PIPE MANIPULATOR: PRODUCTIVITY IN A MATERIAL YARD ENVIRONMENT

by

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REPORT

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ABSTRACT

This study of the Pipe Manipulator was undertaken to determine if it could improve the productivity of pipe movement at the Dow Corporation Freeport, Texas material laydown yard. The goals of the study were threefold: (1) Assess the productivity of the Pipe Manipulator versus the standard Cherry Picker in performing repetitive pipe unloading and stacking activities; (2) Assess the safety aspects of the Pipe Manipulator versus the Cherry Picker; (3) Identify possible improvements and other focused tasks amenable to the Pipe Manipulator.

Upon analyzing the equipments' performances, the following conclusions were obtained: (1) The Manipulator could not compete with the Cherry Picker in pipe movement productivity in its current configuration and usage mode even though the crew size was reduced from 5-6 workers for the Cherry Picker, to 1-2 workers for the Manipulator. The primary deficiency in the Manipulator's performance was its inability to achieve multi-pipe lifts like the Cherry Picker, however this can be changed with relatively small modifications; (2) The unloading operation's safety could be significantly improved by the Manipulator since workers are removed from all possible unsafe conditions, and, therefore, are prevented from committing unsafe acts.

Several improvements are recommended in this report to enhance the manipulator's performance. It is recommended

that these improvements be implemented and further productivity studies be performed to evaluate the improvements, and to determine if advances can be achieved.

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CHAPTER ONE

INTRODUCTION

Background

A decade ago, the Dupont Corporation envisioned a piece of equipment that could more efficiently position pipe in an industrial plant construction environment. Up to this point, hydraulic cranes (or "Cherry Pickers") were the standard equipment for pipe unloading , lifting, and positioning. The Cherry Picker approach required a pipe fitting crew to perform an assembly task, and a lifting crew composed of two laborers to rig the pipe, and a crane operator. What Dupont envisioned was a machine which required only one worker in the lift crew: the crane operator. A collection of engineers developed a manipulator attachment which fit on the boom of a crane in place of the hoist. The assembled machine would give a single operator complete hydraulic control over gripping, locating, and orienting various sections of pipes.

Several studies, (Glass, 1984; Hughes, 1987; Fisher, 1989; Hughes, 1990) have been conducted analyzing and assessing the productivity of the manipulator. Several deficiencies were discovered which limited the productivity of the equipment in industrial plant construction environments. This paper will focus on the application of the manipulator in the more simplified and repetitive environment of a pipe laydown yard.

The Pipe Manipulator is an electro-hydraulically controlled, multi-function, large bore pipe handling device which attaches to the boom nose of a 22 ton rough terrain crane. It is all steel construction consisting of a gravity leveled operator's basket, a support frame, a two section telescoping boom, lift cylinders, and a manipulator head assembly (Figure 1.1).

The study by Glass (1984) noted that the basket, attached to the manipulator, introduced a number of limitations (these limitations are discussed later in this report). To eliminate these problems, the basket was removed for this study. The control panel, previously located in the basket, was removed and attached to the equipment via 75 foot electrical cables and pneumatic tubing. This new control arrangement allows the operator to work from the ground, and provides him with the flexibility to locate the controls at a point most advantageous for safety, vision and productivity.

The control panel allows complete control of both the manipulator attachment and the crane. The panel consists of three crane boom functions, six manipulator functions, a hand throttle, a kill switch, and a stability alarm (Figure 1.2). The operator has the capacity to swing the manipulator

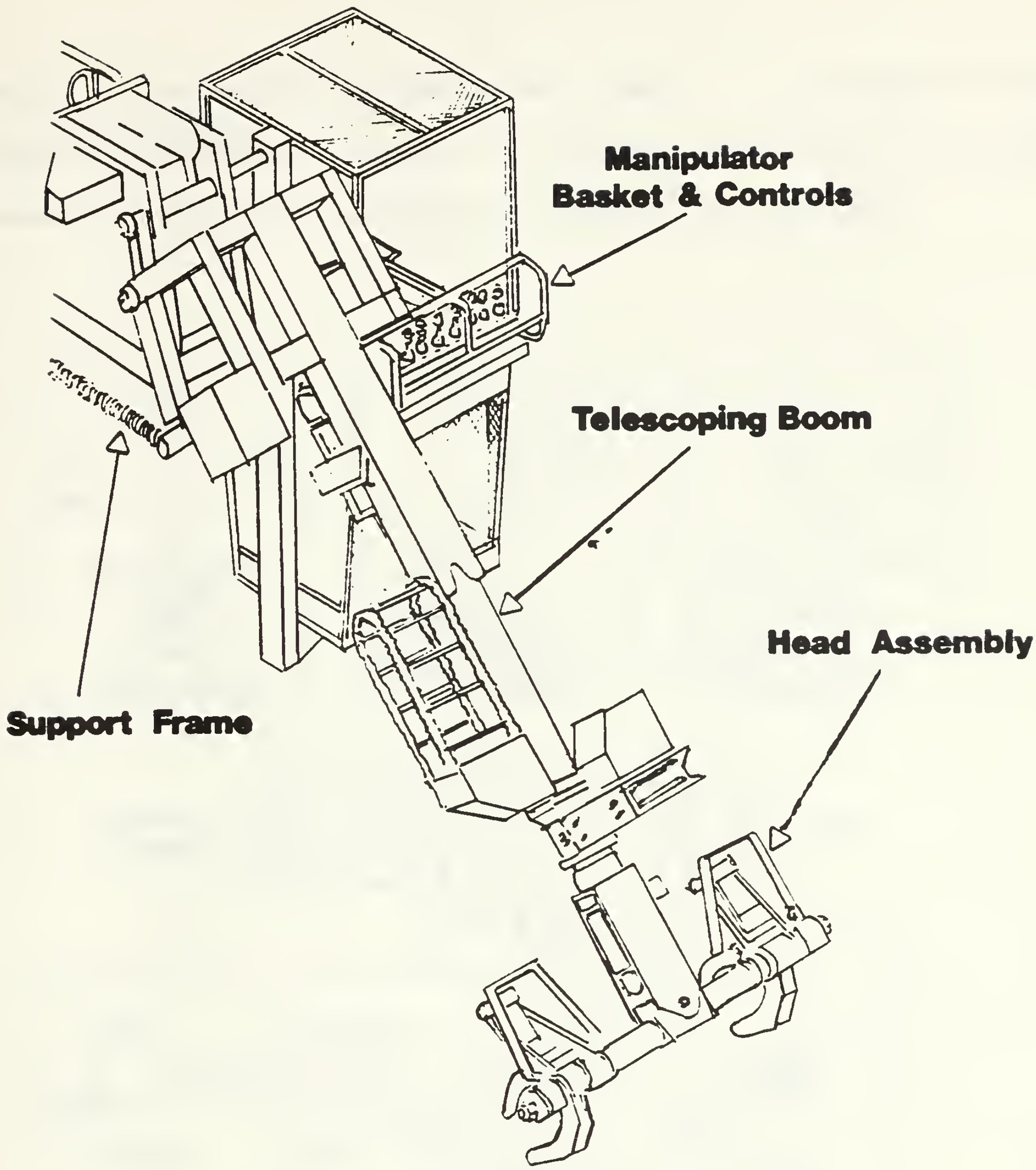


Figure 1.1: Pipe Manipulator and Components (Glass 1984)

to a flat bed delivery truck, grab a section of pipe, lift and swing to the designated laydown area, and position the pipe into the yard pile.

The power to the Manipulator is supplied via an extendable power track mounted on the right side of the crane. The power track supports three lines which deliver

hydraulic, pneumatic and electrical power. The support frame has quick disconnect couplers to provide continuity of power and ensure easy installation and removal of the unit.

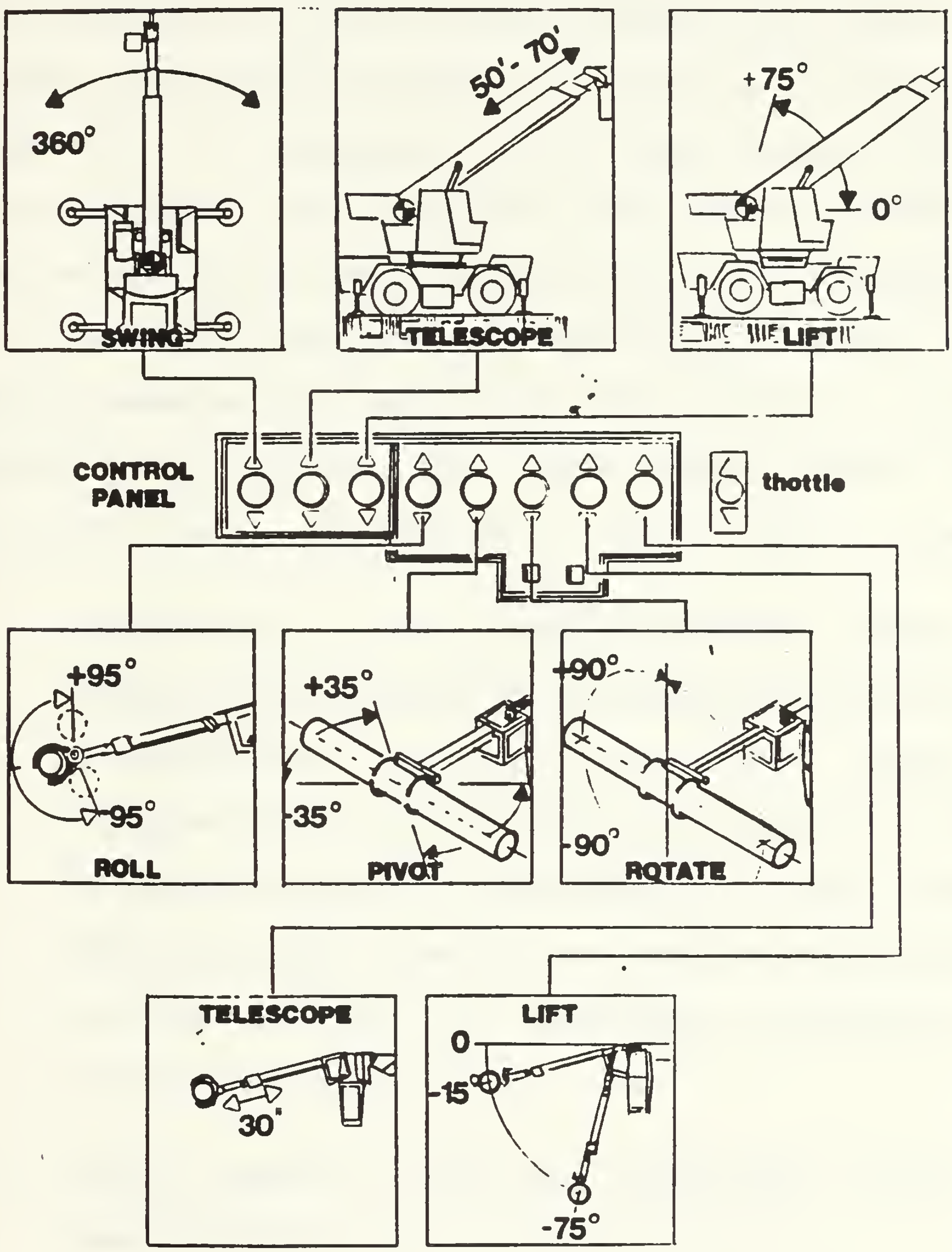


Figure 1.2: Manipulator Controls and Functions (Glass 1984)

Purpose of the Study

Based on the results of several studies, (Fisher 1989; Glass 1984; Hughes 1987; Hughes 1990), the Pipe Manipulator possessed several limitations regarding its potential as a complete replacement for a Cherry Picker, so rather than immediately attempting to design and develop a better piece of equipment, or initiating major modifications to the existing equipment, both of which would be very costly, it was decided to first perform further focused productivity tests on simpler construction activities. This study, therefore, assesses the merits and deficiencies of the Pipe Manipulator in a construction site pipe laydown yard. Specifically, the objectives are to examine:

1. Productivity of the Pipe Manipulator versus the standard Cherry Picker in performing repetitive pipe unloading and stacking activities. (Areas of analysis will consist of equipment preparation time, equipment manning requirements, and tasking completion time. Results are used to determine cost and time savings, if applicable, resulting from the new equipment.)

2. Safety aspects of the Pipe Manipulator versus the Cherry Picker.

3. Identification of other focused tasks amenable to the Pipe Manipulator.

Study Method

This study was broken down into the following stages:

PRE-ASSESSMENT	-	Analyze past studies performed on equipment to become familiar with capabilities and deficiencies of equipment
PRE-TEST	-	Conduct simple pipe handling tasks to provide operator and researcher hands on experience with equipment's capabilities.
FIELD TESTS	-	Conduct focused pipe handling tasks to obtain productivity and safety data on traditional equipment and the Pipe Manipulator.
ASSESSMENT	-	Analyze data and develop an assessment.

CHAPTER TWO

CURRENT OPERATIONS

A yard at Dow Corporation's Freeport facility in Texas was used to conduct the experiments on which this study is based. Currently, pipe handling at the Dow Corporation material laydown yard is accomplished using standard 15 Ton hydraulic cranes, "Cherry Pickers", with various sling attachments. The current on-site Cherry Picker is capable of handling pipe loads weighing up to 20,000 pounds. In comparison, the Manipulator's capacity is 1,600 pounds.

The standard pipe length delivered to the material yard is 40 feet. This extended length, as opposed to the shorter 20 foot lengths, reduces the number of welds required of the construction contractors during assembly operations. However, this additional length places the Manipulator at a disadvantage in that the increased weight, corresponding to the increased length, reduces the range of pipe diameters which the Pipe Manipulator can safely handle. The shaded areas, referring to 20' and 40' pipe lengths, of Figure 2.1 illustrate the range of pipe sizes (thickness and diameter) which the Manipulator is capable of lifting safely. Also noted in the chart for reference are the most common pipe thicknesses: Standard (STD), Extra Strong (XS), and Extra Extra Strong (XXS). The XXS thickness ends prior to the 8" diameter pipe since this category is not appropriate for

these larger pipe sizes.

The current pipe unloading operation requires a crew of five: one Cherry Picker operator, two riggers on the flatbed, and two workers on the ground for pipe control and placement. With respect to the objectives stated previously, two questions are asked; (1) Can the labor requirements of 5 personnel be reduced with the use of the Pipe Manipulator?,

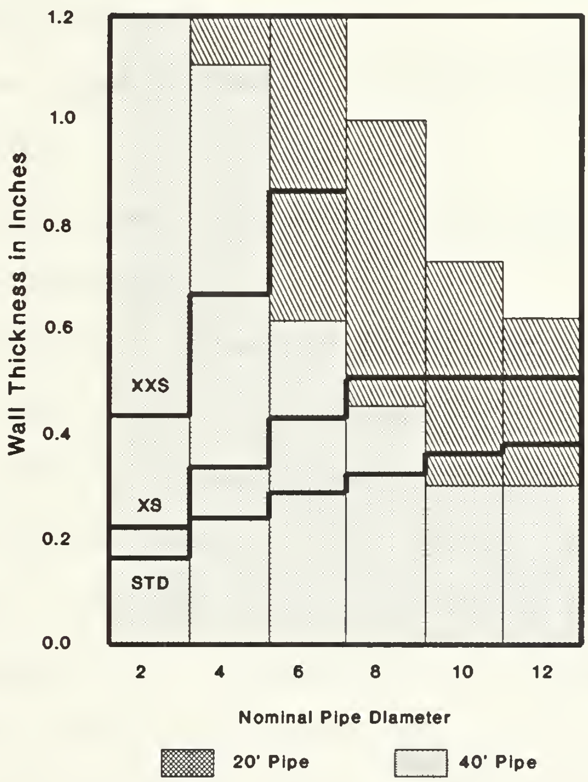


Figure 2.1: Design capacity of the Manipulator

and if so, (2) will the pipe unloading operation become safer with the reduction of the personnel working on the flatbed and on the ground?

Pipe Unloading Operation

Suppliers deliver pipe in standard flatbed delivery trucks. The pipe arrives in several configurations including:

1. Pipe stacked into a pyramid formation with no spacers between the layers, and with pipe resting on pipe.
2. Pipe can be stacked in layers with wood spacers separating each layer.
3. Large pipe placed in a single layer, resting on the flatbed.
4. Smaller pipe in bundles, with metal bands holding the pipe together.

In most situations, standard hold down chains are used to secure the load while in transit. Also, when pipe is delivered stacked, flatbed side stakes are often employed to arrest any lateral motion of the pipe. The configuration of pipe delivery, and the weight of the pipe will influence the type of rigging to be employed during offloading.

Several factors influence the positioning of the crane relative to the delivery truck during offloading operations:

1. Maneuvering room for the delivery truck
2. Space available to position the crane relative to the truck
3. Orientation of the pipe on the ground

4. Space available to traverse the pipe from truck to ground
5. Weight of pipe

The goals are to (1) reduce the movement of the boom while unloading, (2) reduce the horizontal extension of the boom for stability reasons, and (3) reduce the distance required to move the pipe. The reduction in movement of equipment and material results in higher productivity, and improved safety. These five factors are also considered when determining the placement of the Pipe Manipulator for unloading operations.

Based on the five positioning factors, several equipment arrangements can be employed, (Figure 2.2). When working in a confined area where equipment access is restricted to only the access road between lots of material, the crane will position itself behind the flatbed. When more space is available between the access road and the final laydown area, the crane is positioned alongside the flatbed with the final laydown area on the opposite side of the crane. The crane can also be set up along side the flatbed as above, except that the pipe is lifted and placed on the far side of the truck, away from the crane. To unload pipe from the flatbed, two riggers are positioned on the bed to attach the sling to the pipe, two to three workers are positioned on the ground to guide the pipe during placements, and one equipment operator is required.

The primary types of slings used in the yard are chain

link with hook ends, and nylon straps. The hook type lifting device is used as much as possible due to its ease in attaching the device to the pipe, and the safety benefit of allowing the riggers to work near the ends of the pipe rather than along side. The nylon straps are employed when extremely heavy pipe is lifted which is beyond the capacity of the chains, and when attempting to lift more than one pipe length in a single lift. Several rigging configurations are shown in Figure 2.3.

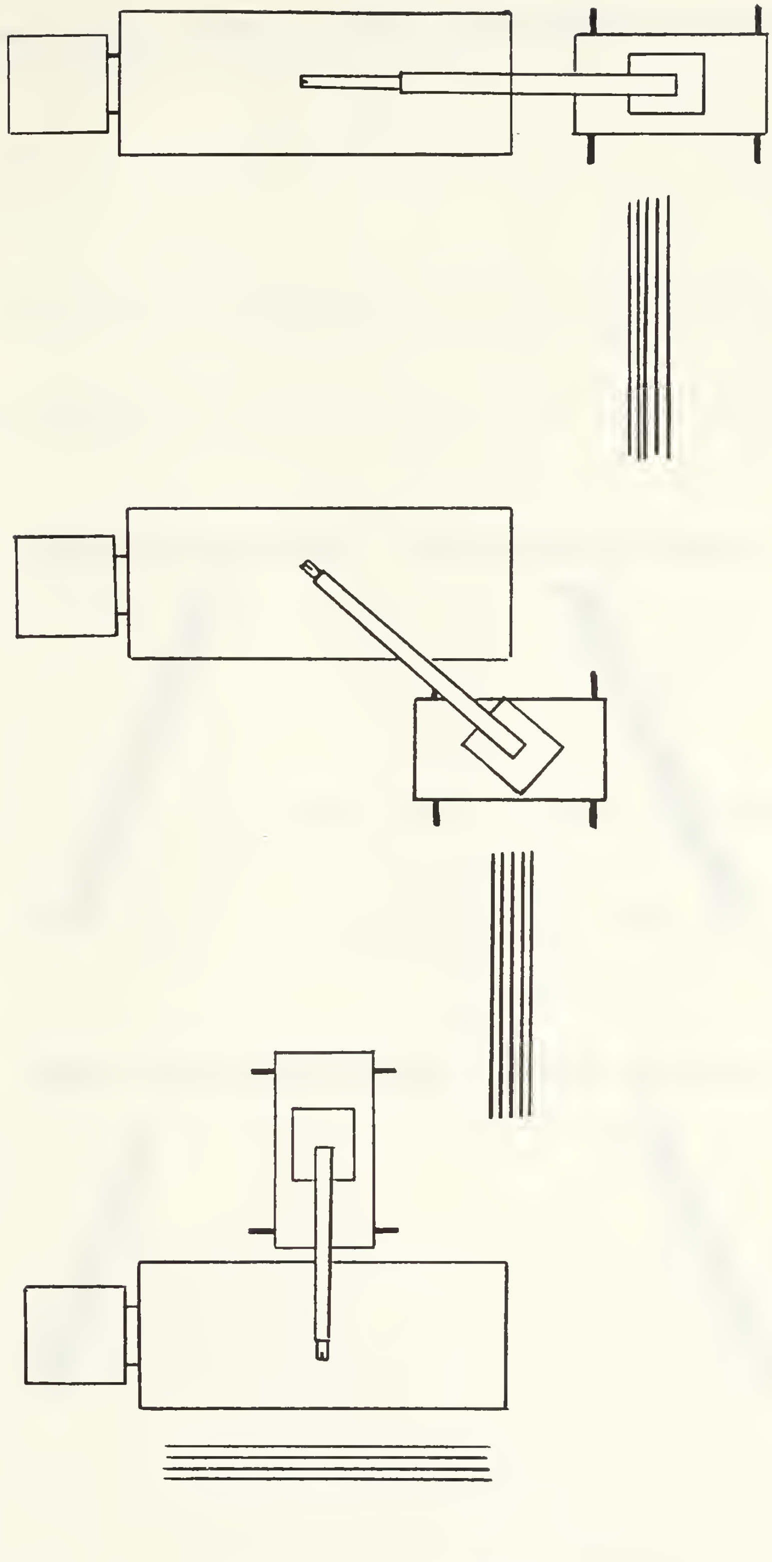
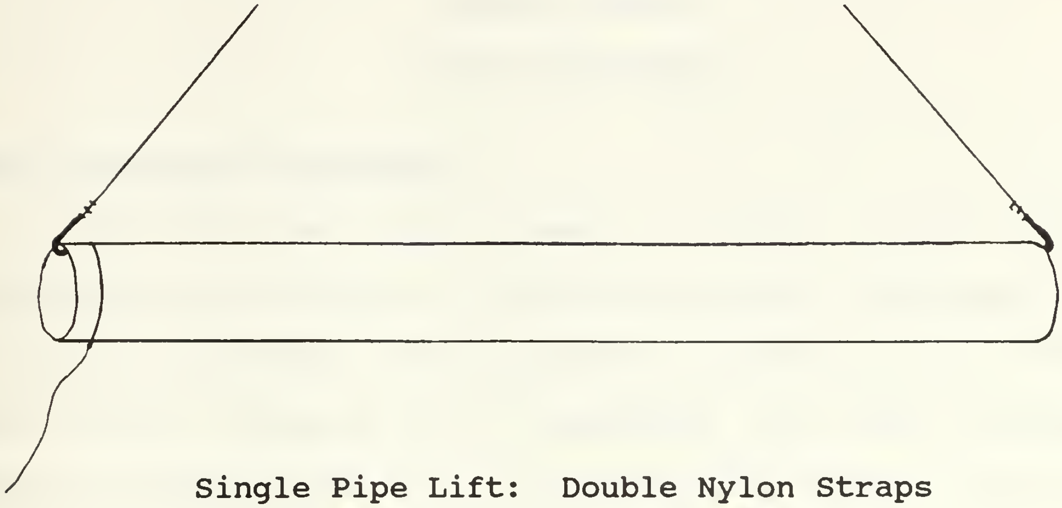
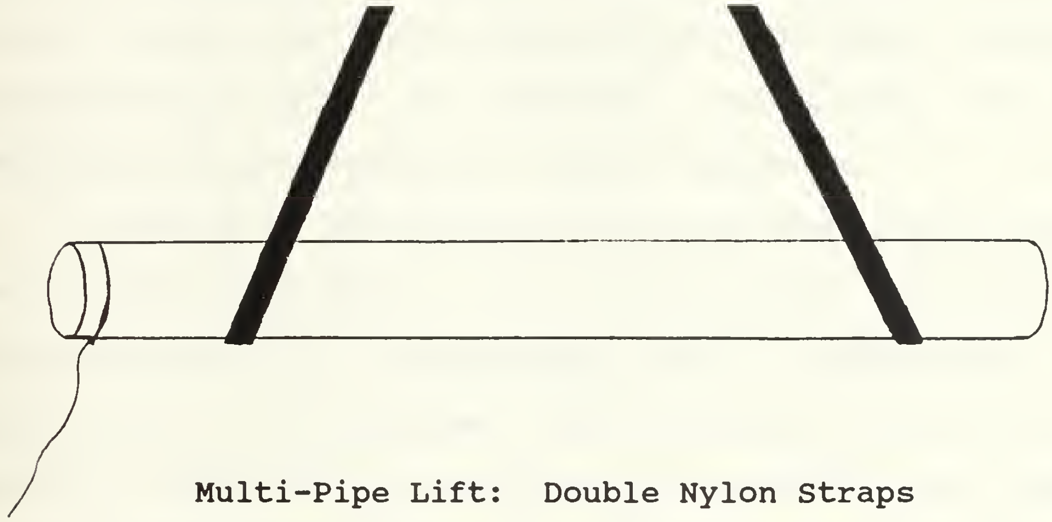


Figure 2.2: Equipment Configurations

Single Pipe Lift: Chain Link with Hook Ends



Single Pipe Lift: Double Nylon Straps



Multi-Pipe Lift: Double Nylon Straps

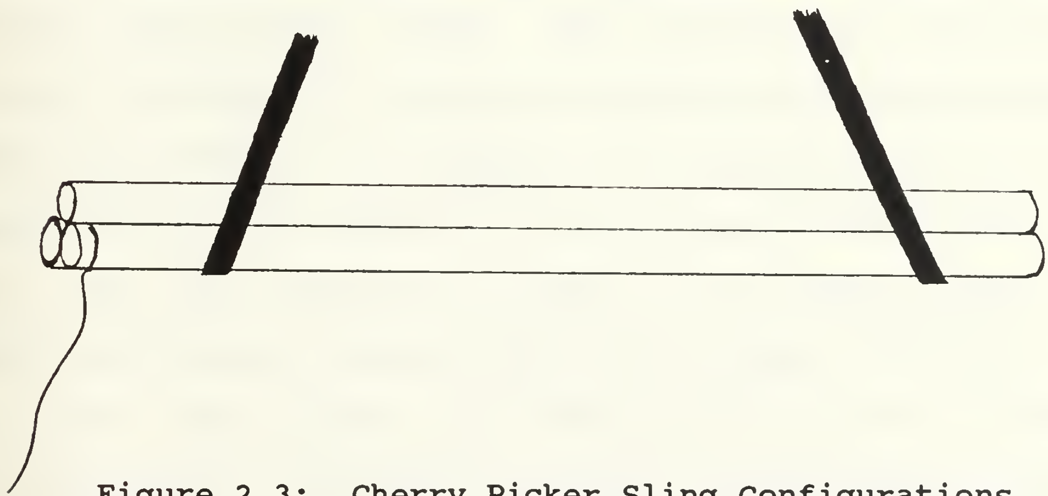


Figure 2.3: Cherry Picker Sling Configurations

CHAPTER THREE

DATA ACQUISITION

Data Gathering Techniques

Two techniques were used to gather data on the equipments' performance: 1) Field tests were videotaped using a standard portable video cassette recorder; and 2) Formal and informal interviews of management and field personnel were conducted. The goal of the filming was to record the Cherry Picker and Pipe Manipulator performing identical operations so that an accurate comparison of their performance and productivity could be obtained.

It should be noted that time-lapse photography was not used in this research, even though it is considered an effective tool in measuring work performance and productivity. The equipment and processing services can be found, but the cost is prohibitively expensive when compared to the costs of VCR taping. The drawback of a standard VCR is that analysis of the tape is much more tedious and time consuming compared to analysis of time-lapse film. Time-lapse film can be viewed at a multitude of speeds such that an 8 hour work day can be viewed in as little as one hour, while VCR analysis requires the full 8 hours to review.

This "full" review time using the VCR was not a drawback in this study. The taping sequences are of short durations as opposed to entire 8 hour days, and the VCR exposes

equipment movement details that time-lapse photography might miss.

To aid in the analysis of the taped evolutions, two data collection forms were used to make field notes and sketches of the events. Also, a data reduction form was used during the analysis of the tape. Examples of these forms are shown in Figures 3.1, 3.2, and 3.3.

Productivity Analysis

To perform a productivity analysis, both the inputs and the outputs of the work process must be measured. The rate of productivity is the ratio of the inputs to the outputs. In this case, the inputs analyzed are manhours, and equipment hours while the output is the length of pipe unloaded. The work sequence is reduced to quantities of input and output data.

Productivity Ratio

The input/output data is applied to simple equations to arrive at the **Productivity Ratio (PR)** of the equipment. The equations are as follows:

$$\text{Productivity Ratio (PR)} = \frac{\text{Input}}{\text{Output}} \; ; \; \frac{\text{Manhours}}{\text{\# Pipes}} \; ; \; \frac{\text{Equipment Hrs}}{\text{\# Pipes}}$$

Productivity improvements are reflected by a decreasing Productivity Ratio. This is in turn accomplished by reducing

Figure 3.1: Data Collection Form, Filming Record

FILMING RECORD

Project: Pipe Manipulator Prod.
Owner: U of T
Equipment: Pipe Manipulator
Site Location: Freeport Tx
Date: 19 Nov 92

Tape Id.:
Tape Type:
Tape Speed:
Elapsed Time:
Filming Distance:

Construction Operation Filmed

General Description: Unloading XS, 2 inch diameter, 40' long carbon steel pipe

Sketch of Operation:

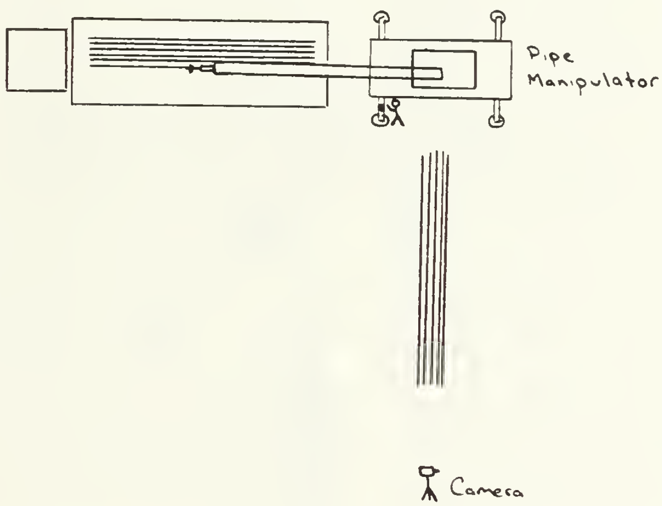


Figure 3.2: Data Collection Form, Crew Composition

CREW COMPOSITION RECORD

Crew Member:	Personnal Description:
1. Operator	Manipulator Operator
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

Sketch of Personnel Location during Filming:

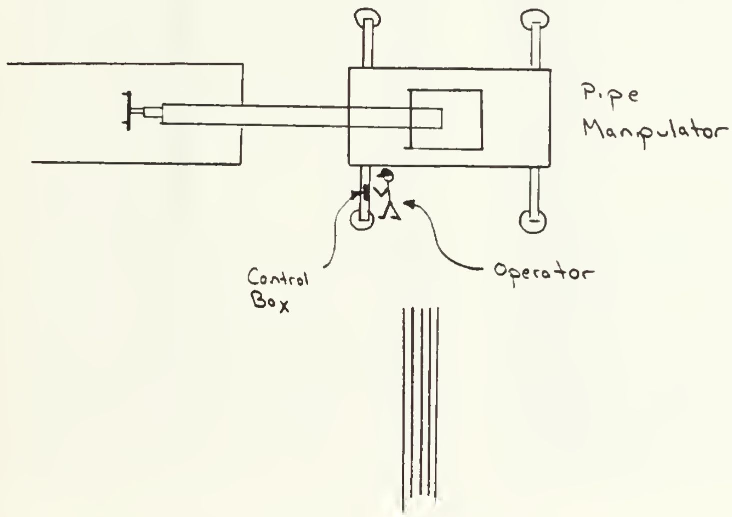


Figure 3.3: Data Analysis Form

ANALYSIS OF FILMING

Project: Pipe Manipulator Prod.
Owner: U. of T
Equipment: Pipe Manipulator
Material: XS, 2" dia, 40' Steel pipe
Date filmed: 19 Nov 92

Tape ID.:
Elapsed Time:
Elapsed Tape:
Time Interval:
Date Analyzed: 20 Nov 92

Tape Time Hour	Tape Time Min	Tape Time Sec	Time Hour	Time Min	Time Sec	Description of Interval
1	11	45				
	12	20			25	Grasp
	13	30		1	10	Swing & Release
	14	19			49	Return
	15	00			41	Grasp
	16	30		1	30	Swing & release
	17	20			50	Return
	18	20		1	00	Delay to adjust tubing
	18	42			22	Grasp
	20	02		1	20	Swing & release
	20	44			42	Return
	21	14			30	Grasp
	22	35		1	21	Swing & release
	23	15			40	Return
	23	55			40	Grasp
	25	16		1	21	Swing & release
	26	20		1	04	Return
	27	00			40	Grasp
	28	00		1	00	Swing & release
	28	55			55	Return
	29	35			40	Grasp
	31	54		2	19	Swing & release
	32	50		1	04	Return
	33	13			23	Grasp
	34	22		1	09	Swing & release
	35	35		1	13	Return
	35	45			10	Grasp
	36	34			49	Swing & release
	37	25			51	Return
	37	46			21	Grasp
	39	22		1	36	Swing & release
	40	20			58	Return
	41	23		1	03	Grasp
	42	19			56	Swing & release
	43	14			55	Return
	43	39				Grasp

Camera battery empty

the input rate (numerator), increasing the rate of output (denominator), or both.

Performance Factor

The **Performance Factor (PF)** is a ratio which expresses actual work productivity as compared to an estimated unit rate of work accomplishment. A Performance Factor of 1.0 would reflect that actual work performance equaled that estimated. A Performance Factor greater than 1.0 would indicate better than estimated performance, and less than 1.0, poorer performance.

$$\text{PERFORMANCE FACTOR} = \frac{\text{Planned or Estimated Unit Rate}}{\text{Actual Unit Rate}}$$

In the case of the Pipe Manipulator, there is no historic data to determine an estimated unit rate of the equipment in a pipe laydown yard. To compare the productivity of the Cherry Picker and Pipe Manipulator, the "estimated" unit rate in the PF equation will be that of the Cherry Picker, while the "actual" unit rate will be that of the Pipe Manipulator. This will allow an easy comparison of the productivity of the equipment. A Performance Factor greater than 1.0 indicates a more productive performance by the Pipe Manipulator, while a Performance Factor less than

1.0 indicates a more productive performance by the Cherry Picker.

$$\text{PERFORMANCE FACTOR} = \frac{\text{Cherry Picker Unit Rate}}{\text{Pipe Manipulator Unit Rate}}$$

Improvements in productivity by the Pipe Manipulator are reflected by a reduction in its productivity unit rate, and larger or increasing performance factor values.

Economics

Financial savings data are obtained in two forms: labor cost, and equipment cost. Calculating the labor cost is simply a matter of multiplying hourly wage rates of each worker by the manhour productivity ratio (manhours/pipe) obtained from an unloading operation. The equipment cost is more difficult. The hourly equipment cost must take into consideration capital costs, operating costs, and maintenance costs, and reduce these to an hourly cost. This hourly cost is multiplied by the equipment productivity ratio (equipment hours/pipe) to obtain the equipment cost per pipe.

After adding the labor and equipment cost/pipe, the equipments' economic productivity can be compared to determine the most cost effective means of unloading pipe.

The Five Minute Rating

The Five Minute Rating is not a productivity measurement per se since it does not measure the outputs of an activity, but it is an effective method for making a general work effectiveness evaluation. The purpose of the Five Minute Rating in this report is to measure the effectiveness of a crew during the pipe unload operation. It is based on the summation of observations made in a short study period.

Individuals in a crew are observed during consecutive blocks of time, from 30 seconds to several minutes, and the ratio of delay time to total observed time is recorded. The sum of effective times for each individual and for the crew, divided by the total time of observation, will then give an effectiveness ratio, or the effective percentage for the individual and crew. This percentage reflects the amount of time an individual or crew is actually busy. It does not necessarily demonstrate the efficiency of the crew or operation, since being busy is not synonymous with using a productive method, but it does point to areas of delay which can be eliminated.

CHAPTER FOUR

SUMMARY OF CONDUCTED TESTS AND RESULTS

Introduction

Several visits were made to Dow Corporation's Freeport Texas material laydown yard to observe and film unloading operations. During these visits, the equipment operator was observed learning the control system, and the Manipulator was observed moving various size pipes about the yard. Due to scheduling difficulties, only one pipe delivery actually coincided with the availability of the Manipulator, thus comparative data is limited.

This delivery consisted of seven bundles of 2 inch diameter extra strong pipe, each pipe 40 feet in length. The total length of the shipment was 8860 feet. The Cherry Picker unloaded six full bundles (31 pipes per bundle), and one half of the seventh. The Manipulator unloaded the remaining loose pipe. As shown in Figure 4.1, the Cherry Picker used a double sling rigging system to lift one bundle at a time, each bundle weighing approximately 6200 pounds. The Manipulator unloaded the remaining pipe one length at a time, each pipe weighing approximately 200 pounds (see Figure 4.2).

To analyze the unloading operation, the evolution was broken into several movements. The Manipulator movements consisted of (1) grasping, (2) lifting, moving and

releasing, and (3) returning. The Cherry Picker movements were (1) attaching the sling, (2) lifting and moving, and (3) detaching sling and returning. Once the film had been broken into these segments, calculations were made to determine the average duration and manhours required to move a length of pipe. Once manhours were determined, equipment productivities could be compared.

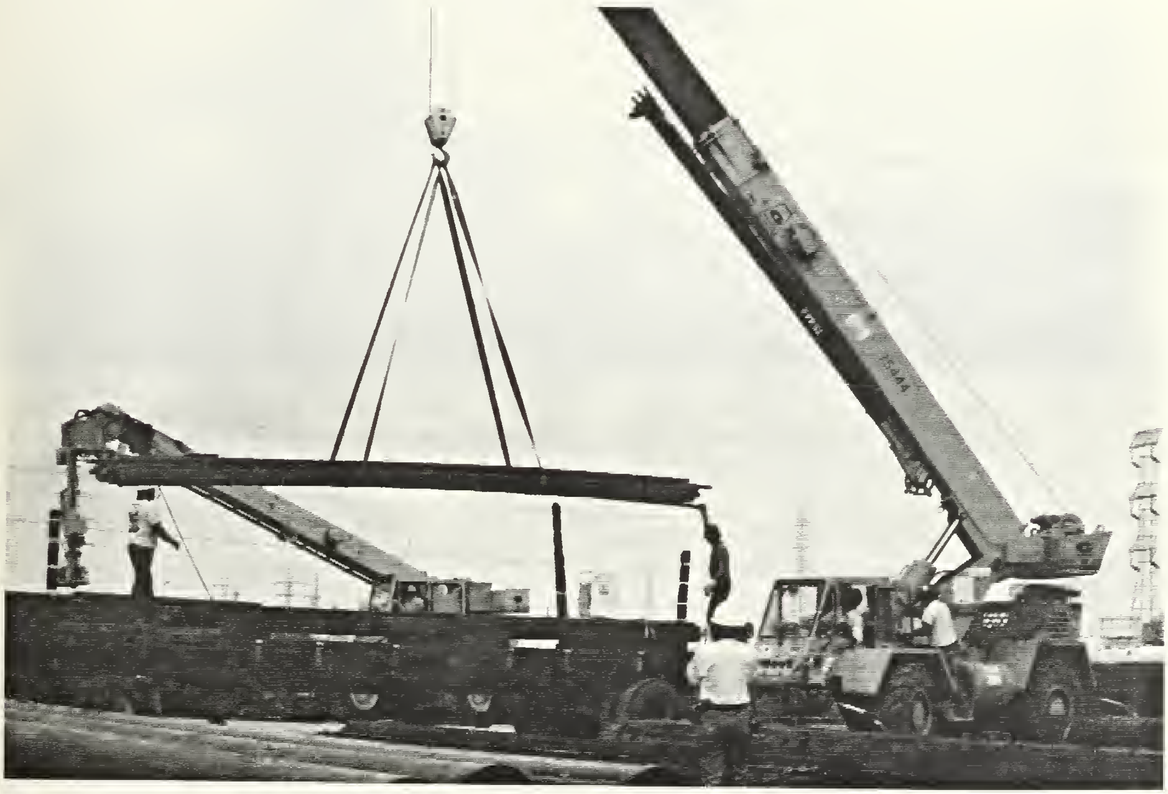


Figure 4.1: Cherry Picker Unloading 2" Pipe

Figure 4.2: Pipe Manipulator Unloading 2" Pipe

Data Presentation

The following is a summary of the equipments' average performance. Note that detailed data is presented in Appendix A.

Pipe Manipulator Data

Movement	Avg. Duration/ Pipe Length
Grasping	32 sec./pipe
Lift/Move/Release	79 sec./pipe
Return	54 sec./pipe
Complete Evolution	166 sec./pipe

Cherry Picker Data

Movement	Avg. Duration/ Bundle
Attach Sling	84 sec./bundle
Lift & Place	64 sec./bundle
Detach Sling & Return	51 sec./bundle
Complete Evolution	198 sec./bundle

The data presented below compare productivity between the Manipulator and the Cherry Picker, as well as performance factors.

Tabulated Man-seconds

Type of Action Observed	# of Lifts	Total Duration	Total ManSec.	Time/ Lift	ManSec/ Lift
<u>Manipulator</u> 2"dia., 40' XS	11	1827 sec	1827	166	166
<u>Cherry Picker</u> bundles 31 pipes/bundl 2" dia.,40' XS	6	1189 sec	7134	198	1188

Equipment Productivity
(unloading full truck)*

<u>Pipe Manipulator</u> — **Productivity Ratio** <u>(manhours/pipe)</u>

Duration 166 sec/pipe x 217 pipe ==> **10.00 hours**

Total Manhours
10.00 hours x 1 men ======> **10.00 manhours** **.046**

<u>Cherry Picker</u> (bundle lift)

Duration
198 sec/bundle x 7 bundles => **.39 hours**

Total Manhours
0.39 hours x 6 men =======> **2.31 manhours** **.011**

x 5 men =======> 1.93 manhours .009

x 4 men =======> 1.54 manhours .007

<u>Cherry Picker</u> (Single-pipe lift estimated)

		Productivity Ratio <u>(manhours/pipe)</u>
Total Time		
198 sec/lift x 217 lifts =>	**11.94 hours**	
Total Manhours		
11.9 hours x 5 men ======>	**59.50 manhours**	**.275**
x 4 men ======>	47.60 manhours	.220
x 3 men ======>	35.70 manhours	.165

* 217 pipes/truck, 7 bundles, 2" dia., 40'length, Extra Strong pipe

Performance Factor

(Pipe Manipulator vs. Cherry Picker (bundle lift))

$$P.F. = \frac{.011}{.046} = 0.24 \quad \text{(6 man crew)}$$

$$P.F. = \frac{.009}{.046} = 0.20 \quad \text{(5 man crew)}$$

$$P.F. = \frac{.007}{.046} = .015 \quad \text{(4 man crew)}$$

<u>Productivity Discussion</u>

With the Cherry Picker's ability to provide multiple pipes lifts, it is by far the more productive piece of equipment both in manhours, and equipment hours. Even though the Cherry picker required a 6 man crew, its speed more than

offset the additional manning requirement, such that it was 400% more productive in manhours (P.F. = 0.24), and 2500% more productive in equipment hours (0.39 hrs vs. 10 hrs).

It is anticipated that, as the size of the pipe increases, the Manipulator will become more competitive since the Cherry Picker will be required to reduce the number of pipes it is able to move in one lift. Theoretically, as the size of the pipe approaches a weight, such that the Cherry Picker is only able to hoist the same number of pipes that it has crew members, the Manipulator's productivity should become very competitive. The Manipulator currently moves one pipe per one crew member. As the Cherry Picker approaches this one to one ratio (# of pipes in lift equals # of crew members), the manhour productivity difference between the equipment will be dictated by the duration of each lift.

Realistically, the Cherry Picker can always lift more pipe than it has crew members when working within the Pipe Manipulator's weight capacity range. The limit of the Manipulator is 1600 pounds. Assuming a Cherry Picker crew size of 6 men (largest crew observed), a lift of 6 pipe (1 pipe per 1 crew member), at 1600 pounds per pipe, will only reach 9,600 pounds, 10,400 pounds short of its capacity. By adding more pipe to each lift, the Cherry Picker again outperforms the Pipe Manipulator.

The 1600 pound weight capacity of the Manipulator is

extremely limiting on its productivity. This capacity is governed by the Manipulator assembly hydraulics, the strength of the Manipulator parts, and the stability of the crane at full load and extended boom. Since the Manipulator movements during pipe unloading are different than those required for pipe installation, and that the operator basket and operator have been removed from the end of the boom, the actual lift capacity of the Manipulator in an unloading configuration might be much more than the current rated 1600 pounds. The Manipulator should be placed through a battery of lift tests to check the validity of its weight capacity.

Five Minute Ratings

The five minute ratings provide the observer with a measure of effectiveness of the crew and its members. Figure 4.3 shows the Five minute rating for the Cherry Picker.

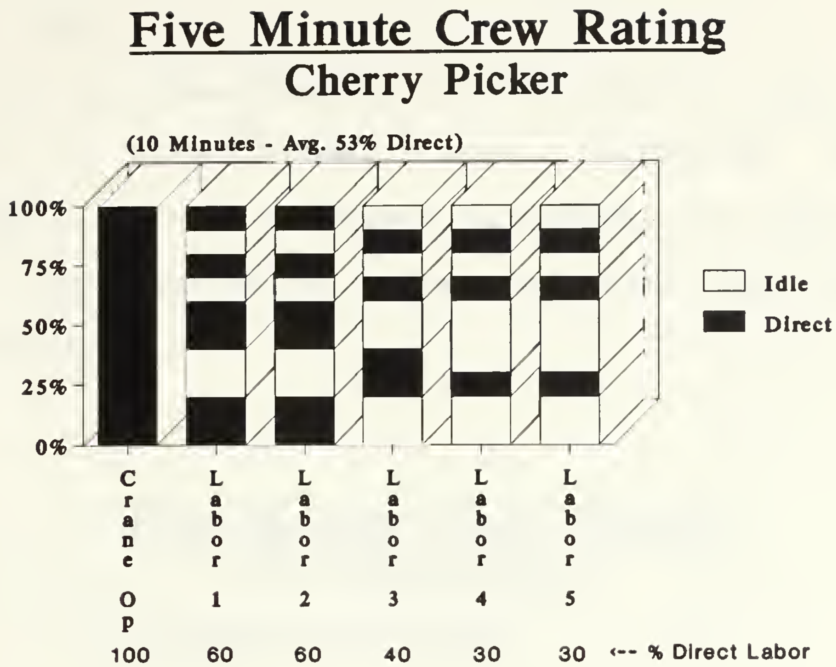


Figure 4.3: Cherry Picker Five Minute Rating

As can be seen by the effectiveness of the crew members, workers can be removed from the crew to improve the overall crew effectiveness. By removing laborer 5, the crew effectiveness improves from 53% to 58% without increasing the workload on the other workers. A second laborer can be removed increasing the effectiveness to approximately 72%, but would require one worker to work both pipe rigging on the truck, and pipe placement on the ground. A drawback of eliminating the second man is that climbing on and off the truck increases the chance of an accident.

The manhour savings obtained from reducing the crew size

is a viable alternative for the Cherry Picker to improve its productivity.

Figure 4.4 demonstrates the reduction in crew size and increase in effectiveness when employing the Pipe Manipulator. During the tests conducted, only the equipment operator was required to unload the pipe, thus maintaining 100% effectiveness.

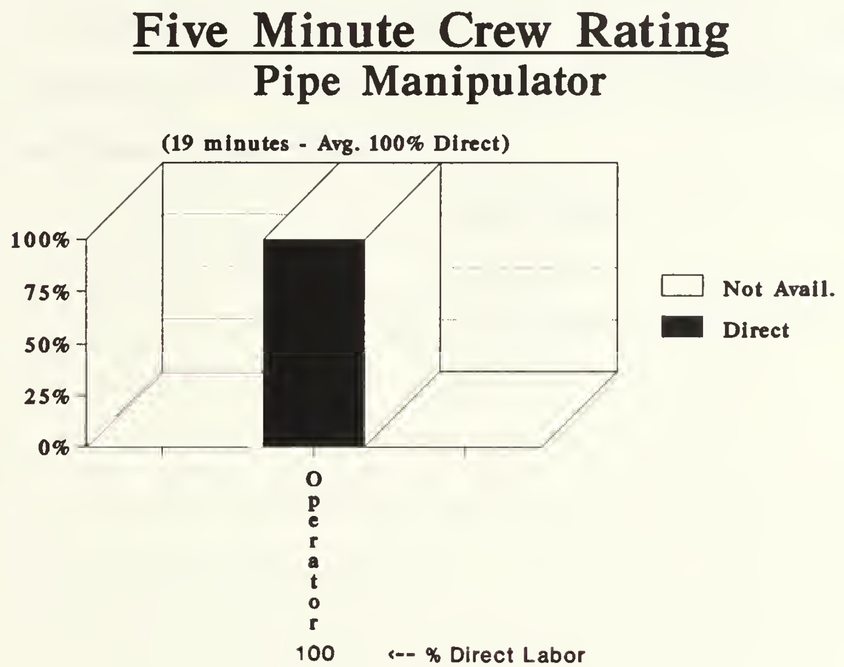


Figure 4.4: Pipe Manipulator Five Minute Rating

Even though only the Manipulator operator was involved in the unloading operations observed, a second worker will usually be on hand to provide support. This second worker was not included in the Manipulator's productivity calculations

since none was present during the observed operations. Several support tasks must be performed which were not evident in this filming.

1) As pipe is unloaded, wooden spacers must be removed or adjusted.
2) Labor will be required to arrange the lumber on which the pipe will rest in the yard.
3) Labor will be required to guide the operator in situations where pipe might not be clearly visible.
4) A safety observer should be on site to ensure safe operation and provide immediate assistance if an accident does occur.

CHAPTER FIVE

IMPROVEMENTS AND RECOMMENDATIONS

Introduction

As with any new development in industry, there is always room for improvements to be made. This chapter focuses on deficiencies observed during data gathering and attempts to make useful recommendations for overcoming those deficiencies. This chapter also reviews recommendations from Glass' 1984 Masters Thesis that have previously been implemented on the Pipe Manipulator, and gives a brief description on their success or failure is presented.

Lift Capacity

One of Glass' remarks in his thesis is that the Manipulator's weight limitation (1600 pounds) "generally encompasses a large percentage of all the piping installation at any given construction site." This was not the case at the Dow material yard where a large percentage of the pipe was heavier than the weight limitation of the manipulator. One reason for this is that the majority of the pipe is delivered in 40 foot lengths to improve the welder's productivity during installation. The longer the length of pipe, the less the number of welds that are required. A second reason for his observation is that his study analyzed the placement of 2 to 6 inch diameter pipe which the

Manipulator can easily handle in any standard length. The Dow yard, on the other hand, maintains pipe sizes which range from 6 to 36 inches. A case in point; the unloading of 20 inch diameter pipe weighing approximately 15,000 pounds per length, far in excess of Manipulator limitations, was filmed during this study.

A repeated comment by yard workers is that the manipulator could prove to be a productive piece of equipment if it had greater lift capacity. One laborer remarked, "It's a boy sent to do a man's job" when comparing the Manipulator to the Crane. Increasing this particular Manipulator's lift capacity is impractical for numerous reasons, most notably the cost requirement. Effort must instead be placed on finding operations in which the weight limitation does not come into play. These observations may, however, influence the design of a new manipulator.

Versatility

A material laydown yard handles a wide variety of materials and equipment including pipes, pumps, compressors, transformers, cooling equipment, etc. The Manipulator cannot handle many of these materials due to, (1) their odd shape, and (2) their weight.

The crane portion of the Manipulator looses its ability to act as a Cherry Picker when the end effector is attached. If a material yard operation used a Manipulator to handle

pipe, they would also be required to either maintain a second crane to handle the odd size/heavy materials or, remove the manipulator attachment so the crane could be used. Unlike a production environment such as a construction site, the material yard would not be too adversely impacted by the time required to install and remove the Manipulator assembly as their requirements change.

It seams however that if a crane is used to move the odd shaped materials, since it can also move the pipes as well, there may be no requirement for the Manipulator. This will be true unless the productivity of the Manipulator is improved.

Removal of the Operator's Basket

Glass' 1984 Thesis noted several disadvantages associated with the operator basket design:

1. Bulkiness
2. Decreased visibility
3. Basket swing
4. Lack of safety.

His recommendation, to remove the basket and use an umbilically attached control system, was implemented in this study.

This new operating configuration worked well, in that all four disadvantages noted above were eliminated. The basket's bulkiness, which often interfered with the placement of pipe in confined spaces, was eliminated. The operator

could position himself such that he had full view of the truck and pipe. The operator no longer had to contend with the freely swinging basket when transporting the Manipulator from one area to another. Finally, he was out of danger from the possibility of being hit by the pipe, and no longer had to fear being stranded in the basket during a gas release emergency from a nearby chemical processing plant. During an accidental gas release, expedient egress from the area is critical. If the operator was in the process of placing a pipe, the time required to maneuver the pipe to the ground, climb out of the basket, and leave the site could be dangerously long. Also, the time required to set up the Manipulator, lower the basket, climb in the basket, and check all the Manipulator controls was reduced to the set up time required of any other crane doing the same job.

Pneumatic Tubing

As with any change, there were a few deficiencies in the umbilical control system which need correcting. The Manipulator assembly and crane are now controlled through two sets of electrical cables and one pair of pneumatic tubes attached to the operator control panel on the ground. One set of cables control the Manipulator assembly functions, while the second set controls the crane's boom functions. The pneumatic tubing connects the operator control panel to the crane's throttle.

The electrical control cables were routed from the operator control box on the ground, directly to the electrical panel in the crane cab such that there was no interference with the boom movements. The pneumatic tubing, on the other hand, was not connected directly to the crane cab, but was connected from the control panel directly to the Manipulator assembly. This scenario causes the tubing to hang from the manipulator. The tubing then has a tendency to become entangled with the pipe as it's being moved (Figure 5.1).

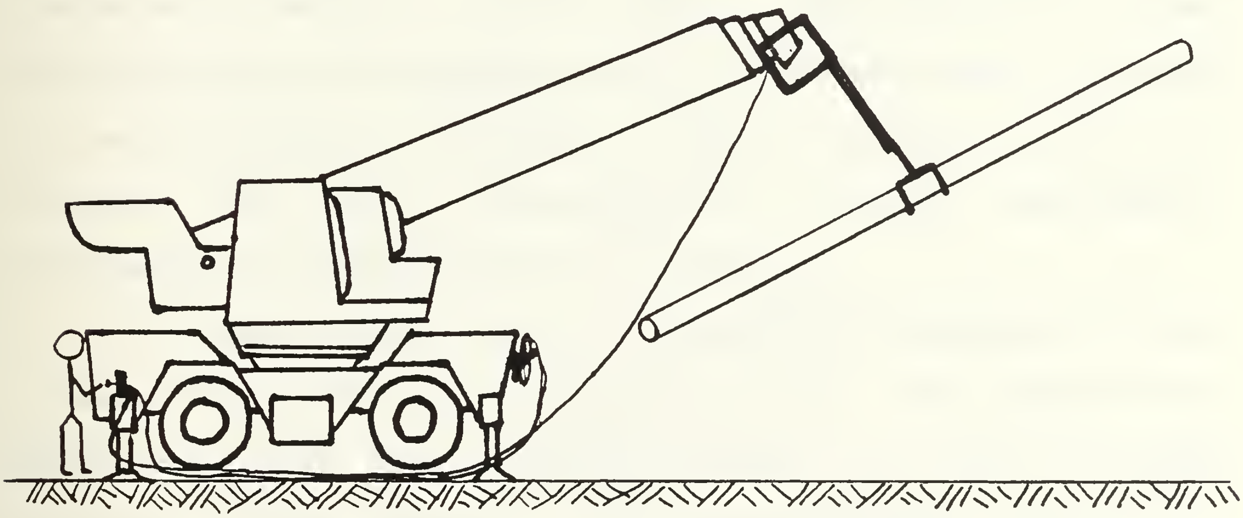


Figure 5.1: Pneumatic Tubing Connections

To avoid the tangling of the pneumatic lines, the tubing should be routed along the boom of the crane, to the cab in such a way that the tubing will not interfere with the extension and retraction of the boom. As noted in the maintenance manual, the electrical cables are routed along the right hand side of the boom by way of the extendable power track assembly. It seems logical that the pneumatic lines, with some work, can also be routed along the powertrack, rather than hanging free from the Manipulator assembly.

Reliability

Equipment reliability is of critical importance in the productivity of any construction operation. This also pertains to material storage yards. When material arrives from suppliers, the material moving equipment must be ready to service the delivery trucks. If the equipment is down for repairs, the only alternative is renting replacement equipment to complete the job at hand.

The Cherry Picker design has proven its reliability over decades of constant use around the world. The Manipulator must also prove its reliability before it will be taken seriously by the industry. Due to its mechanical complexity, this is not an easy task. During this study, the Manipulator was repaired several times due to damage received during both

transportation and operation. The following are a list of maintenance problems that ocurred or were observed during the conduct of this research:

1. The Manipulator has exposed hydraulic tubing which can become pinched or crushed during operation and transportation if care is not taken.
2. Prior to the commencement of the study, while the operator was learning the system, the metal plate supporting the capscrew of the Pivot Motion (see Figure 5.2) began to tear free and had to be replaced with a stronger support.
3. During the study, while moving a 40 foot long, 6 inch diameter pipe (approximately 760 pounds), the vertical rotation cylinder shaft broke in the Vertical Rotation mechanism (see Figure 5.2).

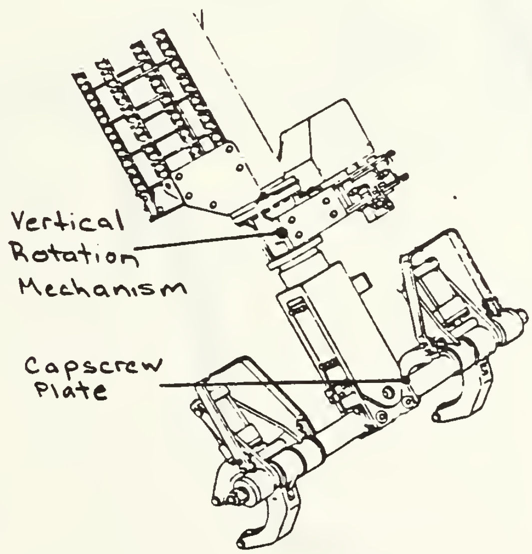


Figure 5.2: Areas of damage to Manipulator

tangling now encountered.

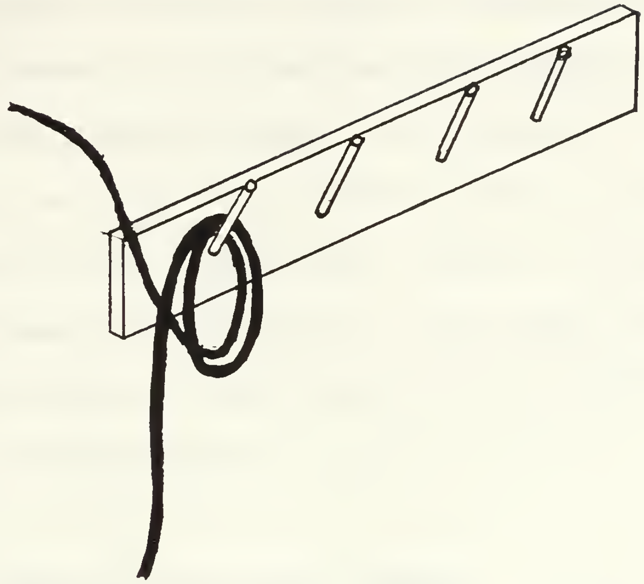


Figure 5.3: Current cable/tubing storage rack

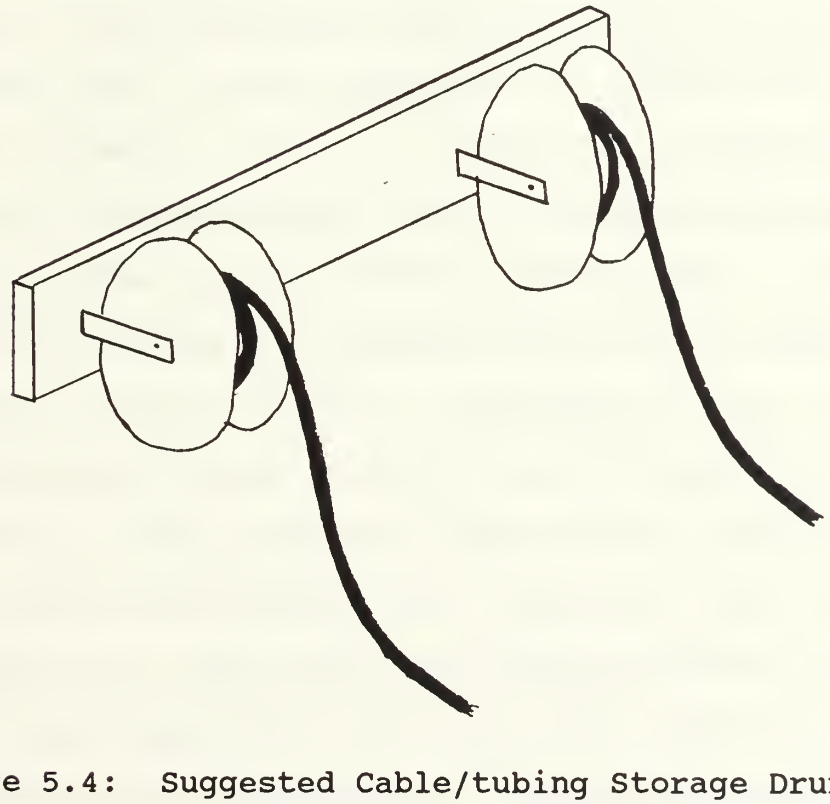


Figure 5.4: Suggested Cable/tubing Storage Drums

It appears that the hydraulic pressures were increased by the equipment leasing company involved in the study to improve the speed of the Manipulator motions. In so doing, the Manipulator reacted much more quickly to the controls, but this may have had the adverse affect of placing too much dynamic load on the structural parts. A balance must be attained between the speed at which the Manipulator will react to the controls, and the load that the quick reaction will place on the machine.

Cumbersome Control Cables and Tubing

The umbilical control cables and tubing required a device on which to store the cables during movement of the Manipulator. The Manipulator operator welded a cable/tubing rack to the front of the equipment to solve this storage requirement (Figure 5.3). Prior to operating the Manipulator, the cable/tubing must be unwound from the rack and dragged to the location of the control panel. Upon completion of the task, the cable/tubing must be recoiled and placed back in the rack. Eventually the coils of cable/tubing will become tangled from the constant coiling and uncoiling. The operator's suggestion to alleviate this problem, is the installation of a drum for each cable and tube (Figure 5.4). The cables and tubes would be wound upon a rotating drum much like that of a wire rope hoist. This will ensure neat and safe storage, and alleviate the constant

Redesign Recommendations

Through discussions with Dow employees, several recommendations were made which should be considered when designing a future Manipulator.

Modern Hydraulic Controls: The Manipulator's hydraulic system is pre-1980 technology. Since that time, several equipment manufacturers have developed smoother performing control systems. The Manipulator's control system is such that it provides full power, or none at all. This leads to a jerky movement, and makes fine adjustments in material placement difficult. By installing a smoother acting system, the hydraulics will build up to full pressure and thus allow an incremental power selection to satisfy the movement requirements.

Control Panel Design: No matter what direction of movement is desired of the Manipulator, the control levers, to initiate that movement, only move up and down. This control configuration becomes confusing when attempting Manipulator movements other than up/down such as rotation, extension, and pivoting. The operator must mentally convert the up/down movement of the control lever to the required movement of the Manipulator, ie. clockwise/counter clockwise rotation, in/out extension, or left/right pivot. Since the up/down movement of lever does not easily translate to the

required movement of the Manipulator, the operator many times moves the Manipulator in the wrong direction.

Control levers are required that mimic the movement of the Manipulator such that a rotation movement will be controlled by a rotational control lever, a left/right movement is controlled by a left/right lever, etc. The number of control levers will remain, but the direction of movement of those levers will change. Another possibility proposed was an "ergostick" design by Hughes (1990).

Manipulator Movement Reduction: The pipe unloading movements encountered in this study are much simpler than the movements required during pipe placement in a construction environment. The Manipulator operator did not require the Roll, Telescope, or Lift movement of the Manipulator (Figure 1.2). It is possible that if these functions were eliminated, the weight of the Manipulator would be reduced, thus heavier loads could be lifted.

The disadvantage with removing these functions is that the Manipulator becomes less versatile thus its tasking becomes more restricted. Removing these functions would only be worthwhile if the Manipulator is to be used in a simple repetitive environment such as a material yard.

Multi-pipe Lift Capacity: The Cherry Picker's productivity advantage is its ability to lift several pipes

simultaneously using a sling. The productivity of the Manipulator could be drastically improved if it too had multi-pipe lift capacity. Two means to achieve this goal are:

(1) create an attachment at the end of the Manipulator assembly on which to attach a sling. This attachment could be a hook device such as that used on Cherry Pickers. This device must have the ability to be removed easily prior to actual Manipulator use.

(2) modify the jaws such that bundled pipe can be grasped and lifted.

With both these options, the one restriction to success of the muli-pipe lift is the Manipulator's limited weight capacity.

Dual Crane/Manipulator Capability: A major improvement in the Manipulator would be the ability of the equipment to act as a crane while maintaining its Manipulator capabilities. Presently the Manipulator assembly must be removed from the boom for the crane to be used as a crane. The Manipulator removal and crane re-rigging is time consuming. To accomplish this, the Manipulator requires structural modifications to allow the crane's wire rope and the Manipulator assembly to remain on the crane simultaneously.

CHAPTER SIX

SAFETY

Introduction

Worker safety must be a prime concern on construction sites these days. With Worker's Compensation claims rising, OSHA fines becoming stiffer, and the general loss of efficiency and effectiveness after accidents, companies must strive to eliminate unsafe working environments.

The Pipe Manipulator is one means to attain this goal by directly controlling the workers, materials, process, and environment.

Current Operations

Cherry Pickers are the predominant equipment employed for unloading operations. As discussed earlier, various devices are used in conjunction with the crane, such as slings, chains with hooks, and cables. The dangerous periods during an unloading operation are:

1. Climbing on\off and working on a raised platform
2. Attaching the lifting device to the pipe
3. Initial lifting of the pipe
4. Releasing the lifting device from the pipe

Raised Platform: The bed of a delivery truck can be thought of as a raised platform. The pipe unloading

operation requires workers to climb on and off the flatbed as pipes are unloaded. Although it is a safe act if done correctly, climbing on and off vehicles causes a large percentage of lost time accidents when performed incorrectly. Usually in the rush to accomplish a task, workers will commit unsafe acts without realizing they are doing so. Jumping off the equipment may result in twisted or broken ankles at the least, and serious back injuries and permanent damage at the worst. While dismounting too quickly, fingers have been torn off as rings become entangled in protrusions from the equipment.

The second safety concern while working on the flatbed is the lack of railings. Though flatbeds are not usually considered a high working platform, a five foot fall backwards can result in serious injuries. As will be discussed later, stacked pipes can shift during the unload operation. The personnel working on the flatbed have limited room in which to maneuver to avoid any shifting pipe, and thus can be forced off the side.

The third safety concern is that due to the restricted movement area on the flatbed, the pipe must be lifted over the workers head, or they must dismount the truck prior to the material movement from the truck to the ground. Keeping personnel out from under a hoisted object is standard practice for crane operations.

Pipe Rigging: During the attachment of the lifting device, at least one, usually two, personnel must stand on the bed of the delivery truck. In the case of slings, the worker must loop the sling around the pipe which usually requires the placing of his arm under the pipe to be lifted. If spacers are employed during delivery, the rigging operation is made easier since space is available to slide the sling underneath. If spacers are not used, the operation becomes more difficult. The crane's hook must be employed to lift one end of the pipe to provide access underneath for the sling. During this period, the pipe is partially off the truck and can, if slippage occurs from the crane hook, crush arms or legs of the workers.

The chain and hook device is the safest and most productive crane device for lifting pipe since workers on the flat bed: (1) are not required to place their hands and arms underneath the pipe; and (2) can stand at the ends of the pipes rather than along side the pipes when attaching the hooks. The improved safety of the first situation is self evident. The second situation improves safety by removing the worker from the danger area (along side the pipe) in the event any of the pipes become unsettled and begin to roll. But again, this operation requires workers to be on the flatbed during unload operations which inherently is a dangerous area due to its raised platform with no railings.

Lifting: The shifting of pipes during the offload operation is a situation which could cause serious injury. During the transportation to the construction site, jostling of the pipes can destablize them. Lifting a pipe could shift underlying pipes which might roll across the bed to the ground, or into the truck stakes at the edge of the bed. Any worker standing along side of the pipes in this situation is in imminent danger of being crushed.

Pipe Placement and Release: After pipe has been set in place on the ground, the lifting device must be removed in a similar fashion to which it was attached. This will involve the same dangers experienced during attaching the device. The possibility of crushing limbs when removing slings exists if the pipe shifts from its resting place; though, the probability of this situation is lessoned since the sling can be removed by pulling the material from underneath as opposed to pushing the sling underneath when attaching.

Several situation were observed in which the sling acted much like a projectile as it was being pulled away from the pipe on the ground. As the crane was lifting the sling away from the pipe, the sling became caught between two adjoining pipes. The crane continued to pull on the sling stretching it taught. The sling eventually broke free, but since it had been stretched taught, the release was that of a rubber band with one end of the sling flying to a height of approximately

20 feet. If a worker had been in the way of the sling, the impact would have caused some type of injury. Although this situation is not a usual occurrence of crane operations, it demonstrates a potential hazard.

Pipe Manipulator Safety

The main safety feature of the Manipulator is that the workers are removed from the unsafe conditions outlined above:

1. The workers are removed from the bed of the truck since the jaws can grasp the pipes themselves.

2. Since workers are not required on the truck, they are not required to repeatedly mount and dismount the bed.

3. The workers are able to stay a safe distance from the pipes at all times during the operations.

The Pipe Manipulator removes the workers from unsafe conditions, and prohibits the workers from committing unsafe acts near the pipes.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

This paper's results indicate that the Manipulator cannot compete with the productivity of the Cherry Picker in a material storage yard environment as it is currently configured and used. The Cherry Picker's ability to move several pipes simultaneously is the main factor in its productivity advantage. A material yard is also a dynamic environment where equipment must unload varying construction materials and installed equipment. The inability of the Manipulator to deal with these varying materials restricts its potential for predominant use in a material yard. In addition, the capital investment of approximately $265,000 ($85,000 for the Manipulator attachment and $160,000 for the hydraulic crane) to procure a device such as the Manipulator, is difficult to justify when compared with the initial cost of a Cherry Picker at $155,000. The one clear advantage of the Manipulator is its ability to remove workers from numerous unsafe conditions that exist while using a Cherry Picker.

As discussed in Chapter Five, several recommendations are put forth to enhance the productivity of the Manipulator. Multi-pipe lift capacity redesign, control panel redesign, addition of modern hydraulic control systems, and dual crane/Manipulator capability are a few of the avenues to be

explored further.

Suggested and implemented Manipulator changes from previous studies (Glass 1984) have proven successful. The removal of the operator's basket has eliminated a multitude of problems experienced by the operator, the most important of which is his safety. A further recommendation to increase the lift capacity needs to be further explored. Material unloading in a laydown yard involves less strenuous movements on the machine than pipe erection. This fact, combined with the elimination of the weight of the operator's basket and operator, may permit the Manipulator to lift heavier loads. This potential productivity enhancement should be explored in an equipment yard testing facility.

Although the Manipulator did not fully live up to its performance expectations, it cannot be considered a failure, for it serves to stimulate new ideas which lead to future innovations in construction technology. Companies exploring new innovations must endure a frustrating incubation period, and consider each innovation as part of a continuous learning process. Only through fostering such research, will the U.S. construction industry retrieve its pre-eminence as a technology innovator rather than a follower.

By studying the Manipulator's deficiencies and advantages, the construction industry can develop an improved material handling device which will one day replace the Cherry Picker.

APPENDIX A

FILM ANALYSIS DATA*
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Pipe Manipulator

	Grasping	Lift & Move	Release & Return	Total Evolution
Pipe #1	25	70	49	144
Pipe #2	41	90	50	181
Pipe #3	22	80	42	166
Pipe #4	30	81	40	151
Pipe #5	40	81	61	185
Pipe #6	40	60	55	155
Pipe #7	40	139	64	243
Pipe #8	23	69	73	165
Pipe #9	10	49	51	110
Pipe #10	21	96	58	175
Pipe #11	63	56	55	174
Average	32	79	54	165

Cherry Picker
(unload bundled pipe)

	Rig Load	Lift/Swing/ /Place	Unrig/ Return	Total Evolution
Bundle #1	101	68	65	234
Bundle #2	75	50	40	165
Bundle #3	30	45	60	135
Bundle #4	125	55	45	225
Bundle #5	140	110	45	295
Bundle #6	30	55	50	135
Average	84	64	51	198

* times in seconds

REFERENCES

(Fisher 1989) Fisher, D.J., "Piping Erection Constructability Issues in a Semi-Automated Environment", Dissertation, The University of Texas at Austin, May 1989.

(Glass 1984) Glass, C.C., "The Pipe Manipulator: A Complete Assessment of a New Idea in Construction Equipment Technology", Thesis, The University of Texas at Austin, December 1984.

Grove Manufacturing, "Operator's Handbook for the Pipe Manipulator", 1981.

(Hughes 1987) Hughes, P.J., "Automated Piping Erection in Process Plants Using a Heavy Manipulator", Thesis, The University of Texas at Austin, December 1987.

(Hughes 1990) Hughes, P.J., "Construction Manipulator Tele-operation with 'Ergosticks'", Dissertation, The University of Texas at Austin, May 1990.

McElroy, Frank E., Supervisors Safety Manual, National Safety Council, Chicago Illinois, 1984.

Parker, Henry W., and Oglesby, Clarkson H., Productivity Improvement in Construction, McGraw-Hill Series in Construction Engineering & Management, McGraw-Hill Book Company, New York, NY. 1989.

Sprinkle, Howard B., "Analysis of Time Lapse Construction Films", Journal of the Construction Division, Proceedings of the American Society of Civil Engineers: Volume 98, CO2. 1972.

Summey, Stephen W., Construction Operations Research: Time-Lapse Photography, Thesis, University of Texas at Austin. 1984.

Thomas, Randolph H., and Mathews, Cody T.: An analysis of the Methods for Measuring Construction Productivity; Construction Industry Institute, Source Document 13; University of Texas at Austin, 1986.

Thomas, Randolph H., and Mathews, Cody T.: The Manual of Construction Measurement and Performance Evaluation; Construction Industry Institute, University of Texas at Austin, 1988.

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