimum Obtained from Grand Average Curve	41.0	51.0	73.0
Range Common to - 1/2 Defective Object Per Minute from Maximum Number of Picked Objects and Minimum Per Cent of Good Objects in the Pickouts + 1 Per Cent (Optimum Range)	32.0-25.0	41.0-30.0	60.0-51.0

*Replications 2 and 3 only. Omission of replication 1 did not change the optimum belt speed.

result in optimum hand quality picking conditions.

Summary.--A detailed analysis of the experimental data was given in this chapter. The differences between the statistical results of the three replications of the experiment were discussed. By means of a statistical and graphical analyses of the experimental data, optimum picking conditions were established and the effect which each independent variable had upon the picking rate was determined.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations discussed below are based only upon the experimental results of this investigation which entail the following limitations:

1. The experimental subjects were:

    a. Male college students rather than female factory workers, who are largely employed in hand quality picking.

    b. Unskilled operators with a limited time available for training in hand quality picking, which resulted in a small acquisition of skill effect. This effect was almost completely offset by analyzing each replication separately, and by the use of a balanced experimental plan described in Chapter V.

    c. Highly motivated because of the experimental nature of this study.

    d. Prospective engineers with considerable interest in investigations of this nature.

2. Great Northern beans used as experimental objects in this investigation are not representative of all the products which require manual quality picking.

3. The Pinto beans, which represented the damaged objects, are not identical in size and shape to Great Northern beans; however, this difference is so small as to be negligible.

4. Only one belt width was used.

Conclusions.--The following conclusions are made for the experimental results and are subject to the above limitations. The objective of this thesis, to determine if there are belt speeds common to the three rates of flow of objects at which optimum picking rates and high quality of pickouts are obtained, was accomplished. The following conclusions were drawn:

1. Picking conditions for optimum net picking rate.--

   The maximum net picking rate was found to occur at a belt speed of 50 ± 2 feet per minute for all flow rates investigated. At this belt speed, the net picking rates of the individual operators deviated by less than 2 pickouts per minute from their maximum rates. At these optimum belt speeds a drop in the picking rate was observed as the flow rate increased (higher densities). Increasing the flow rate from 10.0 to 17.0 pounds per minute decreased the average net picking rate from 105 to 102 pickouts per minute.

2. Picking conditions for optimum quality of pickouts.--

   A *maximum* picking quality was found to occur at a belt speed of 32 ± 2 feet per minute for all flow rates investigated. At this belt speed, the per cent of good objects in the pickouts of the individual operators deviated by less than 1 per cent from their maximum quality. Increasing the flow rate from 10.0 to 17.0 pounds per minute decreased the average picking quality from 3.0 to 4.8 per cent of good objects in the total pickouts.

3. Picking conditions for joint optimum net picking rate and quality of pickouts.--

   The economic conditions within whatever industry is involved will determine the desired high picking rate or high quality picking. For the peanut processing industry, the established belt speed of 50 ± 2 feet per minute, favorable for a high rate of picked defective objects, will result in optimum hand quality picking conditions.

Recommendations.--In view of the limitations, results, and conclusions of this study, it is recommended that further study of hand quality picking be directed toward:

1. The use of objects other than Great Northern Beans.
2. The use of a larger and more representative sample of the

people who do manual quality picking in industry.

3. The effect of illumination on the belt and the color contrast of the objects with the belt color.

4. The effect of the width of the conveyor belt upon the picking rate and quality.

Comments.--It is always desirable that an experiment of this type reveal some information that may be put to use in every day operations. It is felt that this investigation together with those preceding it has brought to light information of value to industry. The plant manager who desires to use these results, with a full understanding of their relative importance of production versus quality, could set up his hand quality picking operation as follows:

1. Require that all operators use the "pick and throw" method, with no restriction upon grasping two objects at a time if they are adjacent to each other.

2. Have all the operators pick from the side of the belt.

3. Provide a minimum illumination of 65-foot candles at the surface of the belt.

4. Operate the picking belt at a speed of 50 feet per minute for maximum number of picked defective objects, or at a speed of 30 feet per minute for highest quality of the pickouts. A plant manager, from a knowledge of the per cent of good objects in the pickouts for each of his operators and the value of the commodity being picked, could determine the best speed to use. He might also group the operators at different picking tables adjusted for their individual preferences. It should be kept in mind that the lowest density at the optimum speed chosen will result in a higher picking rate and picking quality.

APPENDIX I

EXPERIMENTAL APPARATUS

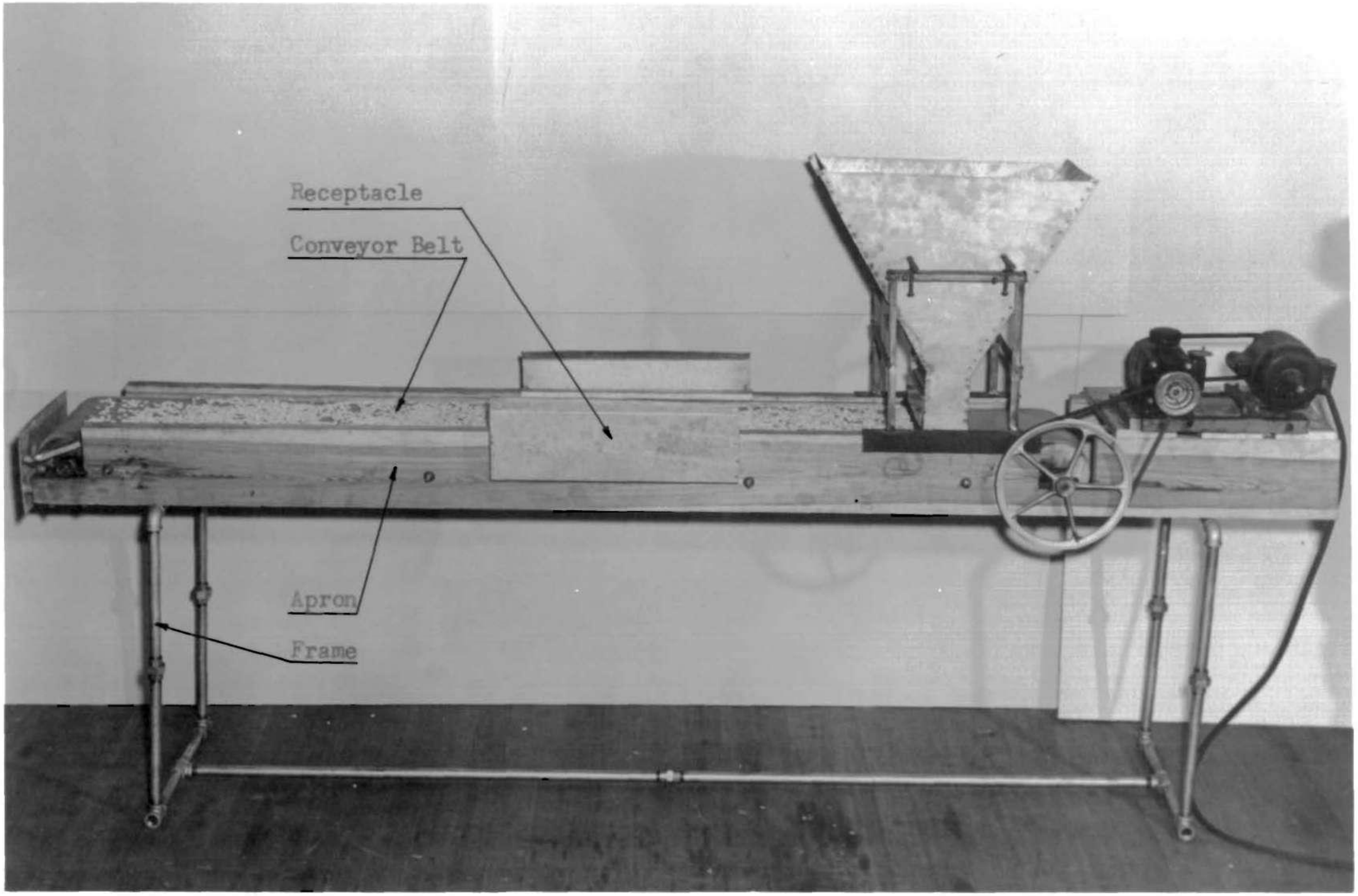


Figure 8. The Experimental Apparatus

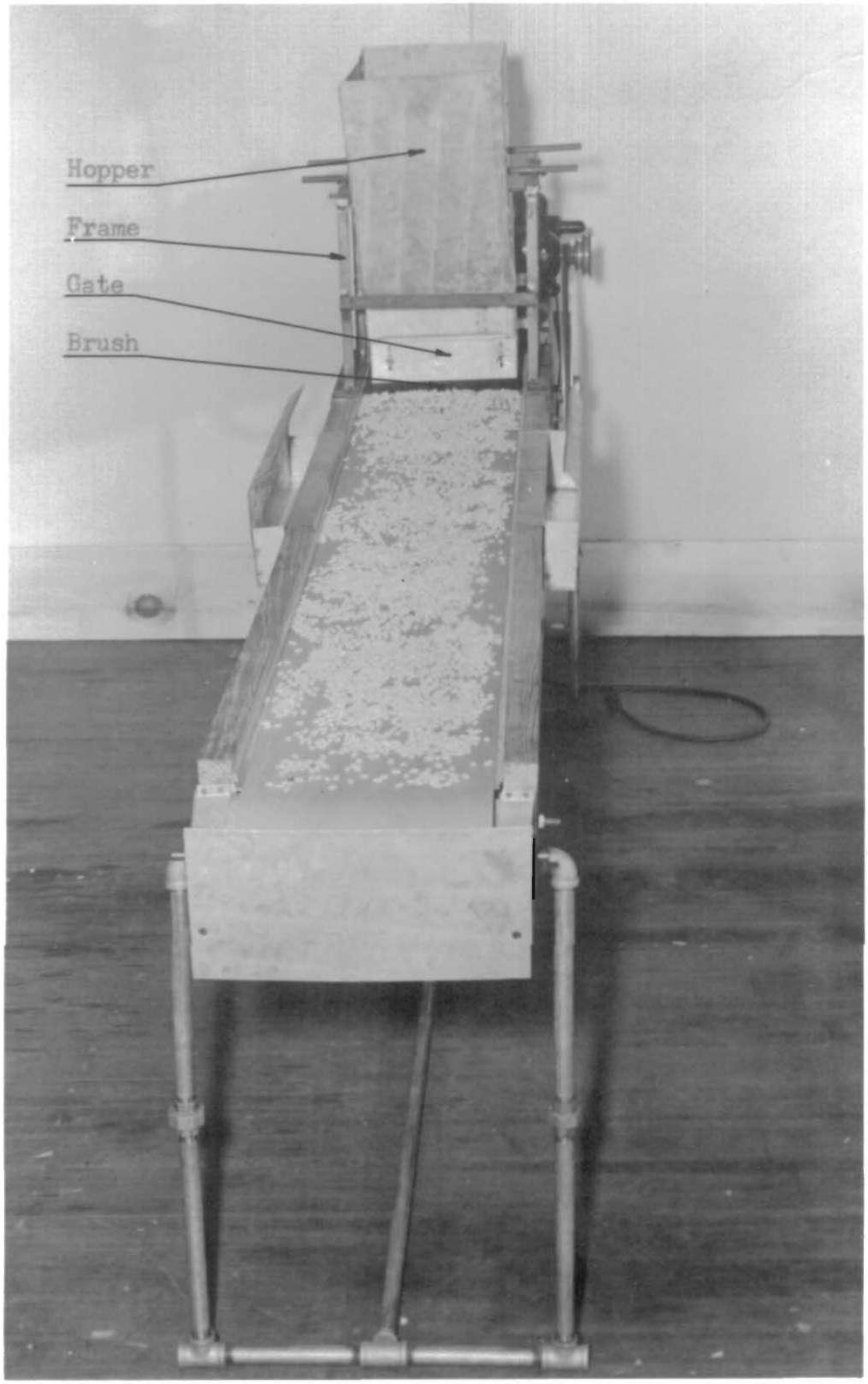


Figure 9. The Hopper and Feed Control of the Experimental Apparatus

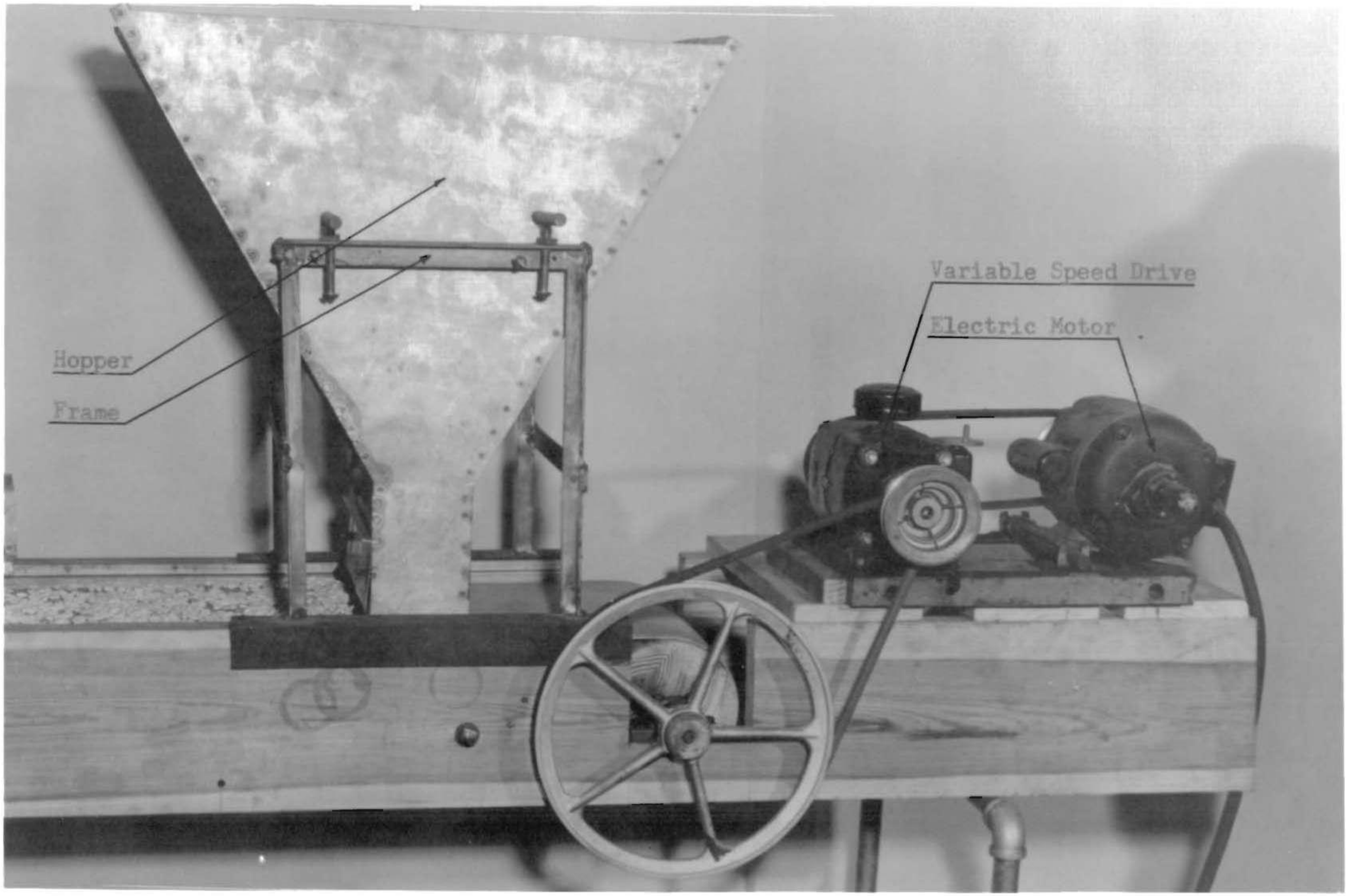


Figure 10. The Drive of the Experimental Apparatus

APPENDIX II

EXPERIMENTAL DATA

Legend to Tables 10 through 13

Operator 1.	O1
Operator 2.	O2
Operator 3.	O3
Operator 4.	O4
Operator 5.	O5
Operator 6.	O6
Flow Rate 1	F1
Flow Rate 2	F2
Flow Rate 3	F3
Density 1	S1
Density 2	S2
Density 3	S3
Density 4	S4
Replication 1	R1
Replication 2	R2
Replication 3	R3

Table 10. Arrangement for Testing Flow Rates

		Sequence of Testing Flow Rates		
		1	2	3
R1	O1	F1	F2	F3
	O2	F2	F3	F1
	O3	F3	F1	F2
	O4	F3	F2	F1
	O5	F1	F3	F2
	O6	F2	F1	F3
R2	O1	F2	F3	F1
	O2	F3	F1	F2
	O3	F1	F2	F3
	O4	F2	F1	F3
	O5	F3	F2	F1
	O6	F1	F3	F2
R3	O1	F3	F1	F2
	O2	F1	F2	F3
	O3	F2	F3	F1
	O4	F1	F3	F2
	O5	F2	F1	F3
	O6	F3	F2	F1

Table 11. Observed Number of Picked Defective Objects Per Minute Based on a Three-Minute Test Run

		F1				F2				F3			
		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
O1	R1	75.33	84.00	84.00	90.33	83.00	80.00	85.00	86.33	75.67	85.67	83.33	79.00
	R2	75.67	75.00	79.67	88.33	71.00	76.00	80.67	82.67	73.00	74.33	74.33	85.67
	R3	73.33	77.33	67.67	78.00	75.33	72.67	77.00	79.67	73.33	73.67	78.00	59.67
O2	R1	90.33	90.00	86.33	92.77	84.00	86.00	85.33	90.67	86.67	89.67	88.33	82.00
	R2	85.00	86.67	88.33	93.00	84.33	86.67	90.67	88.33	88.33	90.00	92.67	87.33
	R3	94.00	90.67	98.67	98.00	96.00	97.00	98.33	99.00	97.00	96.67	101.33	97.67
O3	R1	91.00	88.33	95.00	94.33	88.67	93.00	96.00	87.33	87.00	86.00	87.33	78.33
	R2	95.33	101.67	100.33	101.00	97.00	96.67	98.67	99.67	98.00	111.67	103.33	94.67
	R3	106.33	111.33	112.00	111.67	102.00	110.33	106.33	102.00	107.00	107.00	112.33	100.67
O4	R1	99.00	93.00	108.33	107.67	97.67	104.67	102.67	100.33	87.33	96.67	102.67	106.00
	R2	101.67	107.67	110.33	111.67	102.33	100.67	108.00	102.33	106.33	111.33	107.33	106.33
	R3	106.33	107.00	110.00	111.67	104.67	113.33	113.67	106.00	109.67	106.00	112.00	99.00
O5	R1	109.67	110.33	115.67	124.67	108.00	110.33	116.33	120.33	112.00	111.67	116.33	120.00
	R2	107.67	110.67	118.67	118.33	102.67	106.33	103.00	121.33	104.67	117.33	113.33	114.00
	R3	103.67	107.33	120.33	124.00	109.00	116.33	122.33	115.33	107.00	115.33	115.67	108.33
O6	R1	84.33	95.33	93.67	97.33	92.00	93.33	87.33	84.67	83.00	90.33	90.33	87.00
	R2	99.33	104.67	111.00	115.33	107.00	101.67	111.33	118.00	101.33	99.67	105.00	104.00
	R3	97.67	100.33	105.67	112.00	102.33	105.67	109.00	114.33	102.00	97.00	105.33	99.67

Table 12. Observed Number of Picked Good Objects Per Minute Based on a Three-Minute Test Run

		F1				F2				F3			
		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
01	R1	1.00	4.33	1.67	2.33	3.00	2.33	2.67	4.67	.67	2.33	2.67	10.67
	R2	1.00	1.00	1.00	2.67	.33	.33	1.67	1.00	3.33	.67	3.67	2.00
	R3	.33	1.00	.33	-	.33	1.33	.33	1.67	.33	.67	1.00	1.33
02	R1	8.33	10.00	5.33	7.33	4.00	5.67	2.67	7.00	8.67	8.00	12.67	14.67
	R2	11.00	3.33	7.33	8.33	7.00	8.00	6.00	7.67	10.00	8.67	6.67	11.67
	R3	3.67	2.67	2.67	6.67	4.00	3.67	4.33	4.67	6.33	6.67	7.33	5.67
03	R1	4.67	4.33	3.67	3.33	7.67	5.67	5.67	12.00	6.67	4.33	7.67	4.67
	R2	4.33	2.67	1.67	2.67	4.67	4.67	1.33	5.33	6.33	6.00	9.33	6.67
	R3	3.33	4.00	4.00	3.00	4.67	3.67	3.67	3.00	4.33	3.33	3.67	5.67
04	R1	9.33	10.33	7.00	7.33	11.00	12.33	13.67	11.00	20.33	17.33	19.67	17.67
	R2	6.67	4.33	4.67	9.00	8.33	10.33	5.67	10.67	6.33	5.33	11.00	15.00
	R3	7.67	5.67	6.67	7.67	5.67	5.00	8.33	9.33	7.00	7.67	8.00	14.33
05	R1	3.33	2.67	2.67	2.67	2.67	2.00	1.00	2.67	3.00	4.67	4.00	4.33
	R2	2.00	1.33	2.67	3.33	1.33	1.67	1.00	1.67	1.67	1.67	2.00	2.33
	R3	1.67	.67	.67	1.33	.67	-	1.00	2.67	.33	.33	1.67	.33
06	R1	-	1.67	-	1.67	1.33	-	3.00	1.00	-	.33	.67	3.00
	R2	4.00	7.67	9.33	7.33	7.33	5.33	4.33	9.67	14.67	7.67	7.33	16.00
	R3	4.00	1.00	1.33	3.00	4.67	3.00	2.33	1.67	.33	3.67	2.33	2.00

Table 13. Per Cent of Good Objects in Total Pickouts

		F1				F2				F3			
		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
01	R1	1.3	4.9	1.9	2.5	3.5	2.8	3.0	5.1	.9	2.7	3.1	11.9
	R2	1.3	1.3	1.2	2.9	.5	.4	2.0	1.2	4.4	.9	4.7	2.3
	R3	.4	1.3	.5	-	.4	1.8	.4	2.0	.4	.9	1.3	2.2
02	R1	8.4	10.0	5.8	7.3	4.6	6.2	3.0	7.2	9.1	8.2	12.5	15.2
	R2	11.5	3.7	7.7	8.2	7.7	8.5	6.2	8.0	10.2	8.8	6.7	11.8
	R3	3.8	2.9	2.6	6.4	4.0	3.6	4.2	4.5	6.1	6.5	6.7	5.5
03	R1	4.9	4.7	3.7	3.4	8.0	5.7	5.6	12.1	7.1	4.8	8.1	5.6
	R2	4.3	2.6	1.6	2.6	4.6	4.6	1.3	5.1	6.1	5.1	8.3	6.6
	R3	3.0	3.5	3.4	2.6	4.4	3.2	3.3	2.9	3.9	3.0	3.2	5.3
04	R1	8.6	10.0	6.1	6.4	10.1	10.5	11.7	9.9	18.9	15.2	16.1	14.3
	R2	6.2	3.9	4.1	7.5	7.5	9.3	5.0	9.4	5.6	4.6	9.3	12.4
	R3	6.7	5.0	5.7	6.4	5.2	4.2	6.8	8.1	6.0	6.7	6.7	12.6
05	R1	2.9	2.4	2.3	2.1	2.4	1.8	.9	2.2	2.6	4.0	3.3	3.5
	R2	1.8	1.2	2.2	2.7	1.3	1.5	1.0	1.4	1.6	1.4	1.7	2.0
	R3	1.6	.6	.6	1.1	.6	-	.8	2.3	.3	.3	1.4	.3
06	R1	-	1.7	-	1.7	1.4	-	3.3	1.2	-	.4	.7	3.3
	R2	3.9	6.8	7.8	6.0	6.4	5.0	3.7	7.6	12.6	7.1	6.5	13.3
	R3	3.9	1.0	1.2	2.6	4.4	2.8	2.1	1.4	.3	3.6	2.2	2.0

Grand Average = 4.72 per cent good objects in pickouts

APPENDIX III

STATISTICAL ANALYSIS

ANALYSIS OF VARIANCE

Using the notation of Bennett (82), the following equation was designed to express the mathematical model of the experiment:

$$Y_{ijk} = \mu + F_i + S_j + O_k + FO_{ik} + SO_{jk} + FS_{ij} + FSO_{ijk}$$

Explanation of each term in this equation is given in Table 14. According to the model equation, which shows the possible main effects and interactions, Table 15 was constructed to give the equations from which the sums of squares were derived. The actual sums of squares are shown in Tables 16, 17, and 18. The mean squares were found by dividing the sums of squares by their degrees of freedom. The expected mean squares were appropriate for testing the various null hypotheses with the use of the Fisher F distribution (83 and 84). It can be seen, for instance, that the F main effect was tested against the F x O interaction, whereas the F x S interaction was tested against the residual. The S main effect was tested against the S x O interaction, and the O main effect and the remaining interactions were tested against the residual.

The calculated ratios were compared with appropriate values taken from tables of the F distribution. The ratios were rejected when their magnitudes were greater than the tabular values at the indicated probability levels. Rejection of the ratios meant that the source of variance was significant at that level of probability.

Table 14. Analysis of Variance Table

Source of Variance	Designation	Subscript	Model	Symbol	Number of Levels
Flow Rate	F	i	I	F_i	3
Density	S	j	I	S_j	4
Operator	O	k	II	O_k	6

Table 15. Components of Analysis of Variance Table, Part I

Source of Variance	Degrees of Freedom	Components of Sum of Squares
F	2	$\sum_{i} S^2_{i..}/JK - S^2_{...}/IJK$
S	3	$\sum_{j} S^2_{.j.}/IK - S^2_{...}/IJK$
O	5	$\sum_{k} S^2_{..k}/IJ - S^2_{...}/IJK$
F x S	6	$\sum_{ij} S^2_{ij.}/K - \sum_{i} S^2_{i..}/JK - \sum_{j} S^2_{.j.}/IK + S^2_{...}/IJK$
F x O	10	$\sum_{ik} S^2_{i.k}/J - \sum_{i} S^2_{i..}/JK - \sum_{k} S^2_{..k}/IJ + S^2_{...}/IJK$
S x O	15	$\sum_{jk} S^2_{.jk}/I - \sum_{j} S^2_{.j.}/IK - \sum_{k} S^2_{..k}/IJ + S^2_{...}/IJK$
F x S x O	30	$\sum_{ijk} X^2_{ijk} - \sum_{ik} S^2_{i.k}/J - \sum_{jk} S^2_{.jk}/I - \sum_{ij} S^2_{ij.}/K + \sum_{i} S^2_{i..}/JK$
		$+ \sum_{j} S^2_{.j.}/IK + \sum_{k} S^2_{..k}/IJ - S^2_{...}/IJK$
Total		$\sum_{ijk} X^2_{ijk} - S^2_{...}/IJK$

Table 16. Components of Analysis of Variance Table, Part II - Replication I

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	Expected Mean Square	F- Test
F	2	1,473.6	736.8	$\sigma_o^2 + J\sigma_{FO}^2 + JK\sigma_F^{2\prime}$	$\frac{736.8}{95.6} = 7.72$ **
S	3	2,838.8	946.3	$\sigma_o^2 + I\sigma_{SO}^2 + IK\sigma_S^{2\prime}$	$\frac{946.3}{237.7} = 3.98$ *
O	5	72,856.8	14,571.4	$\sigma_o^2 + IJ\sigma_O^2$	$\frac{14,571.4}{117.1} = 124.44$ ***
F x S	6	1,489.0	248.2	$\sigma_o^2 + \sigma_{FSO}^2 + K\sigma_{FS}^{2\prime}$	$\frac{248.2}{117.1} = 2.12$
F x O	10	955.5	95.6	$\sigma_o^2 + J\sigma_{FO}^2$	$\frac{95.6}{117.1} = .82$
S x O	15	3,566.4	237.7	$\sigma_o^2 + I\sigma_{SO}^2$	$\frac{237.7}{117.1} = 2.03$ *
F x S x O (Residual)	30	3,514.4	117.1	$\sigma_o^2 + \sigma_{FSO}^2$	
Total	71	86,694.5	16,953.1		

* Denotes significance at the .05 level
** Denotes significance at the .01 level
*** Denotes significance at the .001 level

Table 17. Components of Analysis of Variance Table, Part II - Replication II

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	Expected Mean Square	F - Test
F	2	469.8	234.9	$\sigma_o^2 + J\sigma_{FO}^2 + JK\sigma_F^{2\prime}$	$\frac{234.9}{205.5} = 1.14$
S	3	4,737.3	1,579.1	$\sigma_o^2 + I\sigma_{SO}^2 + IK\sigma_S^{2\prime}$	$\frac{1,579.1}{224.1} = 7.05$ **
O	5	88,213.5	17,642.7	$\sigma_o^2 + IJ\sigma_o^2$	$\frac{17,642.7}{91.3} = 193.34$ ***
F x S	6	1,742.9	290.5	$\sigma_o^2 + \sigma_{FSO}^2 + K\sigma_{FS}^{2\prime}$	$\frac{290.5}{91.3} = 3.18$ *
F x O	10	2,055.3	205.5	$\sigma_o^2 + J\sigma_{FO}^2$	$\frac{205.5}{91.3} = 2.25$ *
S x O	15	3,361.8	224.1	$\sigma_o^2 + I\sigma_{SO}^2$	$\frac{224.1}{91.3} = 2.46$ *
F x S x O (Residual)	30	2,737.4	91.3	$\sigma_o^2 + \sigma_{FSO}^2$	
Total	71	103,318.0	20,268.1		

* Denotes significance at the .05 level
** Denotes significance at the .01 level
*** Denotes significance at the .001 level

Table 18. Components of Analysis of Variance Table,
Part II - Replication III

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	Expected Mean Square	F - Test
F	2	852.6	426.3	$\sigma_o^2 + J\sigma_{FO}^2 + JK\sigma_F^{2\prime}$	$\frac{426.3}{157.5} = 2.71$
S	3	2,498.5	832.8	$\sigma_o^2 + I\sigma_{SO}^2 + IK\sigma_S^{2\prime}$	$\frac{832.8}{197.5} = 4.22$ *
O	5	110,321.8	22,064.4	$\sigma_o^2 + IJ\sigma_o^2$	$\frac{22,064.4}{93.7} = 235.45$ ***
F x S	6	3,834.4	639.1	$\sigma_o^2 + \sigma_{FSO}^2 + K\sigma_{FS}^{2\prime}$	$\frac{639.1}{93.7} = 6.82$ ***
F x O	10	1,575.1	157.5	$\sigma_o^2 + J\sigma_{FO}^2$	$\frac{157.5}{93.7} = 1.68$
S x O	15	2,961.8	197.5	$\sigma_o^2 + I\sigma_{SO}^2$	$\frac{197.5}{93.7} = 2.11$ *
F x S x O (Residual)	30	2,811.2	93.7	$\sigma_o^2 + \sigma_{FSO}^2$	
Total	71	124,855.4	24,411.3		

* Denotes significance at the .05 level
** Denotes significance at the .01 level
*** Denotes significance at the .001 level

CALIBRATION OF THE GATE

In Chapter II one hundred per cent density of the objects on the belt was described as an experimentally derived figure for which no standard measure is available. This figure was established by weighing the number of objects placed in such a manner in a unit area on the belt that there was no more room for more objects without their having to rest on top of others. Ten consecutive times the objects, placed in a unit area of 288 square inches, were weighed and from the observed values the standard deviation was found to be 21.6 grams and the arithmetic mean was found to be 701.8 grams.

From the standard deviation and the number of samples taken, the standard error of the observed mean was derived as follows:

$$\text{Standard Error of Mean} = \frac{\text{Standard Deviation}}{\sqrt{\text{Samples Taken}}}$$

substituted

$$\text{S. E.} = \frac{21.6}{\sqrt{10}} = 6.76$$

This error was below 1 per cent of the mean, and was considered to be satisfactory for these experiments.

With 100 per cent density defined, the gate was calibrated for each of the tested densities at their respective belt speeds for each flow rate tested. The calibration readings were taken from two scales with divisions of 1 mm. fastened on the left and right sides of the gate and were taken against the markers fastened to the hopper. The calibration readings were not taken until ten random two-feet sections of the belt gave consecutive readings falling within one per cent of the required density. It was found that the calibration readings were the same at each density level for the three flow rates tested.

APPENDIX IV

GRAPHICAL ANALYSIS

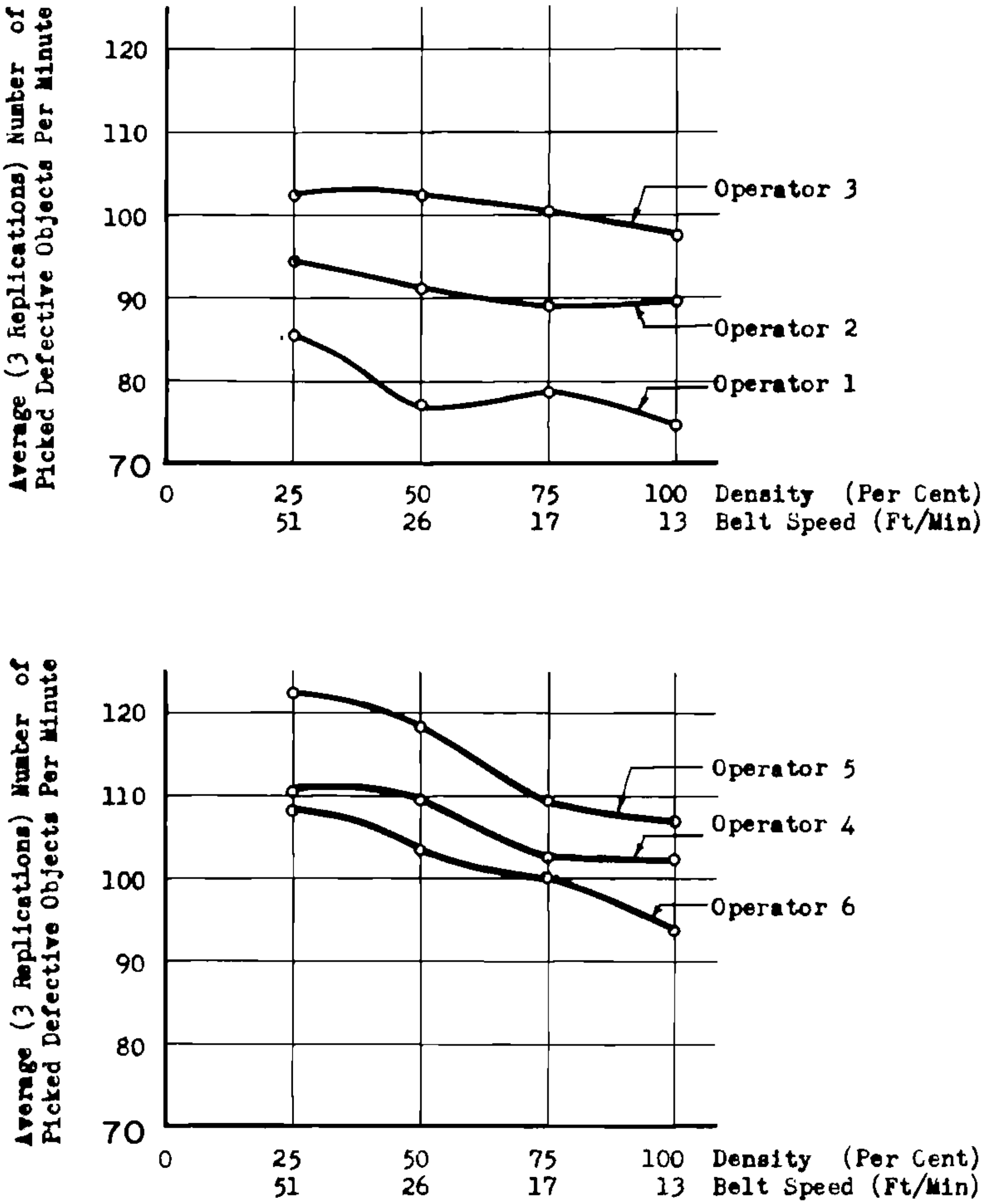


Figure 11. Average Picking Rates of Defective Objects versus Density - Belt Speed Combinations for Operators and Flow Rate 1

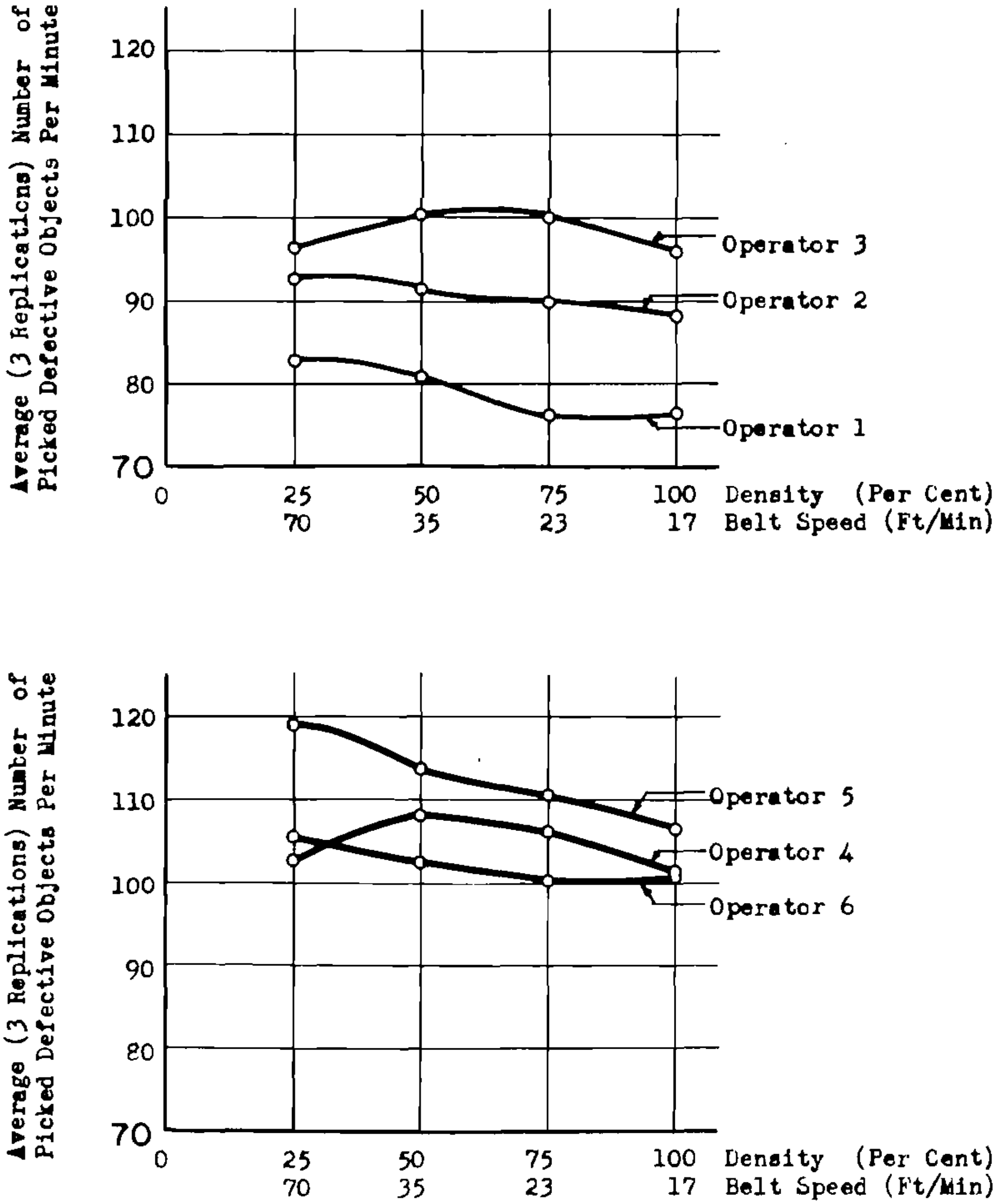
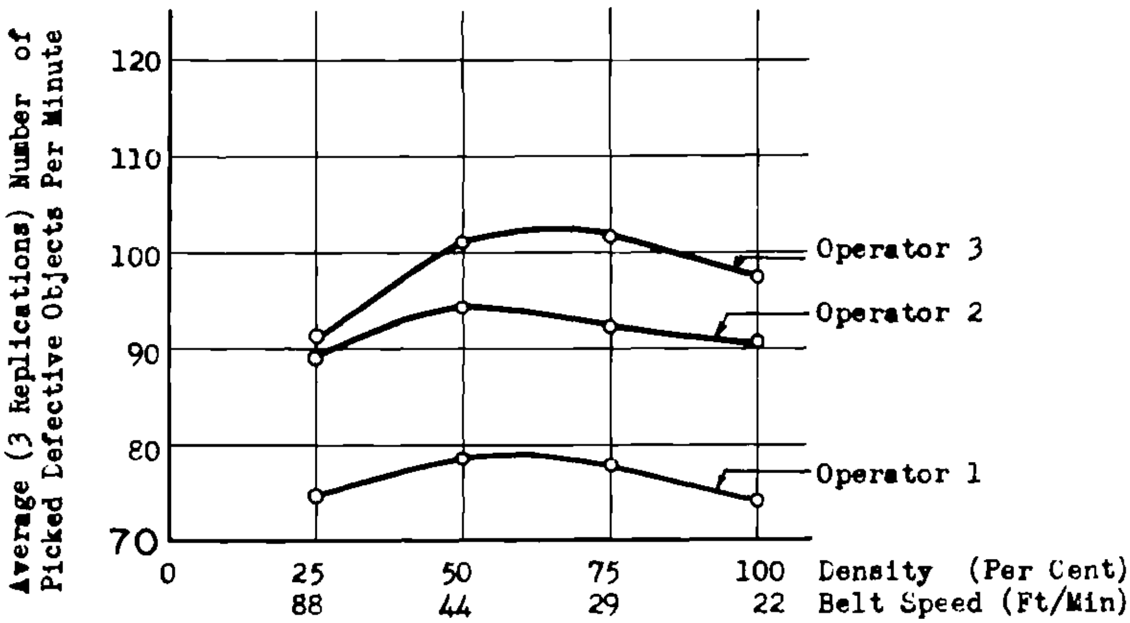


Figure 12. Average Picking Rates of Defective Objects versus Density - Belt Speed Combinations for Operators and Flow Rate 2



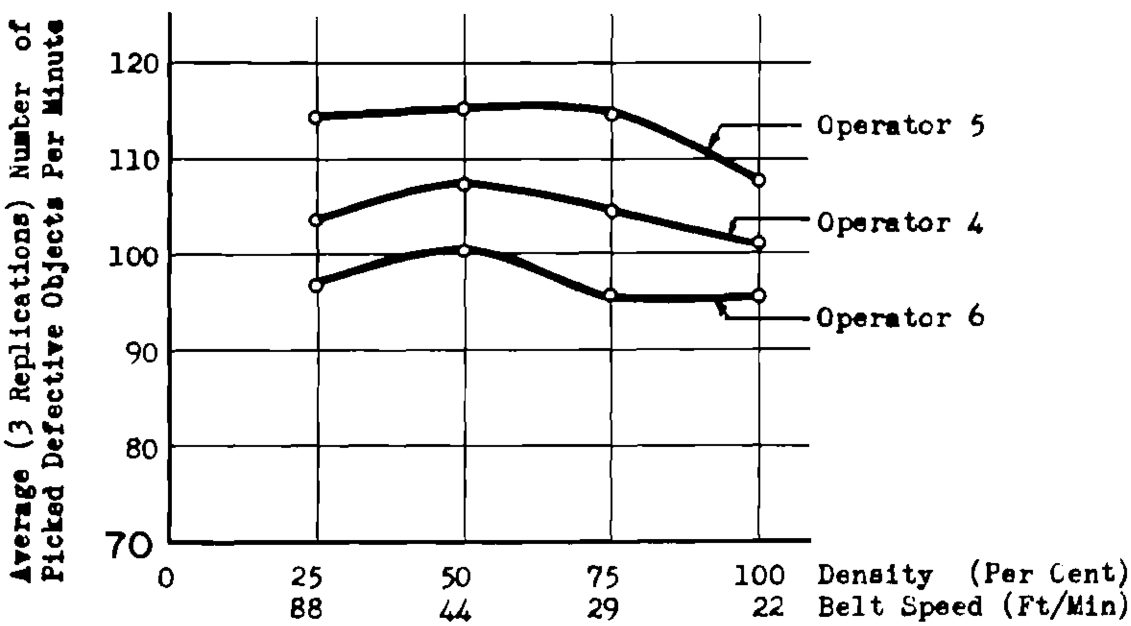
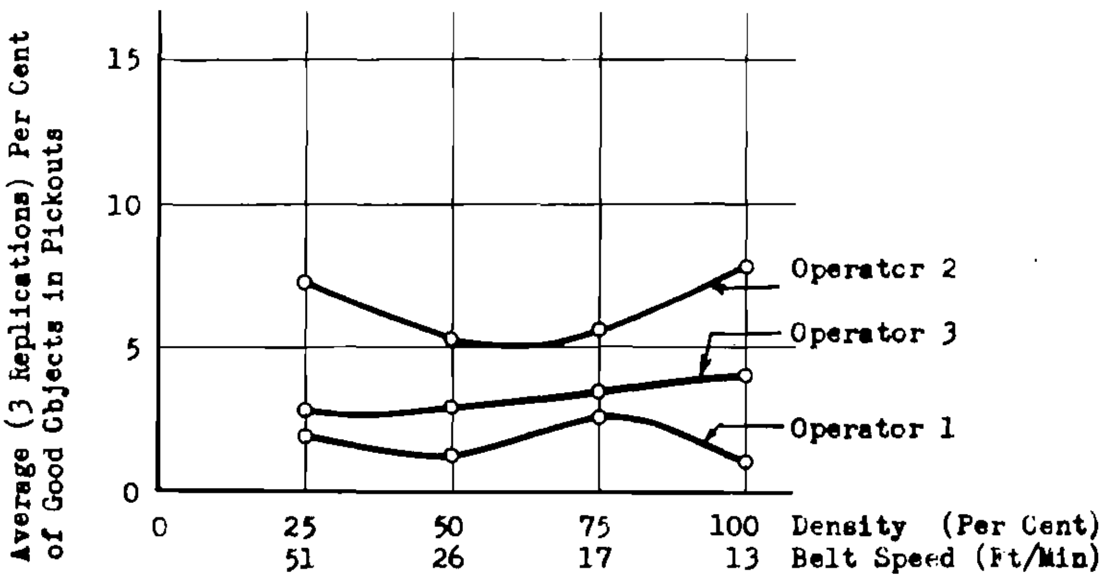


Figure 13. Average Picking Rates of Defective Objects versus Density - Belt Speed Combinations for Operators and Flow Rate 3

Table 19. Ranges of Density-Belt Speed Combinations for Optimum Picking Rates of Defective Objects

Operator	Range of Density in Per Cent for Maximum Number of Picked Defective Objects Per Minute - 2, at Flow Rates of			Range of Belt Speed in Feet Per Minute for Maximum Number of Picked Defective Objects Per Minute - 2, at Flow Rates of			
	10.0 Lbs./Min.	13.5 Lbs./Min.	17.0 Lbs./Min.	10.0 Lbs./Min.	13.5 Lbs./Min.	17.0 Lbs./Min.	Range Common to 10.0,13.5, 17.0 Lbs./Min.
1	32.5-25.0*	42.0-26.0	82.0-35.0	39.5-52.0	41.0-67.0	27.0-63.0	41.0-52.0
2	41.5-25.0*	44.5-25.0	71.5-32.0	31.0-52.0	39.0-70.0	31.0-69.0	39.0-52.0
3	65.0-25.0*	80.0-30.0	85.0-43.5	20.0-52.0	21.5-58.0	26.0-51.0	26.0-51.0
4	48.5-25.0*	74.0-30.5	71.0-31.0	26.5-52.0	23.5-57.0	31.0-71.0	31.0-52.0
5	40.0-25.0*	38.5-25.0	82.5-25.0	32.0-52.0	45.0-70.0	26.5-88.0	45.0-52.0
6	31.0-25.0*	41.0-25.0	60.0-30.0	41.5-52.0	42.0-70.0	37.0-73.0	42.0-52.0
Range Common to All Operators (Optimum)	32.5-25.0*	38.5-30.5	60.0-43.5	41.5-52.0	45.0-57.0	37.0-51.0	45.0-51.0

* Lowest density observed



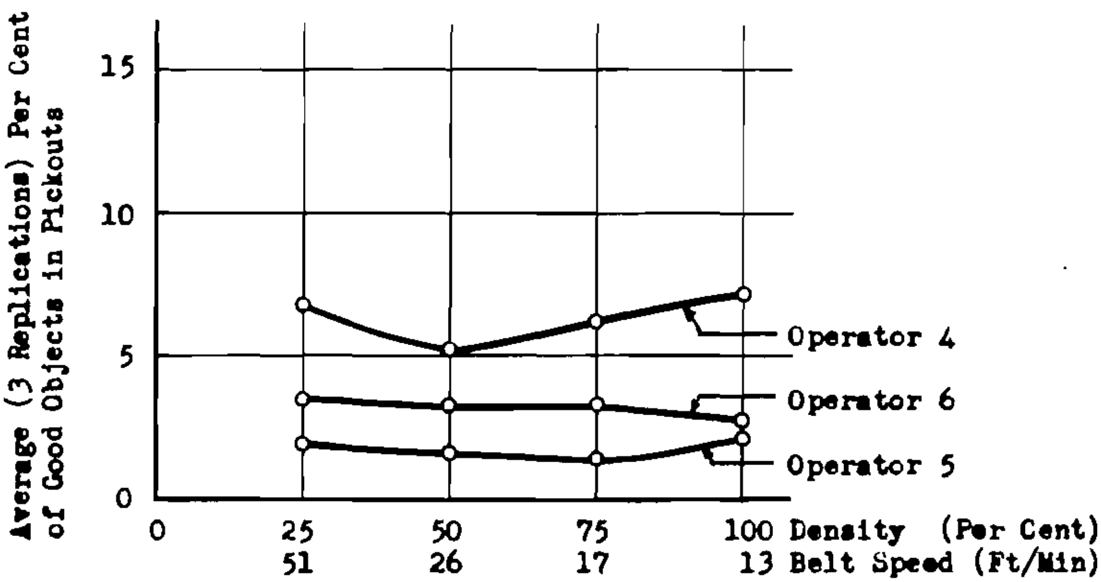
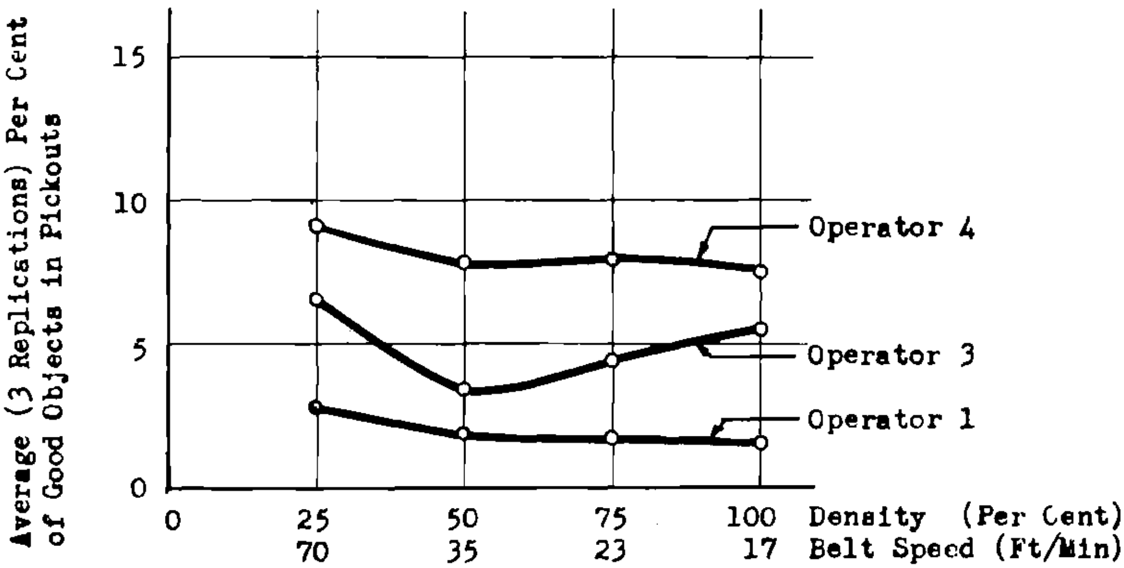


Figure 14. Average Picking Quality Expressed in Per Cent versus Density - Belt Speed Combinations for Operators and Flow Rate 1



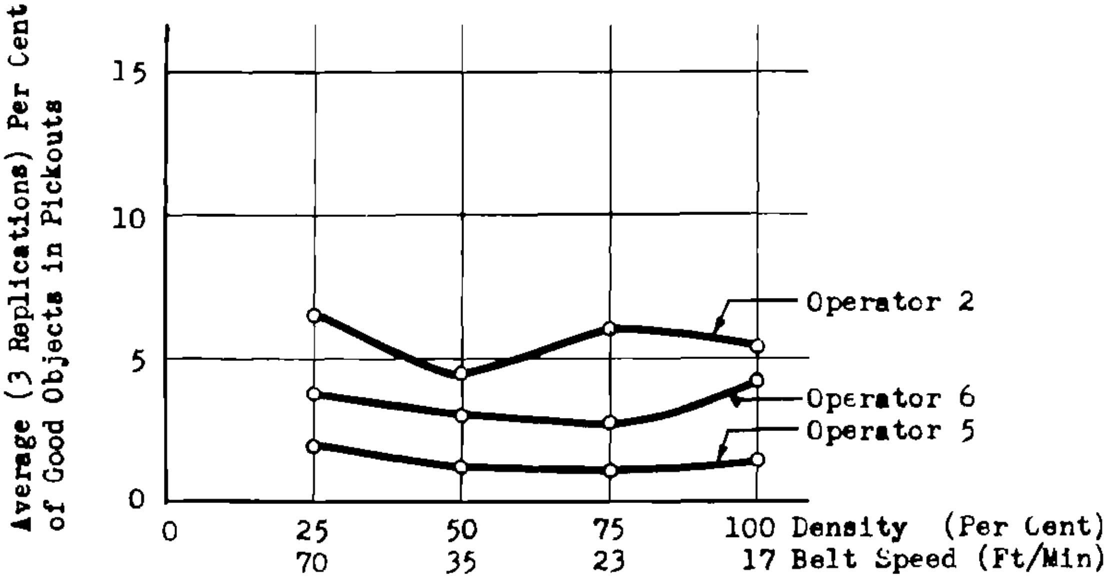
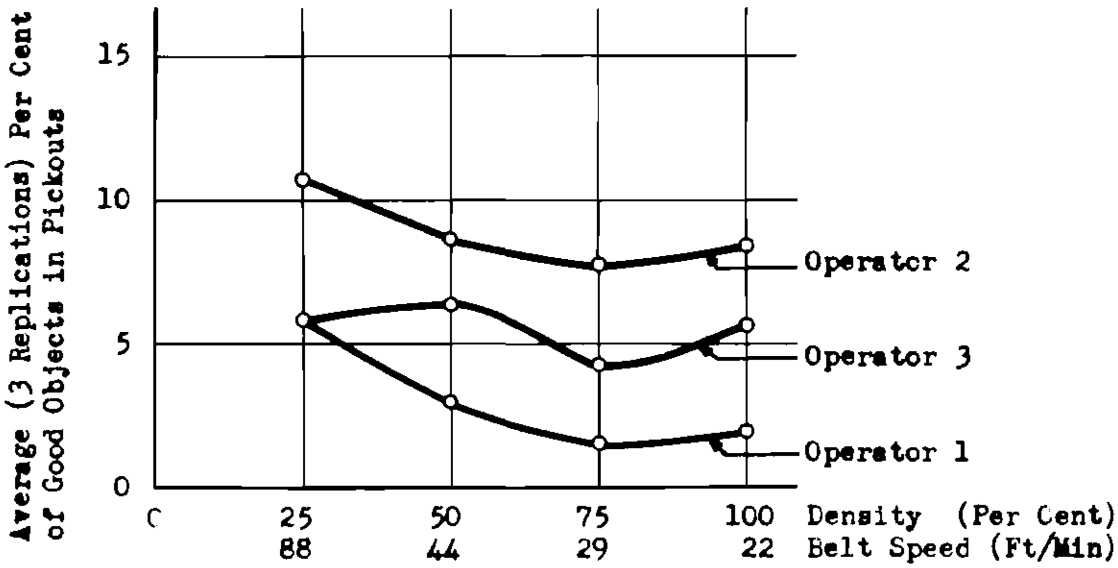


Figure 15. Average Picking Quality Expressed in Per Cent versus Density - Belt Speed Combinations for Operators and Flow Rate 2



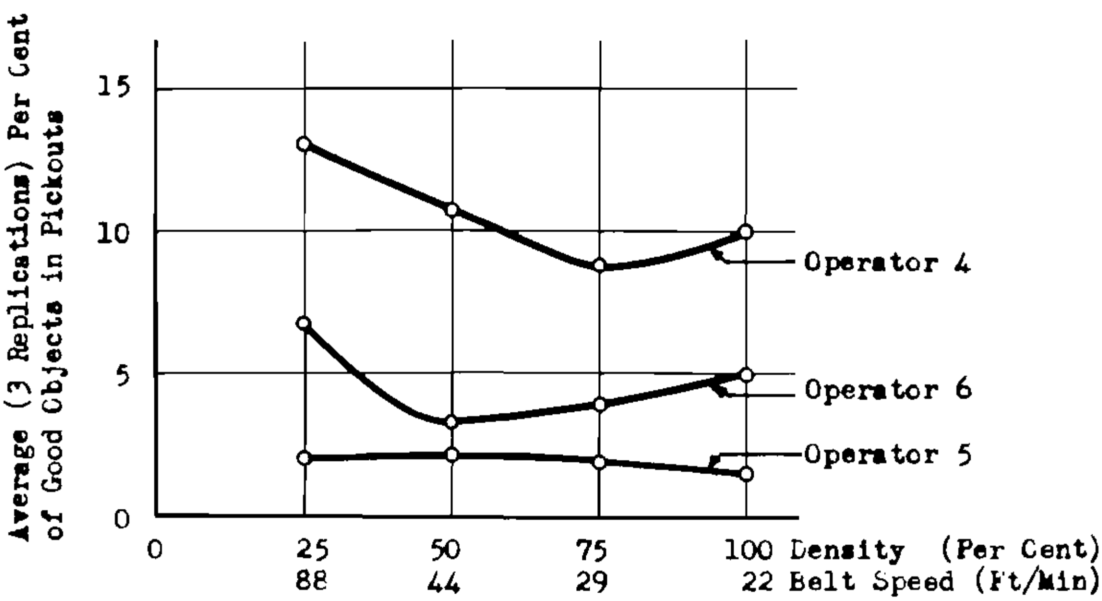


Figure 16. Average Picking Quality Expressed in Per Cent versus Density - Belt Speed Combinations for Operators and Flow Rate 3

Table 20. Ranges of Density-Belt Speed Combinations for High Quality in the Pickouts

Operator	Range of Density in Per Cent for Minimum Per Cent of Good Objects in Pickouts + 1 Per Cent at Flow Rates of			Range of Belt Speed in F.P.M. for Minimum Per Cent of Good Objects in Pickouts + 1 Per Cent at Flow Rates of			
	10.0 Lbs./Min.	13.5 Lbs./Min.	17.0 Lbs./Min.	10.0 Lbs./Min.	13.5 Lbs./Min.	17.0 Lbs./Min.	Range Common to 10.0,13.5, 17.0 Lbs./Min.
1	64.0-25.0	100.0-30.0	100.0-55.0	20.0-52.0	17.5-58.0	22.0-40.0	22.0-40.0
2	84.0-31.0	65.0-32.5	100.0-47.5	15.0-41.5	27.0-54.0	22.0-46.0	27.0-41.5
3	87.5-25.0	75.0-36.5	96.5-61.0	14.5-52.0	23.0-47.5	22.5-36.0	23.0-36.0
4	77.5-28.5	100.0-31.5	98.0-58.0	16.5-45.0	17.5-55.5	22.0-38.0	22.0-38.0
5	100.0-25.0	100.0-26.0	100.0-25.0	13.0-52.0	17.5-67.0	22.0-87.5	22.0-52.0
6	100.0-25.0	94.5-25.0	85.0-40.0	13.0-52.0	18.5-69.5	26.0-55.0	26.0-52.0
Range Common to All Operators (Optimum)	64.0-31.0	65.0-36.5	85.0-61.0	20.0-41.5	27.0-47.5	26.0-36.0	27.0-36.0

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