4. IMPACTS OF THE INDEX OF DIFFICULTY AND PLATES' HEAVINESS ON HEAVY PLATE ASSEMBLY TIMES

4.1 Overview and Research Objectives

In heavy part assembly industry, overhead cranes have become necessary tools that each factory must have. The cranes are employed to hold the heavy parts in almost every step of assembly process. During a full-load production, these cranes are highly utilized and could become limited or insufficient resources. Unfortunately, only a limited number of overhead cranes can be fitted in each factory's assembly row. Therefore, pure human resources or higher-performance overhead cranes may become unavoidable alternative resources.

This chapter studies human performance in performing plate assembly tasks by using a regular overhead crane and three alternative methods. They are:

1.) One person without an overhead crane

2.) Two-person team without an overhead crane

3.) One person with a spring-equipped overhead crane

The previous chapter shows how the difficulties of plate assembly tasks can be measured. However, in heavy plate assembly tasks, the weight of the plate may become a factor that extends the assembly times. The main objective of this chapter is to measure the performances of the workers at different levels of task difficulties and plates' heaviness by using the four assembly methods.

4.2 Experimental Hypotheses

The following hypotheses were formulated:

Hypothesis 1: The relationships between movement time (MT) and index of difficulty (ID) are linear at each level of plates' heaviness.

Hypothesis 2: Different assembly methods require different assembly times at the same level of plates' heaviness

Hypothesis 3: The movement times increase as the plates' heaviness increases.

4.3 Participants

Five male volunteer participants, ranging in age from 24 to 32 were requested to perform four sets of experiments. All were graduate students at Virginia Tech. Prior to the experiments, the participants were required to fill out the questionnaire to indicate their health status. If a person had or had previously experienced muscle or back injuries, he was not qualified as a participant for these experiments.

4.4 Apparatus

Four 12"x12" and four 18"x18" plates were cut for these experiments. The first four plates weight 10, 20, 30, and 40 Lbs. and have the thicknesses of ¼, 2/4, ¾, and 1 inch, respectively. They were used in the experiments where the overhead crane was absent. The heavier plates were assigned to the tasks that required an overhead crane. The later four plates weight 23, 46, 69,and 92 Lbs. and have the thicknesses of ¼, 2/4, ¾, and 1 inch, respectively.

Several sets of target lines were created on wooden boards by using white tapes. The thicknesses of the tapes were calculated form the thicknesses of the plates plus the allowances. Four of the target lines were located 6" away from each other to form one set of target lines.

The last pieces of the equipment were an overhead crane, a gripper (16 Lbs.), and a hook (20 Lbs.). Springs were also used in the last set to create vertical flexibility. They were seven different springs that have stiffness as follows: 4, 13, 27, 32, 45, 55, and 76 Lb./Inch. The appropriate springs were assigned to a particular task according to the plates' heaviness.

4.5 Experimental Design

Four sets of experiments were conducted: One person without an overhead crane, Two-person team without an overhead crane, One person with a regular overhead crane, and One person with a spring-equipped overhead crane. In each set, the index of difficulty and the plates' heaviness were varied. The movement times required to complete the tasks of the four methods at each level of difficulty and heaviness were recorded. The results of these experiments would show the human performance in using different methods to assemble the plate at different levels of difficulties and plates' heaviness.

4.6 Experimental Procedures

In each set of experiments, the participants were asked to tap the plate onto each of a pair of target lines as fast as possible within 20 seconds. However, this research emphasized accuracy rather than speed, thus the participants were required to located the plate within the allowed space before tapping it to the other strip. The number of taps was recorded to indicate the speed of humans in performing a particular task. Prior to the experiments, each participant was asked to perform the tasks until he get used to the tasks, to eliminate the bias effect since the participant may perform the tasks faster in the later runs. During the experiment, the plate needed to be held vertically at all times. Between each run, the participants were given a sufficient resting period to relax their muscles to get rid of the fatigue-caused errors.

1.) One person without an overhead crane:

The participants were asked to perform the tapping tasks similar to those in chapter 3 but four different plates were used: 10Lbs, 20Lbs, 30Lbs,and 40Lbs. The index of difficulty values were varied by the increasing of clearances (1/16”, 1/8”, and ¼”). The amplitude was fixed at 6 inches.

2.) Two-person team without an overhead crane:

The participants were asked to perform the tasks in a group of two. They had to stand facing each other holding the plate in front (Figure 4.1). The same four plates were used as in the previous set. The index of difficulty values were varied by the increasing of amplitude (6”, 12”, and 18”). The clearance was fixed at 1/8 inches.

Figure 4.1: Two-person team without an overhead crane

3.) One person with a regular overhead crane:

Each participant was asked to perform the tasks by holding the plate with one hand and holding the overhead crane controller with the other (Figure 4.2). The plate was manipulated in vertical direction by pressing the Up and Down buttons on the controller. Four heavier plates were used: 23Lbs, 46Lbs, 69Lbs,and 92Lbs. The increasing amplitude (6”, 12”, and 18”) varied the index of difficulty values. The clearance was fixed at 1/8 inches.

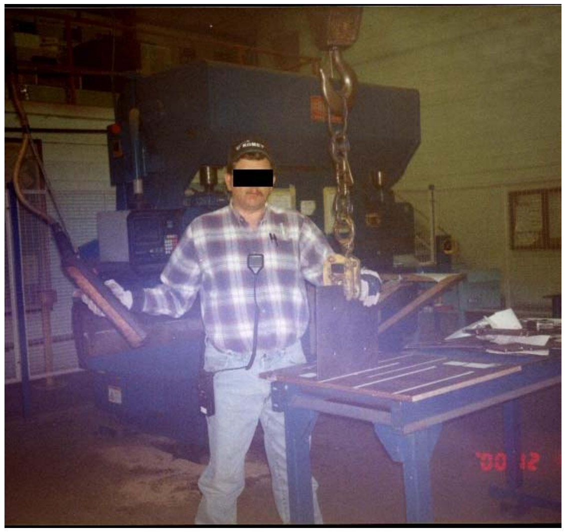

Figure 4.2: One person with a regular overhead crane

4.) One person with a spring-equipped overhead crane:

Each participant was asked to perform the tasks similar to the previous set. However, with the help of the spring, the participant did not have to use the controller to move the plate up and down. The same four plates were used. The increasing amplitude (6”, 12”, and 18”) varied the index of difficulty. The clearance was fixed at 1/8 inches.

Figure 4.3: One person with a spring-equipped overhead crane

4.7 Results and Analyses

The numerical results were recorded in tables E1 to E4 in appendix E. Figures 4.4 to 4.7 show the relationships between average movement times of all participants and the index of difficulty from the four experimental sets. The relationships between weights and the average movement times from the four methods were plotted in figure E1 to E4 in appendix E.

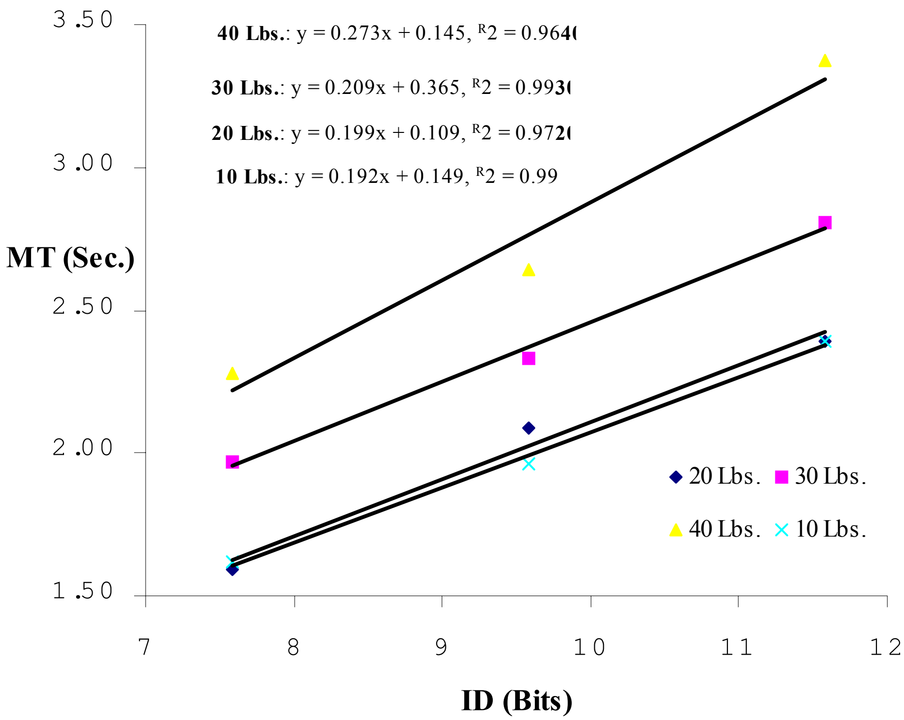

Figure 4.4: One-person method: ID & MT Relationships

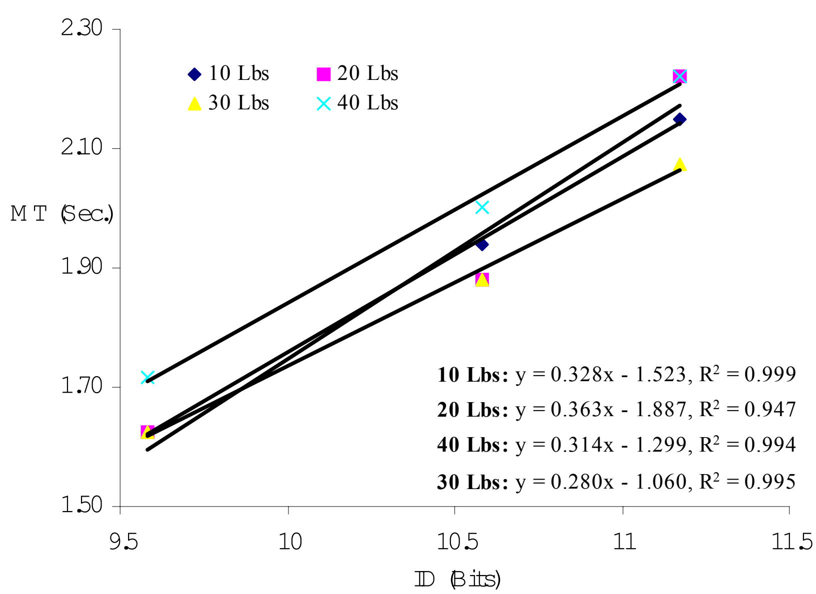

Figure 4.5: Two-person team method: ID & MT Relationships

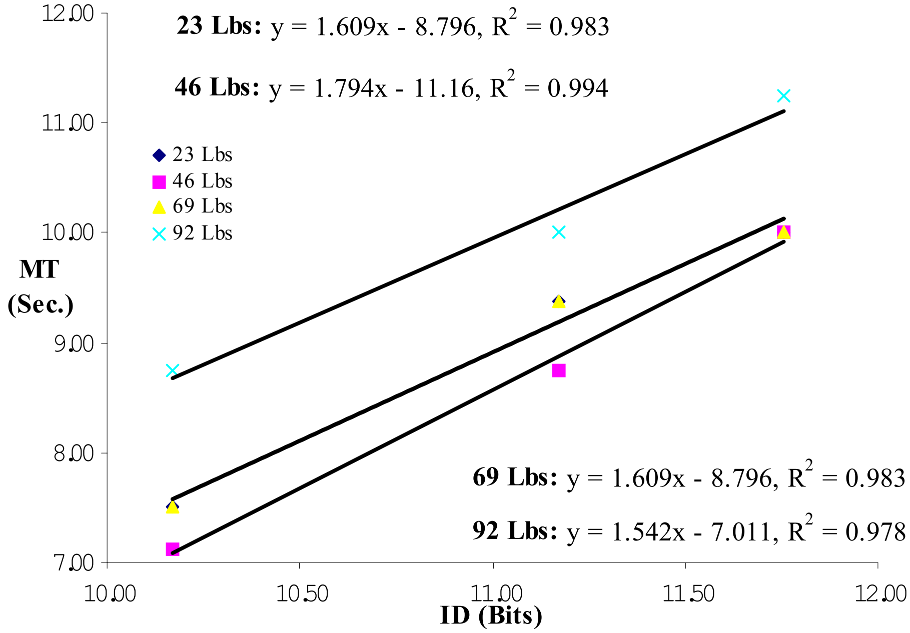

Figure 4.6: One person with an overhead crane method: ID & MT Relationships

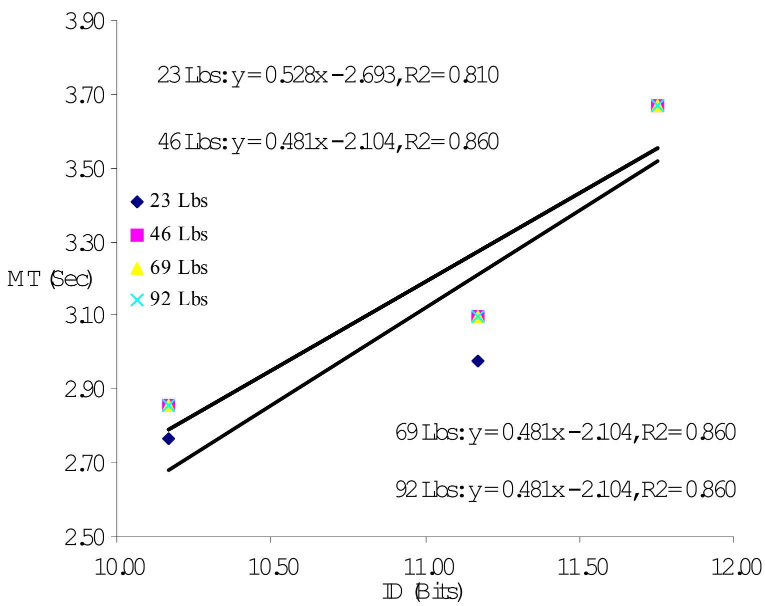

Figure 4.7: One person with a spring-equipped overhead crane method: ID & MT Relationships

From the R^2 values shown in the figures above, it is clear that the relationships between the movement times and the index of difficulty are linear in every method conducted and at all level of heaviness. It means that the movement time can be accurately predicted if the weight, index of difficulty, and method are known.

For the first experimental set, One-person method, figure E1 in appendix E shows that at the same level of tasks' difficulty, the movement times required to assembly the 10Lbs and 20Lbs plates are approximately the same. The movement times start to increase constantly once the weight goes beyond 20Lbs. This indicates that a person can perform a plate assembly task at the same speed for a plate that weights less than 20Lbs. More details concerning this performance-changing point are explained in the next chapter. Therefore, from figure 4.4, the movement time to assemble a plate that weights less than 20Lbs can be predicted as:

$$MT = 0.1 + 0.2\ ID \qquad (14)$$

Once the weight goes beyond 20Lbs, figure E1 shows that the movement times increase constantly as the weights increase at the rate of 0.03 Sec/Lb. Therefore, the movement time required to assemble the plate that weights ranging from 20Lbs to 40Lbs can be calculated as:

$$MT = 0.1 + 0.2\ ID + 0.03\ (Weight - 20) \qquad (15)$$

For the Two-person team method experiments, figure E2 shows no difference of the movement times of 10 to 40Lbs plates. Therefore, from figure 4.5, the movement time could be calculated as:

$$MT = -1.5 + 0.3\ ID \quad (16)$$

With a regular overhead crane, the participants required approximately the same amount of time to assemble the first three lighter plates. The excessive moment of inertia of the heaviest plate could make the assembly time longer. Hence, from figure 4.6, the movement time required to assemble a plate that weights up to 69Lbs by a regular overhead crane could be calculated as:

$$MT = -9 + 1.6\ ID \quad (17)$$

With a spring-equipped overhead crane, the participants required approximately the same amount of time to assemble all four plates. Thus, from figure 4.6, the movement time required to assemble a plate that weights up to 92Lbs by using a spring-equipped overhead crane could be calculated as:

$$MT = -2.1 + 0.5\ ID \quad (18)$$

Since the offsets in equations 16, 17,and 18 are negative values, these equations would be well applied to the tasks that have the index of difficulty ranging approximately from 9 to 12. However, these equations cover most of the plate assembly tasks since most of the index of difficulty of these tasks fall in the range from 9 to 12.

In the case where all accessible overhead cranes are occupied with other tasks, humans might become the only available resources. Figures E5 to E8 in appendix E show the movement time comparisons of One-person method and Two-person team method at each level of heaviness from 10Lbs to 40Lbs. The graphs indicate that for every plate weight, the Two-person team assembled the plates faster. The assembly times of both methods are not much different with the 10Lbs and 20Lbs plates but the differences of the assembly times between two methods start getting greater once the weights go beyond 20Lbs. With the 40Lbs plate, the Two-person team method has the assembly speeds almost double of those of One-person method. However, using just one person to assemble the parts that weight 40Lbs or less is economically attractive.

Even though an overhead crane is available, other alternative assembly methods might be better choices when the parts are not too heavy to lift. Figures E9 and E10 show the movement time comparisons of the four methods at the level of heaviness of approximately 20Lbs and 40Lbs. Both figures show that without a spring, operators require much more time to finish the tasks comparing to the other alternatives. At the 20Lbs level, humans assemble the plate faster without an overhead crane. At the 40Lbs level, Two-person team method is the fastest method to assemble the plate.

In addition, the spring-equipped overhead crane does not help reduce the assembly times for a person to assemble 20Lbs and 40Lbs plates. This shows that even though the weights of the plates are mostly supported by the spring, the assembly times still remain the same, which reinforces the experiments conducted by Wong (1994). Wong found that the movement time varies as the mass of the part, not the weight.

4.8 Discussion

The results demonstrate that the relationships between movement times and the index of difficulty are linear at every level of heaviness in the four methods to assemble heavy plates. Therefore, once the method, plate's weight, and index of difficulty are known, the assembly time can be accurately estimated.

In most methods, the assembly speeds do not reduce as the weights go up. However, in the One-person method experiments, the performance of a person seems to reduce after the heaviness goes beyond 20Lbs. This critical point might also appear in other methods. Therefore, the next chapter was created to investigate in detail this point with respect to the methods mentioned above.

As overhead cranes might become limited resources, human forces or better overhead cranes are the inevitable options. This research shows that, without the crane, humans can assemble the plate faster. However, the workers might get hurt from lifting the heavy parts. Therefore, attaching a spring between the hook and the gripper would be a good solution to insure both safety and speed.