AN IN-FIELD MECHANICAL HANDLING METHOD
FOR ONE-GALLON NURSERY CONTAINERS

By

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PREFACE

This study is concerned with the development of a mechanical alternative to the manual in-field handling of one-gallon nursery containers. Several concepts were generated and an experimental handling mechanism was built and evaluated with respect to performance in placing and removing containers on the ground.

The author gratefully acknowledges that this study was made possible through funding from the Oklahoma Agricultural Experiment Station through Project S-1414 "Design of Experimental Equipment."

The author also wishes to express his appreciation to his major adviser, Dr. L. O. Roth, for his guidance and assistance throughout this study. Appreciation is also expressed to the other committee members, Dr. R. W. Whitney and Dr. C. W. Whitcomb, for their assistance in preparation of the final manuscript.

Finally I wish to express my appreciation to my wife, Martha, and our daughter, Raina Selena, for the time and sacrifices they have made while I completed this research.

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 1

Statement of Problem. 2
Objectives. 2
Approach. 2

II. REVIEW OF LITERATURE 4

Present System. 4
Proposed Systems. 5
Containers. 7
  General. 7
  Size 8
  Taper. 9
  Arrangement and Spacing. 9
  Weight 12

III. SPECIFICATIONS AND PARAMETERS. 13

Specifications. 13
Parameters. 15

IV. CONCEPT DEVELOPMENT. 16

Introduction. 16
  Individual Handling. 18
  Line Handling. 18
  Block of Container Handling. 21
Concept Analysis. 21

V. CONCEPT IMPLEMENTATION 27

Introduction. 27
  Header 27
  Pallets. 28
  Transfer Mechanism 28
Construction. 29

VI. EVALUATION 38

Location. 38
Equipment 38
Mechanical Limitations. 38

Chapter Page

Experimental Design 41
Loading. 41
Unloading. 43
Operation Procedure 44
Loading. 44
Unloading. 44
Data Analysis and Discussion. 45
Loading. 45
Unloading. 46

VII. SUMMARY AND CONCLUSIONS. 50

Summary 51
Conclusions 51
Suggestions for Future Work 51

BIBLIOGRAPHY. 53

APPENDICES. 54

APPENDIX A - IMPLEMENTATION ALTERNATIVES 55

APPENDIX B - LOADING DATA. 61

APPENDIX C - UNLOADING DATA. 68

LIST OF TABLES

Table Page

I. Experimental Sequence for Container Loading 41

II. Comparison of Predicted Spacing and Sample Mean of Container Spacing 48

III. Raw Data for Onloading of Containers Using Various Chain and Tractor Speeds. 61

IV. Raw Data for Unloading of Containers Using Various Tractor and Chain Velocities. 68

V. Data Calculated From Table IV Raw Data. 70

LIST OF FIGURES

Figure Page

1. Diagram Showing Range of Wedge Spaces Between One Gallon Containers. 10

2. Arrangement of Containers in Triangular and Rectangular Patterns. 11

3. Block Diagram Illustrating Mechanical Handling Operations and Functions Relative to the Entire System 17

4. Flow Diagram Showing Operation of Individual Handling Concept 19

5. Flow Diagram Showing Operation of Line Handling Concept . . . 20

6. Flow Diagram Showing Operation of Block Handling Concept. . . 22

7. Graphical Comparison of Handling Concepts in Terms of Containers Per Hour 25

8. View of High-Clearance Tractor With Handling Mechanism and Pallet Mounted Beneath. 30

9. Diagram of Torsion Spring Assembly and Selected Parts 31

10. Closeup View of Header Showing Reinforced Containers, Torsion Springs Mounted on Roller Chains and the Rotating Compression Plate. 32

11. Front View of Header During Edge to Edge Loading Sequence Showing Headers, Pallet, and Support and Lower Portion of Hagee. 34

12. Rear View of Header and Pallet During Unloading Sequence. . . 35

13. Schematic Diagram of Hydraulic System 37

14. Closeup View of Front of Header Showing Guide Bars, Container and Chains During Placement 40

15. Graphical Results of Offloading Trials Showing the Variation of Spacing for Different Speed Ratios 47

Figure Page

16. Sketch of Header Alternative 1 Showing Flexible Belts Operating in Horizontal Plane 56

17. Sketch of Header Alternatives 2 and 3 Showing Single Belt (or Chain) Operating in Vertical Plane 57

18. Sketch of Header Alternative 4 Showing Flexible Belt Across Swath Width 58

CHAPTER I

INTRODUCTION

The highly labor intensive and seasonal nature of container-grown ornamental plants combined with increasing labor and materials costs have made mechanization of various operations increasingly attractive to the nursery industry. Although many operations performed in the propagation and potting[1] processes have been successfully mechanized, the in-field handling and movement of one-gallon[2] containers during the placement, respacing, and harvest processes still requires large inputs of highly repetitious stoop labor. In each process the laborer is required to manually lift and carry containers from one location to another, place them in a particular configuration on either the growing bed or transport vehicle and return for another load. With the requirement that thousands of containers be handled in a relatively short time period, the process rate becomes the limiting factor. Mechanization of in-field container handling and movement has been difficult due to the dirty, abrasive nature of the work environment and industry wide lack of standardization in materials and procedures.

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[1] Refers to the planting of young plants into containers and movement of containers away from a central area toward a field location.

[2] Nominal trade designation.

Statement of Problem

The purpose of this study was to develop a mechanized in-field container handling and movement method[3] capable of reducing the amount of stoop labor required while maintaining or increasing the process rate.

Objectives

1. Identify and describe primary operating parameters and specifications associated with mechanization of the in-field container handling operations of movement, placement, and removal.
2. Develop and evaluate conceptual models of a mechanized in-field container handling and movement method and determine operating characteristics.
3. Construct an experimental model of a handling and movement method and evaluate model performance with respect to input specifications and operating conditions.

Approach

Container field handling specifications and parameters, were established from current literature and/or actual observations. Based on the specifications and parameters, a block diagram of necessary operations was constructed and two or more conceptual models of handling methods developed. Analysis of models was accomplished by use of computer simulation techniques, mathematical modeling, and/or other engineering processes. Based on conformance to specifications, a concept

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[3] Handling and movement method refers to the procedure of placement, transport and removal of containers with respect to the transport and growing bed.

was selected and an experimental model constructed. Evaluation of the experimental model was made to determine effects of field conditions and parameters on the handling method's performance and conclusions were drawn as to the method's usefulness.

CHAPTER II

REVIEW OF LITERATURE

Present System

Due to attractiveness and convenience of finished plant product, greater grower flexibility, lower labor requirements per plant and higher plant concentrations per acre, there is an increasing trend toward large-scale production in containers (Brown, 1976; Furuta, 1974). Although the option of reducing labor inputs by increasing labor productivity through mechanization has generally been recognized by the nursery industry, only in recent years has the subject received significant study (Horticultural Research Institute, 1975). Available equipment as indicated by Bartok (1974) and Shaw (1978) is primarily of a materials handling nature. Container movement mechanization was confined primarily to greenhouse and potting operations where container movement is relatively limited.

For purposes of mechanization research and development, Warneke (1974) conducted a survey of ten southern California nurseries to determine operations having high labor inputs. Of the ten, two kept detailed labor records which indicated that approximately one-third of the labor required to raise plants for market was utilized in handling and movement of containers. This labor was used in three operations during the year:

1. manual loading of the transport vehicle after potting and

manual unloading and placement of containers in growing beds after arrival in the field,
2. individual respacing of containers as the plants grow in size, and
3. manual selection and loading of plants onto a transport vehicle and subsequent unloading of containers at the assembly area.

After assembling and labeling, containers were manually transferred to shipping vans.

In a subsequent study of the potting process, Warneke (1976) showed that labor requirements in moving containers away from the potting area and placing them in the field depended upon the distance hauled as well as the process rate. Rates observed were 1700, 2700, and 4000 containers per hour which, respectively, required 2, 3, and 5 laborers to off-load the trailer and 1, 2, and 3 laborers respectively to haul containers. Two laborers were required to load the trailer at all rates since they moved a limited distance in loading containers.

Chen, Willits, and Sowell (1977) developed a computer simulation of nursery potting operations which indicated status of the potting machine, transports, and workers involved in loading, driving, and unloading transports. For the particular system simulated, results for an output rate of 1434 containers per hour indicated that workers, other than drivers, would be idle 40 percent of the time thus significantly reducing labor productivity.

Proposed Systems

In the interest of increasing labor productivity and process rates, Verma (1978) proposed palletization of the potting, movement and harvest processes. Both the potting and shipping operations would use plywood pallets which could be moved from station to station by the use of roller conveyors. Transport between potting and shipping areas and the field would be accomplished by means of a multilevel trailer which could carry eight pallets (approximately 800 containers) per trip thus increasing transport utilization by decreasing the amount of time spent in transit. Labor productivity in loading or unloading the trailer was increased by extending pallets from the side of the trailer thus making it possible for workers to easily place containers in position on the pallet. The top level of the trailer was loaded first, raised, and then the lower level was loaded. Use of the proposed palletized system would allow the transport to unload pallets from the field into the potting or harvest processes and immediately load processed pallets for the return trip to the field. Data gathered on the use of pallets in the system indicated that workers could attain increased handling rates as a result of the ease with which workers could load or unload pallets.

A similar palletized system was proposed by Brown (1976) in which pallets were placed in the field for loading/unloading operations while the transport hauled loaded/unloaded pallets out of the field. In both palletized systems, the worker is still required to manually move the containers into and out of the growing beds requiring considerable labor input. Jones (1973) patented a device for lifting and moving containers which could be fitted to the front of a fork-lift. The device consisted of long parallel rails upon which hydraulic cylinder actuated slide means were mounted. Containers were held between two slide means as a result of the container top diameter being greater than the rail spacing. Extension of the cylinder extended the first slider of each rail a certain distance after which a connector started a second slider extending and so on until all sliders were separated. The cylinder was retracted to butt the sliders together again thus allowing respacing of containers. Problems with the device were the lack of allowance for container flexibility and the size of the rails required too much distance between one gallon containers for edge to edge spacing. The device was suitable for larger container sizes since more space is available for rail insertion. A similar method of container handling was suggested and tested by Brown (1976). The device tested consisted of two parallel street sweeper brushes mounted in steel channels. With bristles pointed upward, the two brushes were placed alongside a container and the brushes rotated 25° toward the container. By so doing, the brushes caught and held containers up to the five-gallon size adequately for lifting and movement. Although allowing for container flexibility, the size of the assembly was too large to use in handling edge to edge containers.

Containers

General

Numerous parameters such as nursery procedures, container characteristics, and plant characteristics affect any attempt at container mechanization. The group of parameters of concern for the purposes of this study were the physical characteristics of the container which are affected by plant biological requirements and economic considerations. According to Furuta (1974), ideal market characteristics of containers up to five gallon size are:

1. resists decay or deteriorations;

2. does not contribute to inhibition of plant growth;
3. does not create soil conditions, such as temperature, disease, or moisture that inhibits or adversely influences plant growth;
4. should be strong enough to allow maximum stacking of plants for shipment;
5. should not add excessive weight to the product;
6. should be attractive in retail display;
7. creates no hazard to consumers during planting; and
8. facilitates plant removal.

In the past, due primarily to availability and relative cost, metal No. 10 food cans have been widely used as one gallon containers. However, such containers require painting to avoid deterioration, may be unattractive on display and dangerous to the consumer when cut for plant removal. As a result, reusable containers in a tapered cylindrical shape are becoming widely used although they may lack stacking strength and stability.

Size

A survey of Lawyer (1978) of containers available for use in container nurseries revealed a lack of uniformity in any distinguishing characteristic although minimum one gallon dimensions are 13.97 cm in diameter and 15.24 cm tall (American Standard, 1973). For horticulture containers, a length to diameter ratio of from one to five was reported with variations of from 7 percent to 27 percent in volume from the nominal one-gallon size. For purposes of standardization, Lawyer suggested that a standard container description be used detailing characteristics such as material, number of sides, top diameter, base diameter, length, and volume. For purposes of mechanization, characteristics such as strength, weight, lip dimensions and angle of container taper may also be needed.

Taper

For one gallon containers set edge to edge, Brown (1978) reported a range of dimensions for the wedge shaped space between containers of from .64 to 2.54 cm at the top and from 1.27 to 7.0 cm at the bottom (Figure 1). For purposes of space utilization and container stability, it is usually desirable to use nearly cylindrical containers thus forming a relatively narrow wedge space.

Arrangement and Spacing

Present container arrangements in growing beds conform to either triangular or rectangular patterns (Figure 2). The triangular system is primarily used for containers spaced edge to edge since 23 percent more containers per unit area may be placed as compared to rectangular. As containers are spaced out, however, this percentage decreases so that at a spacing of two diameters center to center there is only three percent difference in the number of containers per unit area (Furuta, 1974).

Container spacing will usually vary according to plant type, size, and condition. Thus low, spreading plants require more room than tall, slender plants or dormant plants. For one gallon containers, Harris (1972) suggests an area of approximately 600 cm^2 per plant or approximately 1.4 container diameter spacing center to center for some hardwood species. In practice, greater spacing of 2 container diameters are

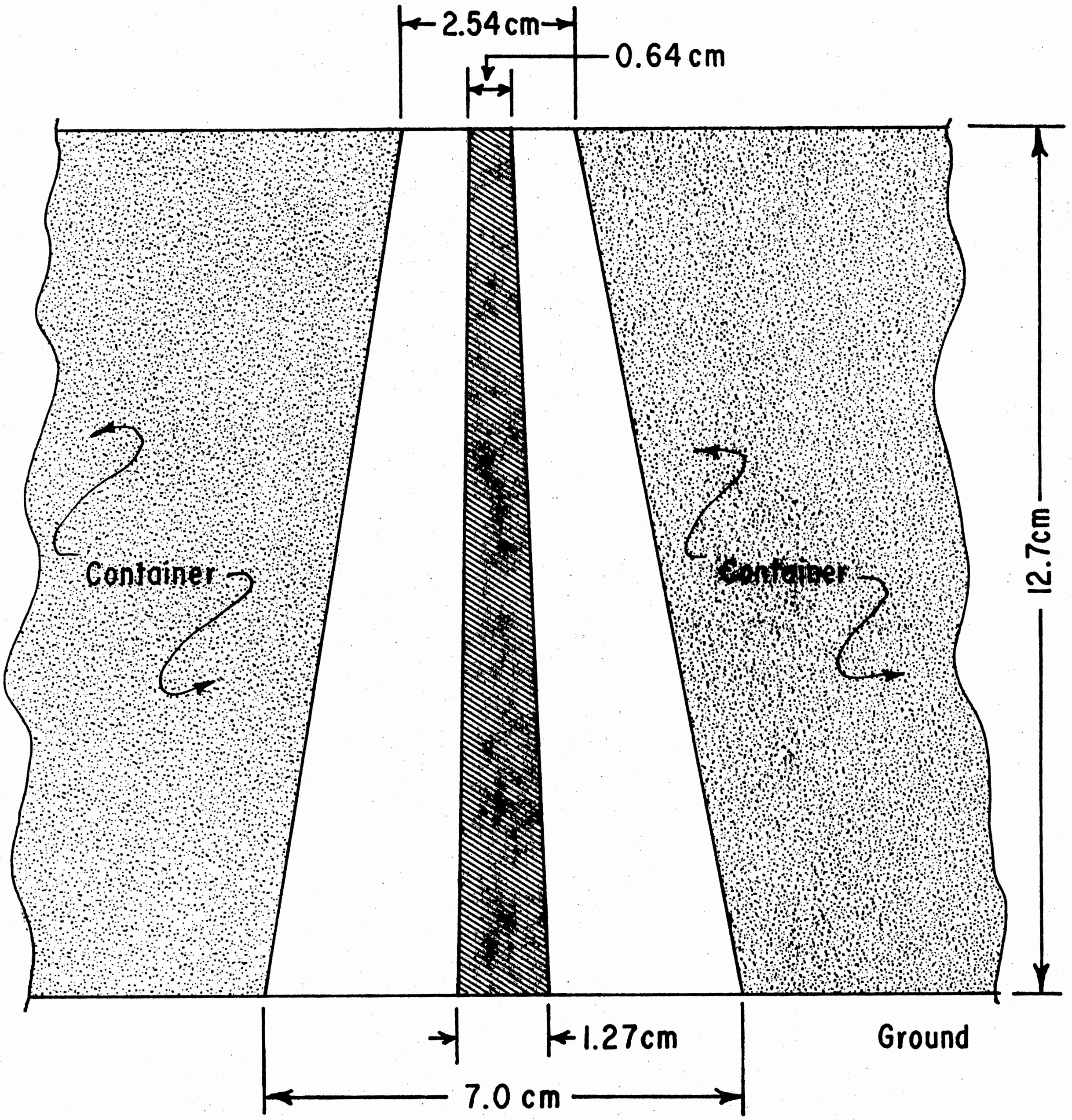
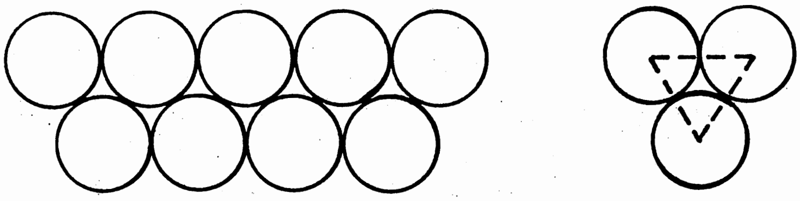
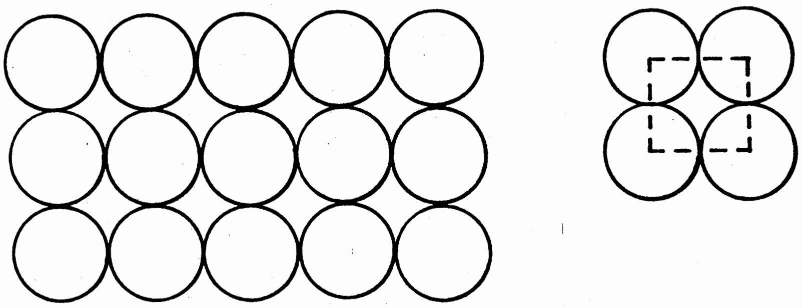


Figure 1. Diagram Showing Range of Wedge Spaces Between One Gallon Containers



Triangular Pattern



Rectangular Pattern

Figure 2. Arrangement of Containers in Triangular and Rectangular Patterns

often used to insure plant quality and to allow adequate working space for various cultural operations.

Weight

Container weight is an important factor in determining power requirements for mechanization. This weight will be dependent upon the density and moisture content of the soil mix, container volume, and size of the plant in the container. The variability of container volume combined with the possible variations of soil mix density and moisture content allow a relatively wide range of possible container weights. For this study it is assumed that the soil mix has a bulk density when wet of .14 kg/m^3 (Furuta, 1974). This gives a container weight range of 3.78 to 4.77 kg per one-gallon container based on Lawyer's range of container volumes.

CHAPTER III

SPECIFICATIONS AND PARAMETERS

Specifications

To guide formulation and analysis of alternative concepts, characteristics of a mechanical handling method were established from review of literature, personal communication, and direct observation.

Present systems of in-field container movement generally use either a self-propelled flat bed vehicle or trailers of some type (Warneke, 1974). Since a trailer would be relatively hard to accurately maneuver with respect to container beds, a self-propelled handling mechanism is indicated.

Industry acceptance of a handling and movement mechanization method is dependent primarily upon the relative cost of the system with respect to the present system. In terms of measurable factors, this means that any mechanization must at least double labor productivity without significant changes to present growing systems (Horticultural Research Institute, 1975). This could be accomplished by increasing the process rate, reducing the required labor or both, while making use of the predominant characteristics of the growing system.

Warneke (1974) and Furuta (1974) as well as direct observations by the author indicate that during the placement, respacing, and harvest processes, the handling method should perform three primary functions similar to those performed by a human laborer:

1. removal/placement of containers from/to ground,
2. transfer of containers to temporary storage, and
3. temporary storage of containers during transport within growing beds.

With proposed systems advocating the use of pallets, the third function of temporary storge could be performed by one or more pallets. Since the use of pallets would also provide a convenient method of loading and unloading the handling machine[1] outside of the growing beds, the use of pallets is considered a requirement of the handling method to be proposed by this study.

Respacing of containers consists of removing containers from one growing bed and spacing and placing them in another growing bed and spacing. Two specifications result from this procedure. The first is that the first and second functions of removal/placement and transfer must be essentially reversible in operation due to the rapid turnaround time required in the respacing process.[2] The second specification is that the mechanism performing either the first or second functions or both must have a means of controlling the spacing between containers both perpendicular and parallel to direction of machine travel.

The nature of the work environment places a significant restriction upon mechanism components. Numerous articles in the literature describe the growing mixes used at various nurseries. Most, if not all, contain

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[1] Machine will be considered to refer to entire self-propelled vehicle whereas mechanism will refer to a particular portion of the machine.

[2] Since the handling mechanism is to be essentially reversible in operation, except for purposes of clarity, only the placement portion of the operation will be referred to in the remainder of this paper.

high proportions of highly abrasive granular materials such as sharp sand and perlite. Small quantities of this material are lost through drainage holes during handling. The handling mechanism must, therefore, be either resistant to abrasion or be of such low cost as to be inexpensively replaceable.

Parameters

The only significant set of parameters are those pertaining to container characteristics. The lack of container standardization noted by Lawyer (1976) allows flexibility in the choice of container characteristics.

After examination of the numerous styles of containers available, a commonly available extruded plastic container was selected. Container dimensions were:

Height	17.8 cm
Top Diameter	20.3 cm
Lip Height	4.4 cm
Lip Width	1.2 cm
Bottom Diameter	14.0 cm

These dimensions result in a wedge-shaped space between containers of 2.5 cm at the top and 3.8 cm at the bottom. The maximum weight of one of several randomly selected containers and plants from Oklahoma State University Horticulture Nursery stock was 3.25 kg. With a range of container weights possible due to variation of soil mixtures and their moisture contents, a maximum design weight for each container was selected as 4.54 kg.

CHAPTER IV

CONCEPT DEVELOPMENT

Introduction

As described in the specifications, the handling method performs three functions in the movement of containers: placement/removal, transfer to/from storage, and temporary storage during transport within the growing beds. These functions are diagrammed in Figure 3 with respect to the entire system. The sequence of operation for a self-propelled mechanism would be to load palletized containers either from a hauling vehicle or at the potting source, transport these palletized containers into the desired location on the growing bed and offload containers from pallets into the placement mechanism which would then place containers on the ground at the required location and spacing until all pallets were empty. The machine would then return to the source of loaded pallets and exchange empty pallets for loaded ones. Regardless of the manner of handling containers, this general process must be followed. The primary problem is still the actual method and mechanism of handling the containers.

Three approaches to mechanical container handling are suggested by container arrangement in the growing beds:

1. handling of individual containers,
2. handling of lines of containers, and
3. handling of blocks of containers (n x m lines).

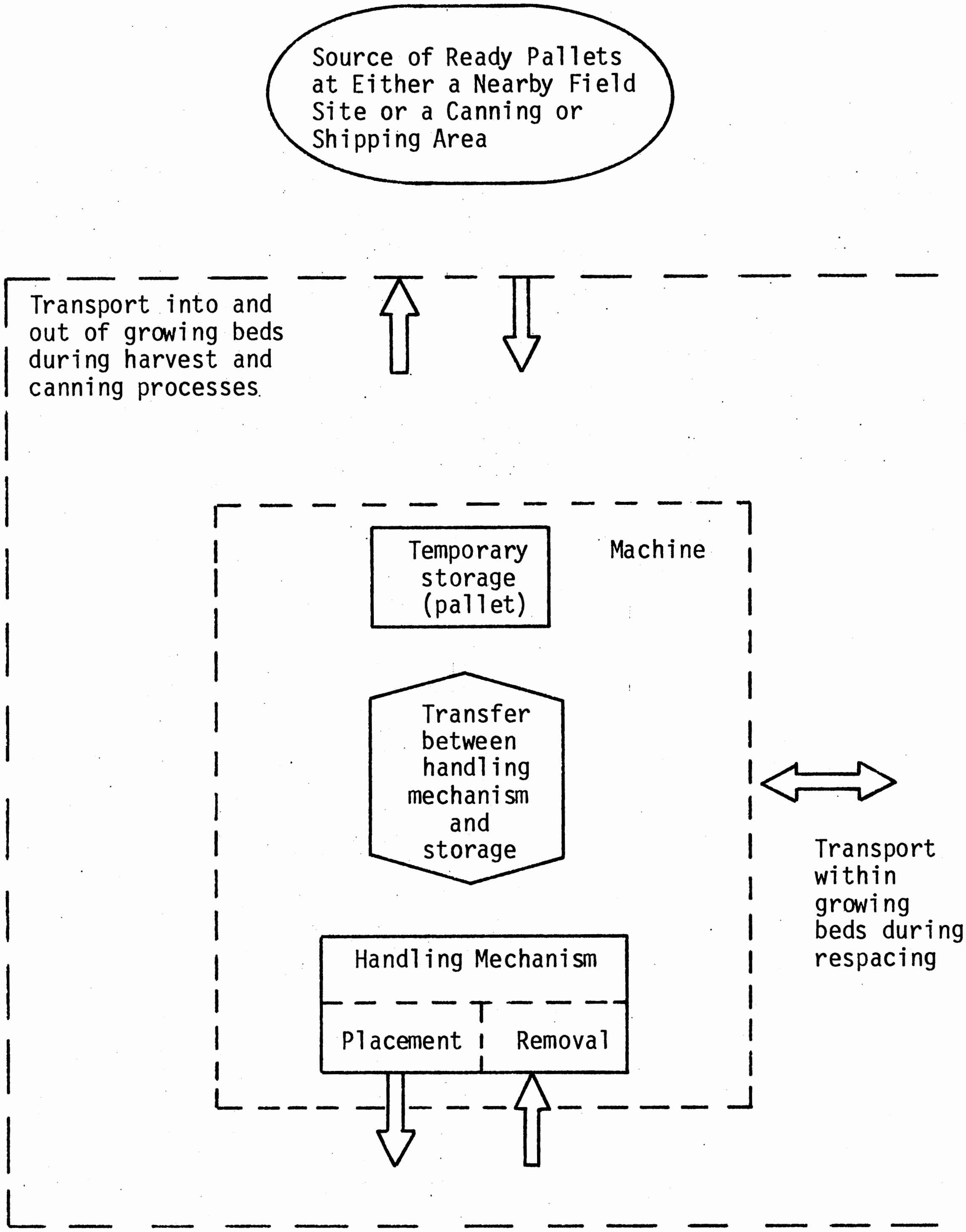


Figure 3. Block Diagram Illustrating Mechanical Handling Operations and Functions Relative to the Entire System

For purposes of classification, description and development, the mechanism of each concept will be considered to handle each container unit individually.

Individual Handling

Since by definition the handling mechanism would handle containers one at a time. Unless the mechanism is operator guided the mechanism must locate each container, process it, then continue to the next. For any given swath width, this type of operation would require that the mechanism track back and forth across a swath width necessitating a stop and go motion on the part of the machine for each swath width of containers. A second alternative is that the machine must pick up a single line of containers parallel to the direction of travel thus requiring a forward and reverse movement of the machine which would be inherently inefficient as well as being rather difficult due to increased dependence on operator control. Selecting the first of these two alternatives, a flow diagram may be constructed to describe the handling process (Figure 4).

Line Handling

The handling of a line of containers could be done with the lines either perpendicular or parallel to the line of travel of the handling machine. Since less stop and go motion is associated with handling containers perpendicular to the swath width, this method will be considered for further discussion. Again, a block flow diagram (Figure 5) may be constructed to describe the operation of the handling mechanism. In this case, a line of containers one swath width wide and perpendicular

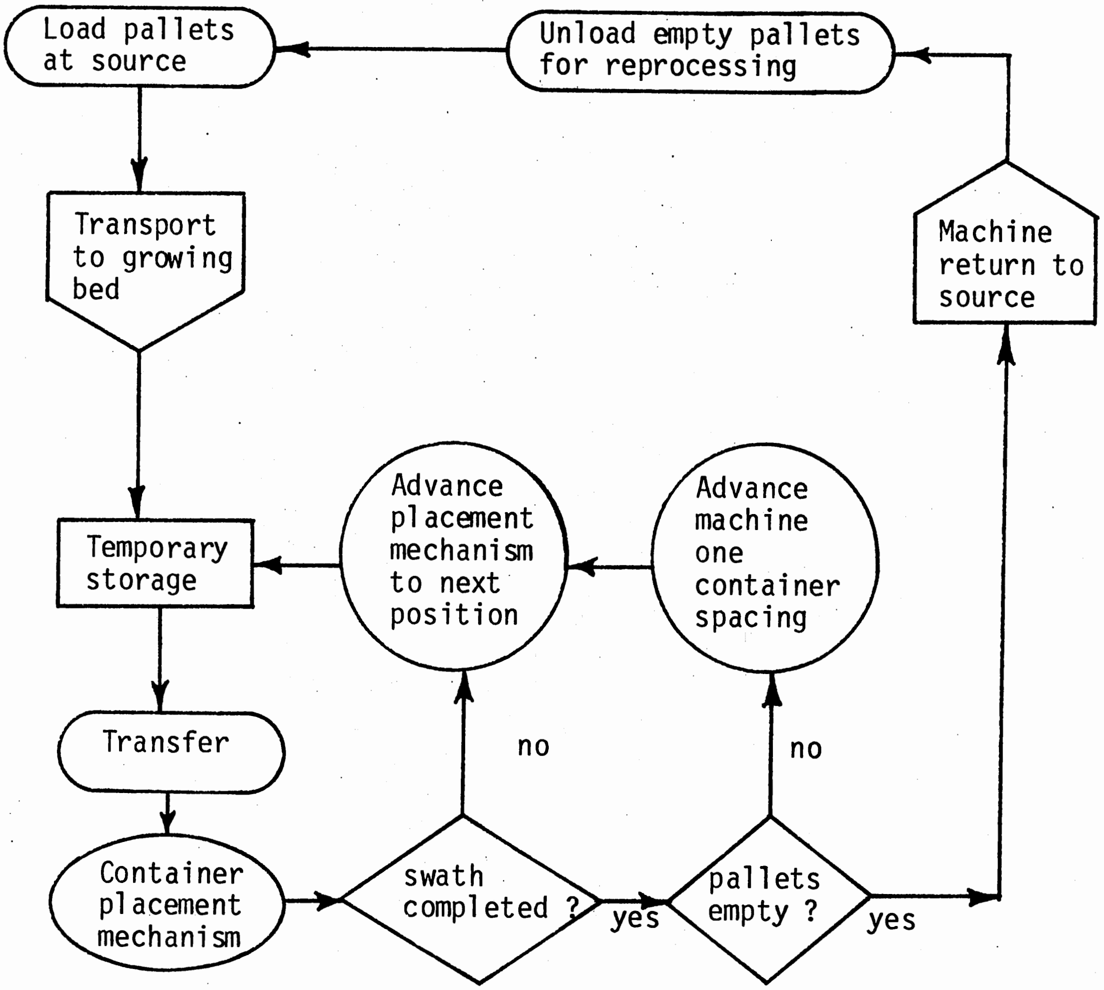


Figure 4. Flow Diagram Showing Operation of Individual Handling Concept

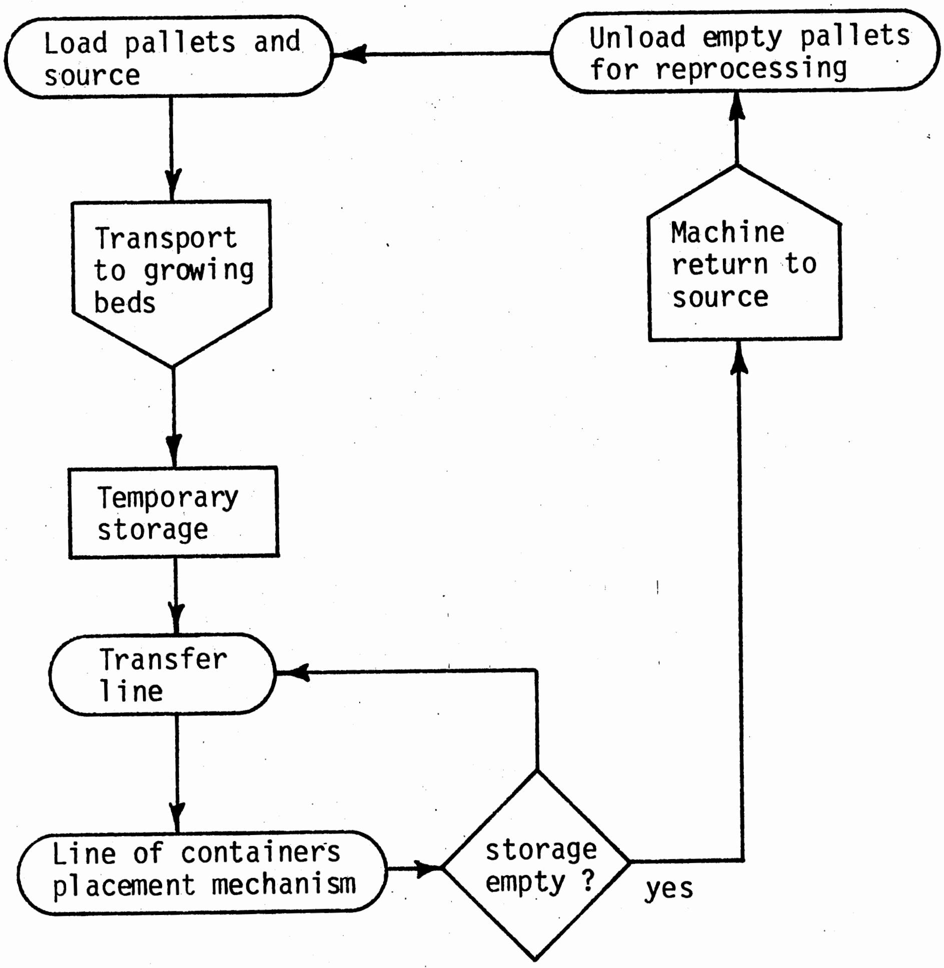


Figure 5. Flow Diagram Showing Operation of Line Handling Concept

to the line of travel is handled as a unit by the placement and transfer mechanisms. It should be noted that either the transfer or placement mechanism must provide a means for respacing of containers. Since the handling mechanism would be required to place the containers edge to edge, spacing in the direction perpendicular to the line of travel would probably be in integer container spacings with spacing parallel to line of travel controlled by the speed of the handling mechanism relative to the speed of the machine itself.

Block of Container Handling

The handling of blocks of containers of n x m lines was the logical first concept to be tried by previous investigators (Brown; 1976; Jones, 1973). It was observed that two variations of block handling were possible. The first was to handle small blocks of containers in a manner similar to those of the previous two concepts. The second method will be considered in which one unit or block of containers is handled per machine trip into the growing beds. In this particular case, only one cycle of the placement mechanism would be required in transferring and placing the containers. As a result, the entire handling cycle would be operator controlled due to the necessity of careful positioning of the machine and is described by Figure 6.

Concept Analysis

Each of the three concepts previously described were diagrammed as to their processes. One of the primary gauges of efficiency of the handling method is the handling rate. For this reason each of the concepts will be compared relative to the handling rate possible. Such

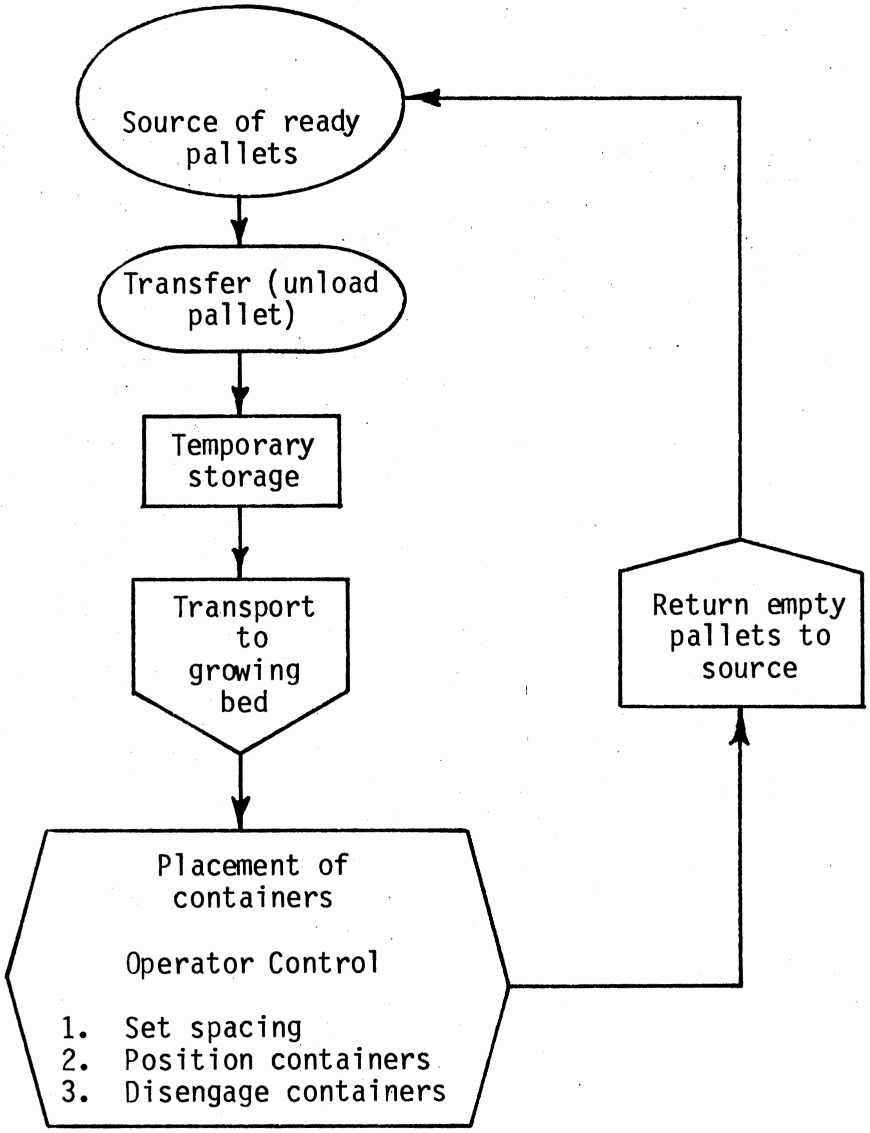


Figure 6. Flow Diagram Showing Operation of Block Handling Concept

comparison of handling rates was made by use of the general equation

$$\text{Handling Rate} = \frac{L}{T + P + C} \qquad 4.1$$

Where: L = Containers per load

T = Transit time between source and growing bed

P = Pallet transfer time

C = Container transfer time

Since each of the quantities L, T, and P would be relatively constant for given conditions, they were considered as such for comparison purposes. Transit time T was set at 45 seconds (60 meters at 1.33 m/s) and the pallet transfer time was arbitrarily selected as 75 seconds. For comparison to block handling, L represented one pallet of up to 150 containers. The main variable for each concept then becomes the container transfer time C, which describes the time required for unloading from the pallet and placement of containers in the growing bed.

To handle containers singly, the handling mechanism would be required to track back and forth across the swath width necessitating a stop and go motion on the part of the overall vehicle. The single container transfer time may then be described by

$$\text{Single Container Transfer Time} = L\left[R + \frac{(RS) + (CS) + (D)}{(S)\ (W)}\right] \qquad 4.2$$

Where: L = Containers per load

R = Time to load and unload one container

RS = Row spacing

CS = Container spacing

D = Container diameter

S = Machine speed

W = Number of containers per swath width

Line handling is more simply described since a line of containers across the swath width is handled simultaneously thus allowing the overall machine to move forward at a regular rate. It was noted that for this condition to exist the placement and transfer mechanism must be synchronized with the ground speed. The equation then becomes:

$$\text{Total Container Line Transfer Time} = \frac{(L)\,(R)}{W} \qquad 4.3$$

Where: L = Containers per load

R = Time to load or unload one line

W = Containers per line

Total block handling time was directly dependent upon the cycle time. As shown in Figure 7, for a constant container transfer time of four seconds the single container handling concept lags behind both the row and block handling methods. This lag is due almost exclusively to the time required to track back and forth across the swath width. In comparing the row and block handling methods, it was noted that a container transfer time of four seconds was unrealistic for purposes of positioning and lifting a block of up to 150 containers. This is especially true if these containers are spaced and the respacing operation is being done. Only one pallet of up to 150 containers was used for comparison purposes. If the more likely alternative of two or more pallets of similar size is considered, then the row handling method becomes the method of highest output and would be the preferred choice.

Further, all methods would require approximately the same personnel to get containers to an exchange point. From this point, only two

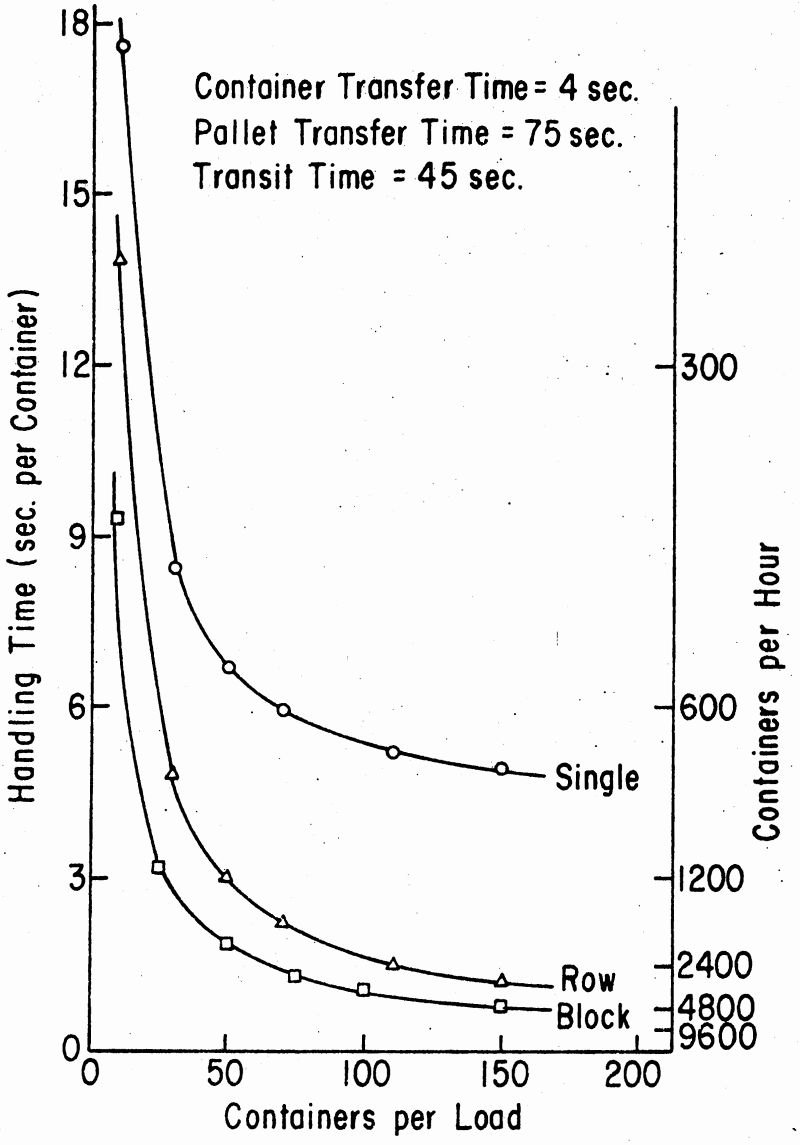


Figure 7. Graphical Comparison of Handling Concepts in Terms of Containers Per Hour

people would be required to handle containers being moved into or out of the growing beds. These would be an operator for the machine and a helper who would provide necessary assistance in transferring pallets from the source to the machine. Since past attempts at mechanization using block handling have had little success and the line handling concept appears to be best capable of meeting specifications, the line handling concept was selected for further development.

CHAPTER V

CONCEPT IMPLEMENTATION

Introduction

Having selected a concept for implementation, the next step in development is the selection of a particular design from various alternatives. Both the placement and the transfer functions of the handling mechanism may be further classified as being either continuous or discrete in their manner of operation. In the continuous type, the mechanism is constantly in operation with no defineable starting or stopping point in the handling cycle. This type of mechanism would handle containers as soon as the container moved within its influence or reach. The only requirement to handling of subsequent containers is that previous containers must move sufficiently clear to allow engagement and movement of subsequent containers.

The discrete handling method is different in that a complete cycle must occur for each container handled, i.e., the same portion of a given mechanism handles each container such that the previous container must be completely handled prior to engagement of a subsequent container.

Header

Of the two possible operation methods for the placement mechanism, the continuous system would be preferrable due to the simpler operation in terms of location and orientation relative to container units. With this choice made, possible header mechanisms would operate by means of belts or chains which could be either collectively or independently driven. Due to the narrow insertion space between containers in edge to edge spacing, such a chain or belt would be limited to operating in a vertical plane in order to allow pulleys or sprockets space to operate. Further, the limitations on space would require each side of the chain or belt to engage one side of the container. Of the alternatives considered in Appendix B, the use of a chain using flexible tines was selected for use due to the availability of parts and their relative durability.

Pallets

Several types of pallets were possible for use. However they did not all meet the requirements of the specifications. Due to the necessity of their being moved on and off of the machine in addition to low cost, accessibility, and high portability, plywood pallets with guide strips and coated with epoxy paint were selected for use with the machine.

Transfer Mechanism

Several possible methods for the transfer mechanism exist. As with the placement mechanism, general classification into continuous or discrete operation is possible. With the continuous method, containers would be moved off of the pallet at a specified rate thus allowing for a given spacing which could be adjusted by varying the speed of the transfer mechanism and/or the machine travel rate. Spacing of containers perpendicular to the line of travel could be achieved by blocking alternate placement or transfer mechanisms or by cycling such blockage in a way that allowed alternating mechanisms to place containers.

Of the possibilities discussed in Appendix B, vibration of the pallet was selected for use due to its lack of moving parts in handling of containers. Additionally, speed could easily be varied by varying hydraulic flow to the vibrator and pallets could easily be moved on and off of the framework.

Construction

Having selected the mechanical components to perform the individual functions, the components were integrated into a single unit with a four container swath width (Figure 8). The header mechanism was constructed of number 40 roller chain with alternating single pitch and high sidebar double pitch links with a 90° torsion spring mounted on each high sidebar link by means of a shaft and pin assembly (Figure 9). Each chain was mounted on a steel track formed by two steel plates. The plates were separated by spacers placed near their edge which provided for both rigidity of the track and a means of keeping the chain from binding between the plates. Idler sprockets mounted on shafts set between the plates allowed the chain to round the corners easily (Figure 10). Springs are compressed by means of the track being extended at the forward and upper sprockets with the extension tapering along the track to allow for gradual compression. The inner edges of the tracks were also beveled and a support welded across the extremities of the extensions. The five track assemblies were connected by a steel tubing framework to which each track assembly was clamped and along which it could slide to allow for adjustment relative to the container diameter. The entire

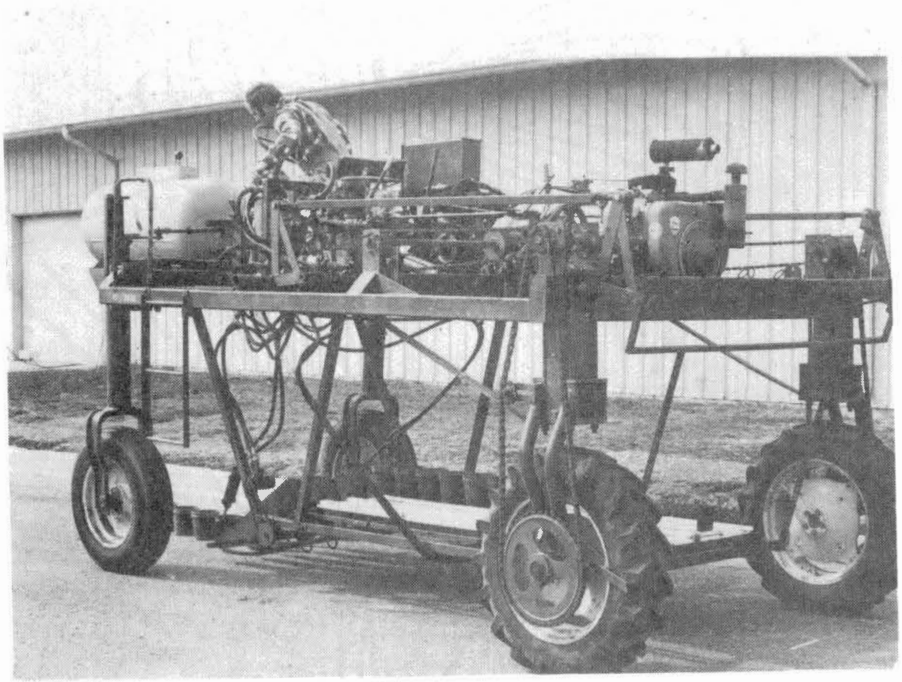
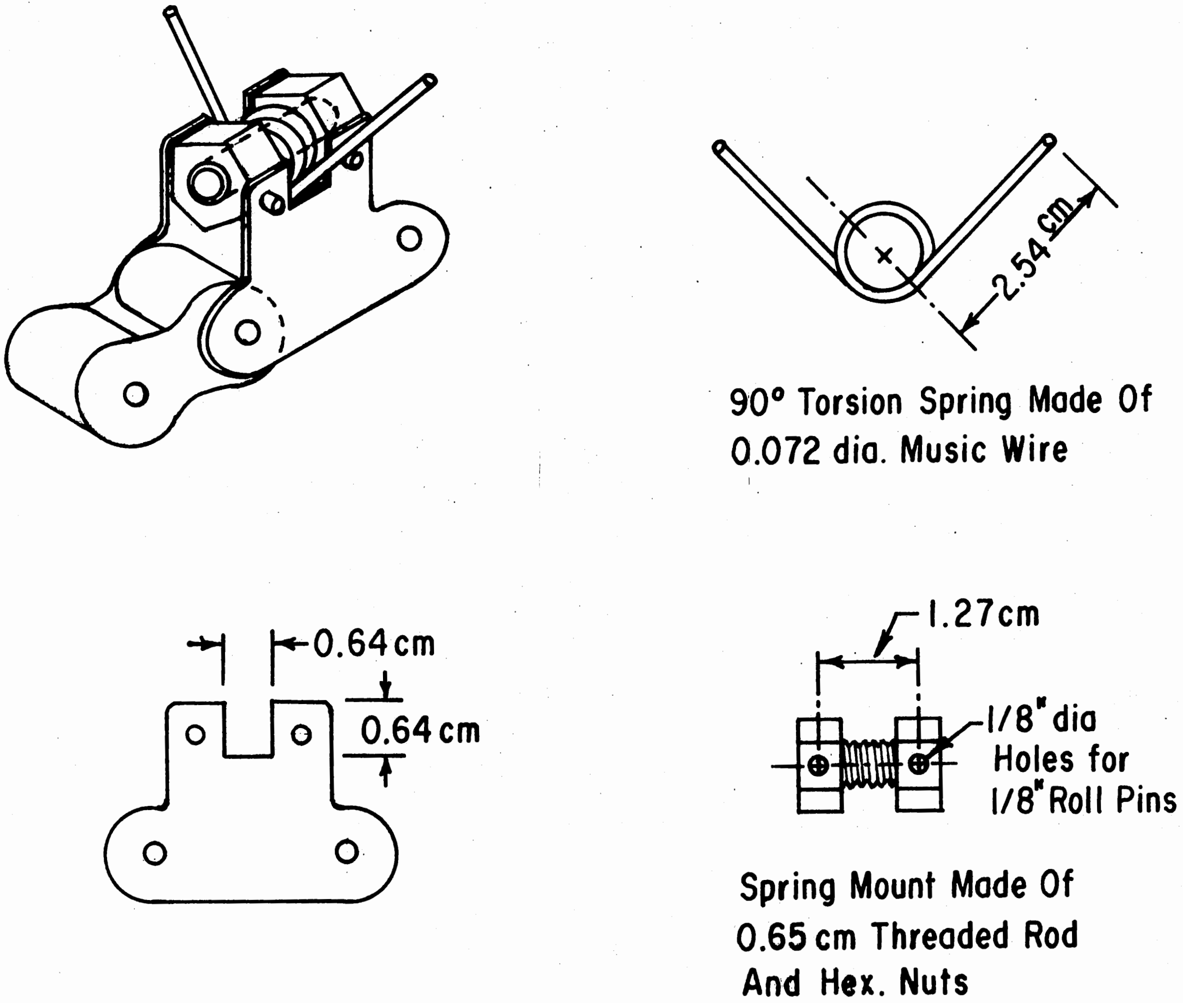


Figure 8. View of High-Clearance Tractor With Handling Mechanism and Pallet Mounted Beneath



90° Torsion Spring Made Of
0.072 dia. Music Wire

Spring Mount Made Of
0.65 cm Threaded Rod
And Hex. Nuts

Figure 9. Diagram of Torsion Spring Assembly and Selected Parts

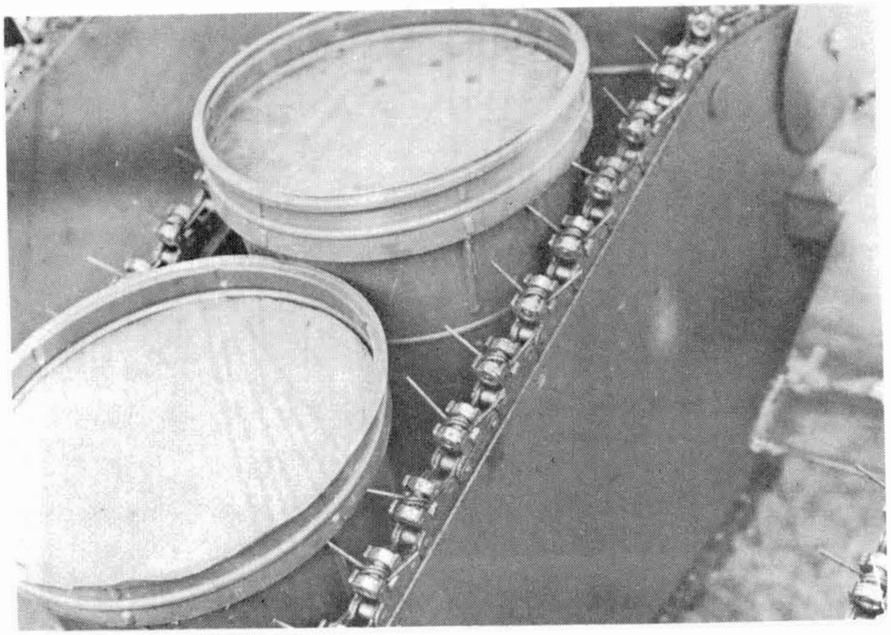


Figure 10. Closeup View of Header Showing Reinforced Containers, Torsion Springs Mounted on Roller Chains and the Rotating Compression Plate

header assembly was mounted on a hydraulically powered steel driveshaft by means of bearings and positioned such that the power sprockets tightened the roller chains evenly. The height of the forward end of the header assembly above the ground was controlled by means of hydraulic cylinders mounted on each side of the header and attached to the main support frame.

The pallet frame was constructed of steel tubing and 7.62 cm steel channel to which a hydraulically driven rotary vibrator was mounted. The pallet frame was supported by rubber blocks used as dampers with two steel springs at the forward end of the pallet. Steel tangs at the forward end of the frame were positioned between the header tracks and provided support for containers moving off the pallet between the chains (Figure 11).

The pallet was constructed of 1.9 cm plywood with 5.08 cm wooden strips used as container guides. The pallet top was coated with white epoxy base paint.

The entire assembly consisting of header, pallet, and pallet support was mounted between the wheels of a high-clearance tractor in such a way that the header was visible to the operator through the tractor platform. The rear of the pallet support assembly was attached to hydraulically actuated levers which could raise or lower the rear of the assembly to change the slope of the pallet for loading or unloading (Figure 12).

Since the tractor was equipped with a variable speed transmission, small changes in ground speed, especially at low speeds could best be accomplished by changing the engine speed or the variable speed drive. For this reason, a separate hydraulic system was used to power the

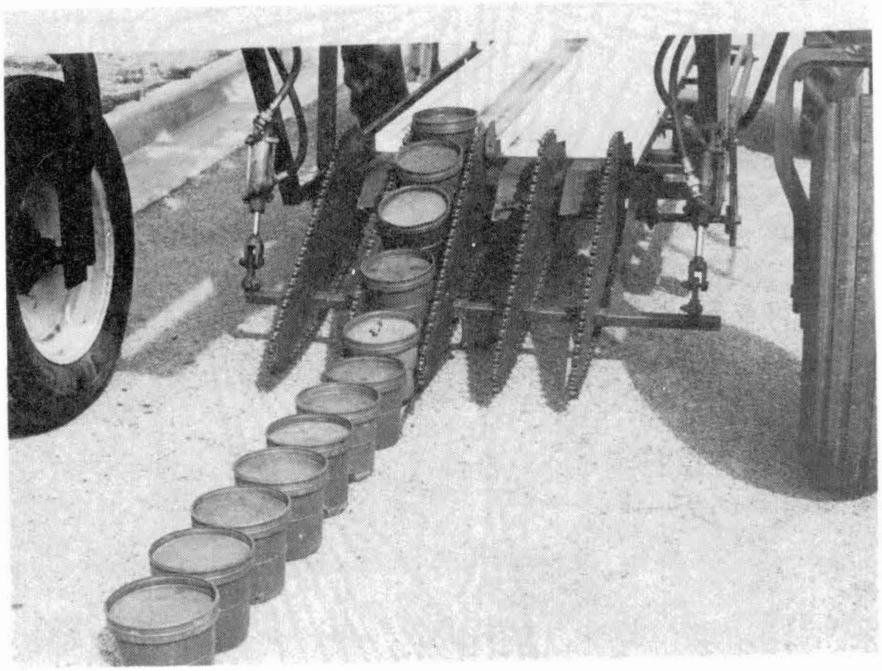


Figure 11. Front View of Header During Edge to Edge Loading Sequence Showing Headers, Pallet and Support and Lower Portion of Hagee

Figure 12. Rear View of Header and Pallet During Unloading Sequence

vibrator and chain drive. The hydraulic system circuit is shown in Figure 13.

The hydraulic system provided a motive force for the chain drive and the vibrator (cylinders controlling pallet and header height were operated by the tractor's hydraulic system). An 8 hp. engine powered a gear pump which supplied flow and pressure to the system. A priority valve then split the system into two branch circuits which supplied the drive and vibrator. Pressure relief valves on each branch monitored the pressure and held it constant. Flow control valves in each branch circuit controlled the rpm of the chain motor and the vibration frequency of the hydraulic vibrator. Control valves allowed the vibrator and chain drive to be easily switched from forward to reverse operation. A limitation of the system was that the gasoline engine used could not supply the desired level of power to the gear pump thus limiting the flow and pressure available. Initial trials of the vibration system demonstrated its unsuitability for this application. The most effective setting for the vibrator was made and remaining flow was diverted to the chain drive motor.

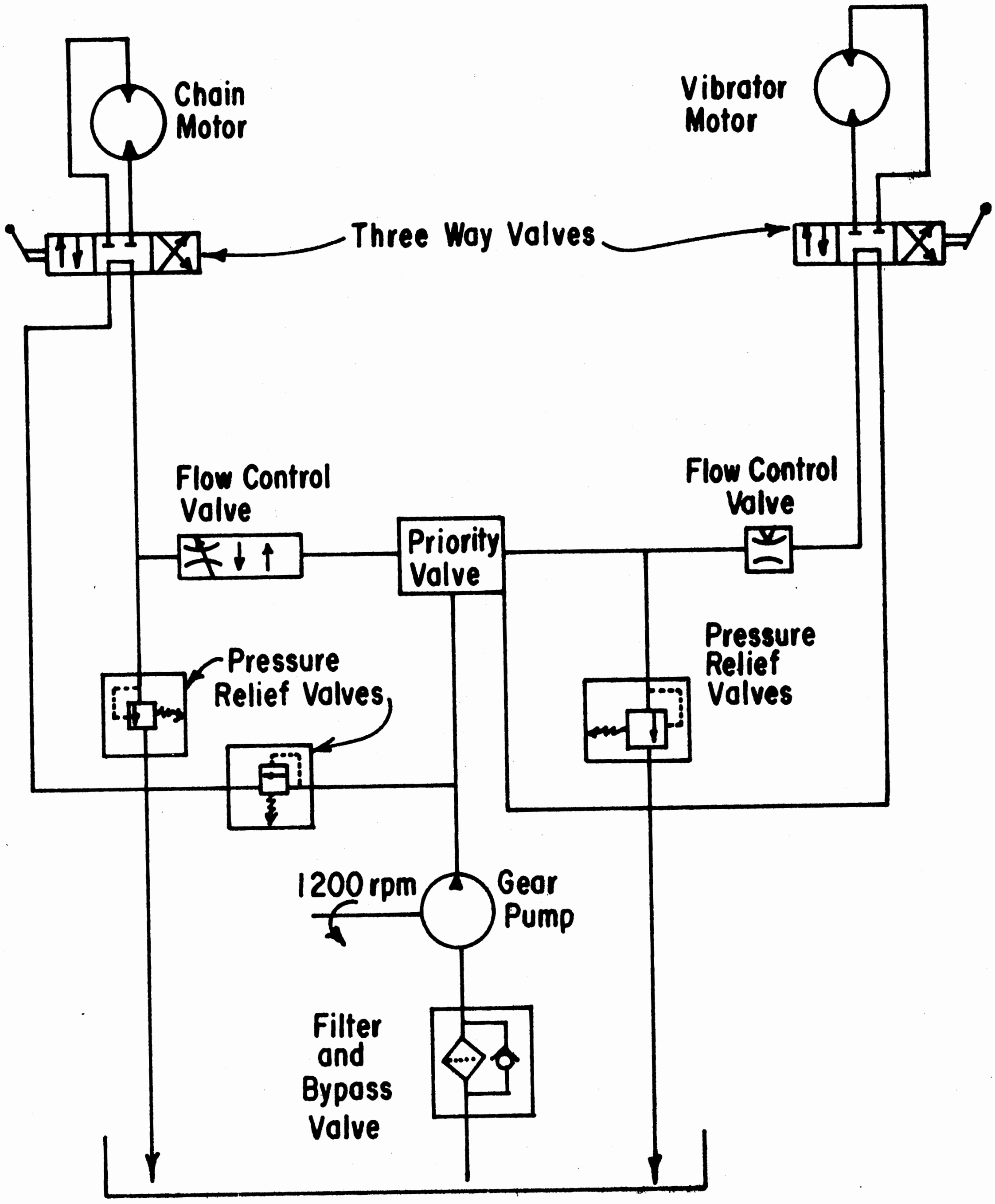


Figure 13. Schematic Diagram of Hydraulic System

CHAPTER VI

EVALUATION

Location

Testing of the machine was made on an asphalt parking lot located adjacent to the Oklahoma State University Agricultural Engineering Research Laboratory. For convenience the edge of a concrete curb served as a baseline for purposes of measurement and guidance of the tractor by the operator. Designated parking stripes painted on the asphalt perpendicular to the curb were used as starting and stopping points for test runs.

Equipment

The necessary equipment for data collection consisted of containers, the handling machine, a stopwatch, and measuring tape. A line of masking tape was laid parallel to the curb for purposes of container alignment and positioning during onloading. The tape was marked in 2.54 cm increments to allow for observation and measurement of movement of the containers along the ground as they were being engaged by the handling mechanism.

Mechanical Limitations

Initial operations of the machine indicated several limitations of the design. The first limitation was the lack of velocities available both on the part of the handling mechanism and the tractor. Although the tractor could move more slowly, the lowest constant velocity of the tractor was .29 m/s. Ideally the chain speed could be increased or slowed to compensate for tractor ground speeds. In actuality it was found that the rigid spring compression plates bent or broke the torsion springs at higher rates of speed. As the insides of the steel plates became scored from the spring tips dragging on them, the breaking and bending action tended to occur at lower speeds as well. To alleviate this problem, the spring compression plates were replaced by rotating disks with beveled inner edges and by guide bars at the leading edge of the header (Figure 14). The disks were mounted on the outside of the track on the same shaft as the idler sprockets at the top rear corners of the track. This arrangement allowed greater flexibility in speeds but still did not allow chain speed to adequately compensate for ground speed in offloading. In offloading, the machine was in reverse and had a faster ground travel speed than the lowest forward speeds.

Another limitation encountered was that movement of containers by vibration could not be evenly maintained with a full pallet load due to the flexibility of the plywood pallet and the change in frequency as the pallet unloaded. As a result only one line of the swath width was used in evaluation and containers were manually moved away from the header during loading. Additionally, soil mixture tended to shake out of the container drainage holes causing containers to bind between guides. The dry soil tended to shake out quite easily, but when wet would shake out only slightly. Excessive soil leaving the container was considered unacceptable as it impeded travel of the containers along the pallet. For this reason, the soil was placed in a plastic bag in the container.

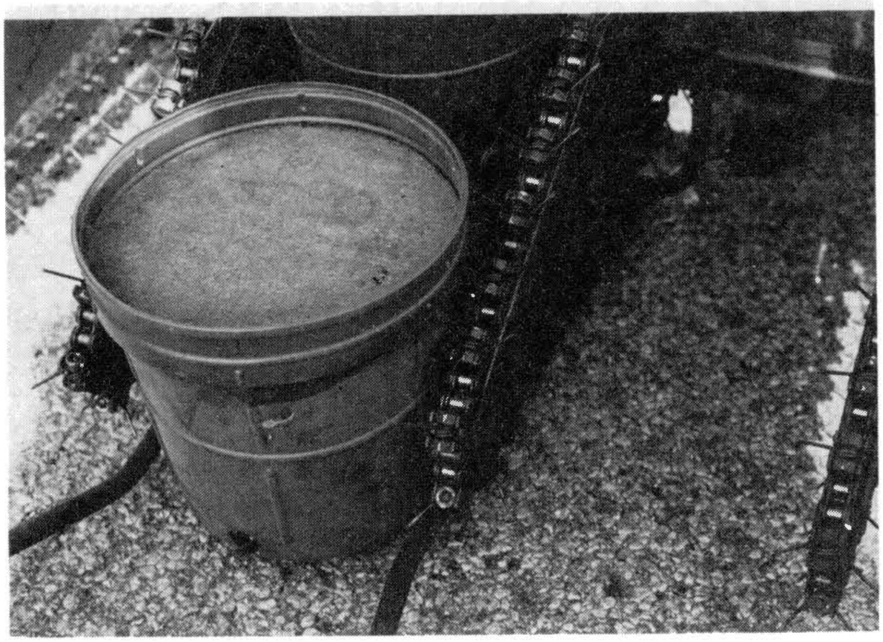


Figure 14. Closeup View of Front of Header Showing Guide Bars, Container and Chains During Placement

Also, as the surface of the painted pallet became wet it tended to impede container movement. After several loading and unloading cycles the paint was sanded off in spots, thus allowing the wood to swell. A strip of stainless steel on the pallet eliminated this problem.

Experimental Design

The objective of machine testing was to measure the success of the placement or removal of containers on the ground and their transfer between ground and pallet. The success of transfer and placement or removal was assessed directly by noting the number of containers successfully handled during various trial runs. Since the mechanism was to be able to respace containers, the factors which affected respacing were of interest. Since the vibratory pallet system was found to be unsatisfactory in transferring containers on or off the pallet as previously described, it was not considered for further investigation. The remaining factors which could affect the spacing of containers were chain and tractor velocities.

Loading

In loading of containers from the ground, no objective measurements could be made other than observation of the number of containers successfully handled and notation of any problems occurring during such handling. Since container loading was affected by the speed ratio or the spacing, the experimental runs consisted of two spacings at two velocity ratios with three runs per combination (Table I). Since tractor ground speed was governed largely by a variable speed belt drive, the tractor speed could not be easily varied within the velocity range of

TABLE I

EXPERIMENTAL SEQUENCE FOR CONTAINER LOADING

Run No.	Velocity Ratio	Chain Velocity (m/s)	Spacing (diameters)	Run No.	Velocity Ratio	Chain Velocity (m/s)	Spacing (diameters)
1			1	1	1.20	.34	2.25
2	.97	.26	1	2		.40	1
3		.25	1	3			1
4			2.25	4			1
5			2.25	5			2.25
6			2.25	6			2.25
1	1.00	.41	1	1	1.22	.26	2.25
2		.40	2.25	2		.31	2.25
3			2.25	3			2.25
4			2.25	4			1
5			1	5			1
6			1	6			1

the header chains. In order to obtain maximum information within the range of chain and tractor velocities available, twenty-four runs were made using two velocity ratios (1.0 and 1.2) and two container spacings (1.0 and 2.25 container diameters).

Unloading

The primary concern in container placement was the spacing and variation of spacing. In placement of containers, a direct relationship was observed to exist between horizontal chain velocity and tractor velocity with respect to container spacing. This relationship may be expressed as:

$$\text{Container spacing} = \frac{\text{(Container Diameter)}}{\text{Velocity Ratio}} \qquad (6.1)$$

$$\text{where velocity ratio} = \frac{\text{Chain Velocity}}{\text{Tractor Velocity}}$$

Since chain velocity was specified by this relationship for a given container spacing, the factors of interest are the tractor velocity and the ratio of chain velocity to tractor velocity. As described in the mechanical limits, the range of ratios possible was limited due to the higher minimum velocity of the tractor when in reverse. For this reason the experiment was set up in a 2 x 2 factorial using two tractor velocities and two velocity ratios. A third ratio was produced when the tractor speed was mis-set resulting in a ratio midway between the original ratios. The tractor velocities used were approximately 0.3 and 0.4 m/s with resulting velocity ratios of 0.253 and 0.36. According to Equation 6.1 these values would produce somewhat larger than desired container spacings but were the best available within machine limitations. The experiment was then run in a randomized block design using tractor velocity as the block and velocity ratio as the treatment with 3 replications.

Operation Procedure

Loading

In the loading operation, 12 containers were set along the line of tape at either 1.0 or 2.25 container diameter center to center spacings. Chain velocity was then set by comparing chain revolution time with a precalculated time and adjusted to match the calculated time. Tractor velocity was then checked and adjusted until the desired velocity was obtained. During a run containers were manually moved away from the header after being placed on the pallet (since the vibratory stystem was inoperative). Following each run, containers were manually unloaded and respaced.

Unloading

In unloading (placement) chain velocities were set similar to the loading operation. Tractor velocities were initially checked over a set distance and subsequently checked by clocking the time it took to place twelve containers on the ground. Since backing of the tractor was difficult, the operator used the straight edge of a concrete curb to align the wheels with while minimizing steering corrections.

During a run, an observer walked beside the pallet to ensure that containers were fed uniformly into the header by the vibratory system. Another observer recorded data and operated the stopwatch. Following each run, the the container locations were established relative to an arbitrary point in the direction parallel to the line of travel and relative to the edge of the concrete curb in the direction perpendicular to the line of travel. Initial and final location and orientation of the pallet was made by measuring the distance from the base line to the center of the container line on the pallet at both front and rear. Containers were then reloaded prior to the next run.

Data Analysis and Discussion

Loading

As noted in the experiment design, the loading operation can supply only a limited amount of information due to the lack of objective measurements other than the success rate. Examination of the data presented in Appendix D, indicates that for velocity ratios greater than or equal to 1.0, 100 percent transfer of containers from ground to pallet is generally possible with no slippage of the containers along the ground. Such slippage is considered unacceptable since on a rougher surface than asphalt (such as bare soil or gravel of a growing bed) the container would be more likely to tip over than to slide.

Maximum tractor velocity attempted was 0.50 m/s at a 1.0 velocity ratio in which only a partial run was made. The run was terminated due to the high velocity of the chain knocking containers away from the header resulting in containers being jammed sideways. The chain springs were also badly bent at this operating speed necessitating replacement and repair of chains. The highest successful tractor velocity was 0.40 m/s at a velocity ratio of 1.0. For the container used, this results in a loading velocity of 2 container diameters per second or 7200 containers per hour per single row of containers on 1 diameter spacings. This rate ignores the time consumed in transport into and out of the growing beds, number of such trips per hour and the time to load and unload pallets. When the velocity information is substituted into the conceptual equations (Equations 4.1 and 4.3), the handling rate is reduced to 1.2 containers per second or 4320 containers per hour for the conceptual conditions. It was noted, however, that the conceptual conditions were for purposes of comparison with other concepts. If a load of 500 containers on two pallets was considered, other conditions being the same, then the handling rate is 2.3 containers per second and the hourly rate is 8456 containers per hour. The limiting factors to higher loading rates are the quantities of time required in traveling into and out of the growing bed and loading and unloading pallets.

Unloading

Analysis of container offloading provided verification of prediction of container spacing based on Equation 6.1 and an indication of the effects of tractor velocity and velocity ratio on the variation of this spacing. Figure 15 provides a graphical presentation of the sample means and deviations with respect to tractor velocity and velocity ratios. Table II provides a tabular comparison of predicted and actual spacings. Some of the differences indicated are considered to be a result of errors introduced by the irregular vibration of the pallet and in observation and recording of data. As shown, predicted spacings (Equation 6.1) for several of the runs exceeds the mean spacings of the samples. This exceedance is most marked on the .30 m/s tractor velocities. The discrepancy in spacings is considered to be mainly due to the

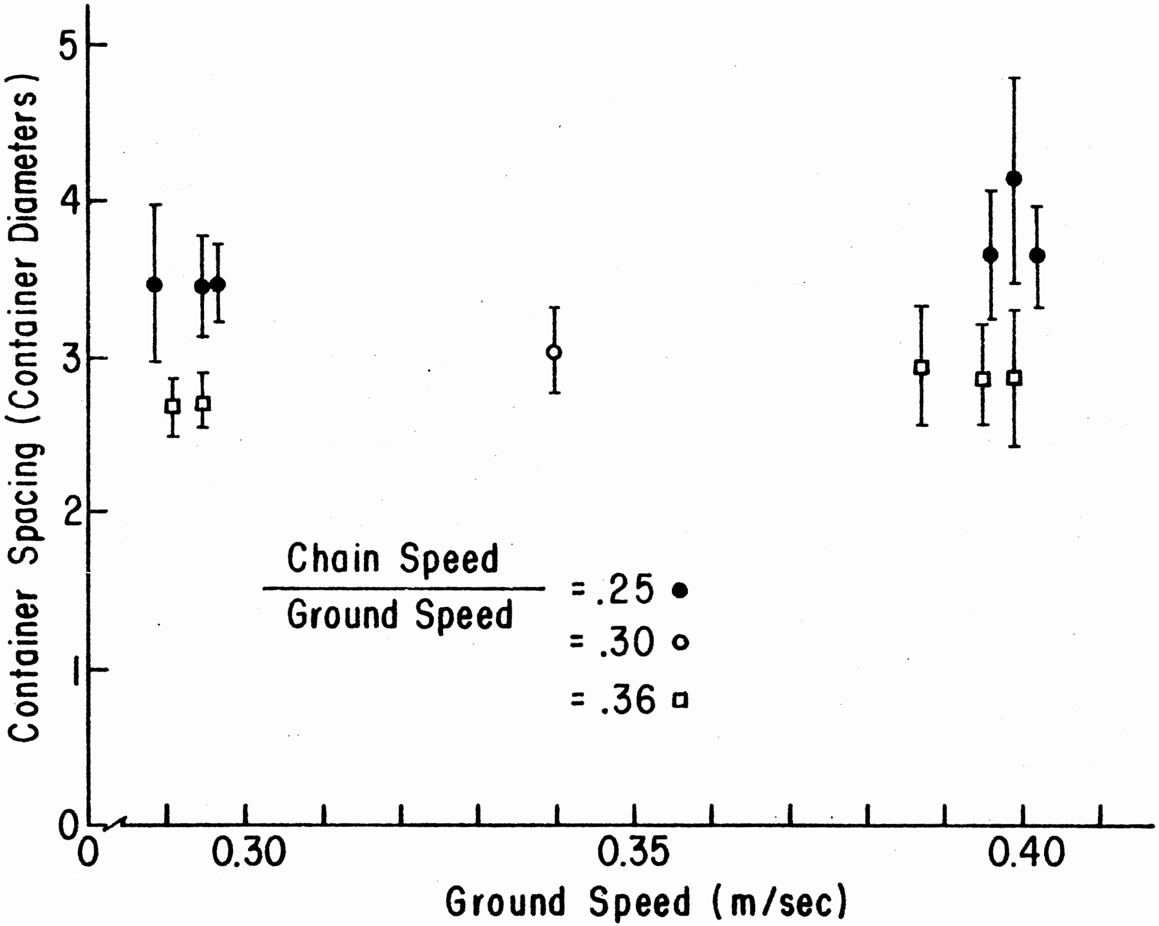


Figure 15. Graphical Results of Offloading Trials Showing the Variation of Spacing for Different Speed Ratios

TABLE II

COMPARISON OF PREDICTED SPACING AND SAMPLE MEAN OF CONTAINER SPACING

Run No.	1	2	3	1	2	3	1	2	3	1	2	3
Tractor Velocity (m/s)	0.40	0.39	0.39	0.40	0.40	0.40	0.28	0.30	0.29	0.29	0.29	0.30
Chain Velocity (m/s)	0.14	0.14	0.14	0.10	0.10	0.10	0.07	0.08	0.07	0.10	0.10	0.09
Actual Velocity Ratio	0.363	o.360	0.366	0.254	0.252	0.250	0.265	o.251	0.253	0.352	0.356	0.30
Predicted Spacing (diameters)	2.75	2.77	2.73	3.93	3.97	4.0	3.77	3.98	3.95	2.84	2.80	3.27
Sample Mean Spacing (diameters)	2.86	2.88	2.93	3.65	4.2	3.65	3.48	3.48	3.45	2.70	2.68	3.0
Sample Standard Deviations (diameters)	.4	.33	.38	.42	.67	.32	.50	.26	.33	.17	.18	.26

effects of the pallet feed rate being ignored in formulation of the equation since the feeding rate was set as a constant. As containers entered the header, the springs engaged containers while traveling horizontally. With containers being fed edge to edge into the header a spacing of one diameter is maintained along the chain. However, the chain slopes downward at a 30° angle after engaging the container. Since the pallet feed rate attempts to maintain an edge to edge spacing, the spacing between container center of gravities was decreased as containers were fed resulting in a reduced spacing. This effect becomes more pronounced as tractor speeds decrease while feeding velocity remains constant since container spacing along the chain tends to be further decreased. Effects of pallet orientation (machine alignment) were negligible on container spacing.

As illustrated in Figure 15, the spacing variation tends to decrease with decreasing tractor velocity and increasing chain ratios. An analysis of variance between the spacing variations indicates significant effects on spacing variation by both tractor velocity and velocity ratio. With consideration of the packing effect of the vibration device, these effects may be insignificant when compared with the effects of an even and uniform feeding rate. Further and more detailed data analysis was limited by the mechanical limitations of the machine and mechanisms. Possible total handling rates could conceivably be as great as those of onloading.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

The objectives of this study were to: (1) identify and describe primary operating parameters and specifications associated with mechanization of the in-field container handling operations of movement, placement, and removal; (2) develop two or more conceptual models of a mechanized in-field container handling and movement method and determine primary operating characteristics; and (3) construct an experimental model of a handling and movement method and evaluate model performance with respect to input specifications and operating conditions.

Study of the literature and direct observations indicated a lack of industry standardization in materials and procedures. The critical factor in acceptance of mechanization was found to be the degree of increase in labor productivity. Other specifications established with respect to current trends in the industry were that palletization be used, that the machine be resistant to the wear generated by the working environment, and that in performing the necessary functions, the machine mechanisms should be reversible in operation.

Three conceptual models were generated and described in equation form with respect to handling rates. Comparison was made on a theoretical basis and the line handling concept selected for implementation.

A hydraulically driven mechanism was built which transferred containers between ground and pallet. The mechanism was mounted beneath a high clearance tractor. The performance of the machine was evaluated with respect to placement accuracy and success of removal from or the placement on the ground. For comparison purposes, actual handling rates were computed by use of the initial conceptual formula.

Conclusions

1. The use of vibration is unacceptable as a means of transferring containers on or off of pallets.
2. For the mechanism evaluated velocity ratios greater than 1.0 were required in loading the pallet.
3. Minimum variation in spacing of containers occurred at lower ground speeds and higher velocity ratios.
4. The workforce required in container handling could be reduced to two persons per handling machine while the process rate could be increased by a factor of two or more with the use of a fullscale machine similar to the prototype.

Suggestions for Future Work

The problems encountered with this design led to several suggestions for changes in future designs. Since the plywood pallet and vibration system proved unsuccessful in transfer of pallets, a new method should be examined. One possibility would be the use of a gravity feeding pallet (such as a roller conveyor) used with a positive feed mechanism to better control container spacing. The gravity feed pallet should have a means to allow loose soil to fall to the ground to avoid jamming of containers or excessive wear.

A smaller narrower chain with more flexible tines should be used to avoid container damage and further reduce space required between containers. A tapered guide ahead of such chains near the ground would aid in alignment of containers.

Design of a special transport vehicle would greatly aid in placement and removal of containers. Such a vehicle should be steerable from either end, provide steering location(s) from which the operator may closely monitor the placement and transfer mechanisms, and be capable of handling several pallets or levels to increase load size.

The final suggestion is that a more durable container be designed with less flexibility and smaller size.

Two areas are suggested for further study. One concerns the improvement of the experimental model to result in a working prototype. Another is a study of how nursery operations would be altered to accomodate and take advantage of such a machine.

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APPENDICES

APPENDIX A

IMPLEMENTATION ALTERNATIVES

Header Alternatives

The primary requirements were that the header or leading edge of it be able to be inserted between containers spaced edge to edge, that it be continuous in its operation mode, and that it be reversible in operation. Generation of alternatives was done with respect to these two main parameters. Secondary characteristics were used to select the most desirable.

1. Highly flexible belts operating back to back in the horizontal plane (Figure 16). Engagement would be by means of the distance between opposing sets of belts being slightly less than the container diameter at the point of contact. Containers would then be flexed slightly as the belts pushed the container onto a ramp. Each belt would be backed by a metal stiffener. Drive power would be in the horizonal plane beneath the pallet end of the header.

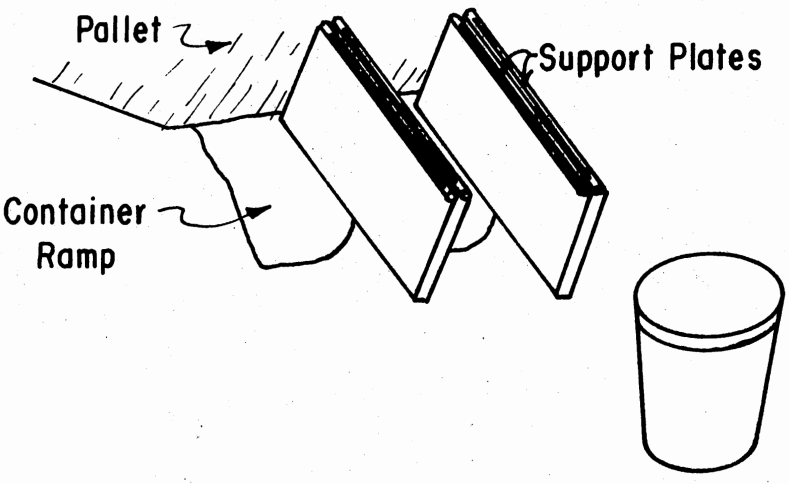

Figure 16. Sketch of Header Alternative 1 Showing Flexible Belts Operating in Horizontal Plane

2. One belt operating in the vertical plane which engages containers by either difference between the container diameter and the space between belts or by the container lip riding on top of the belt (Figure 17). Flanges could be attached to the belt or molded into the shape of the belt to allow better engagement.

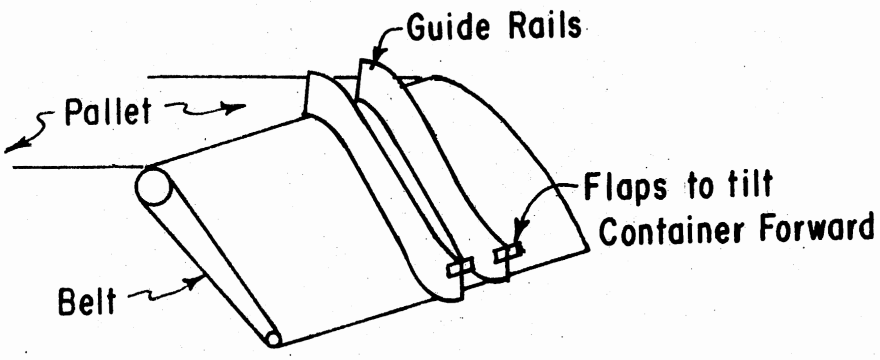

Figure 17. Sketch of Header Alternatives 2 and 3 Showing Single Belt (or Chain) Operating in the Vertical Plane

3. A similar arrangement could exist in the use of chains with attachments such as spring tines which would engage the container by means of the container lip (Figure 17).
4. Another alternative is the use of a flexible belt as wide as the swath width and operating parallel to the ground (Figure 18). The leading edge would be of low radius in order to slip under containers tilted forward by rails with flexible flaps.

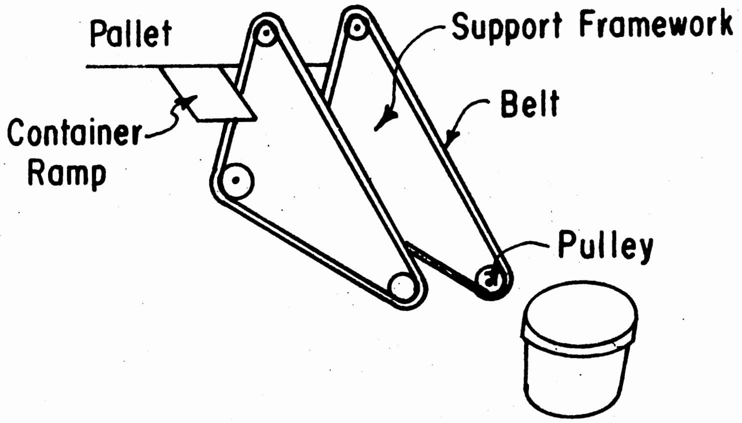

Figure 18. Sketch of Header Alternative 4 Showing Flexible Belt Across Swath Width

Each of these four alternatives were possible conceptually. However their practicality with respect to durability, cost, and component availability enables a choice to be made.

Options 1 and 4 both depend on highly flexible wide belts which are both expensive and not readily available. A further question in light of cost and availability is their durability for this application. Options 1 and 4 were not further considered for these reasons.

Option 2 is acceptable in terms of probable component parts cost and availability. However component belt costs would rise as if the cross section were of special design or flanges were attached to the belt. Another problem might arise in the belts flexibility on the longitudinal axis thus allowing for the possibility of containers being dropped or jammed. Providing an inexpensive and readily accessible belt were used durability is of relatively low priority.

Option 3 would allow for attachment of virtually any type of flange or tine and would have minimal flexure in the longitudinal axis due to the planar nature of the chain link connections. Although cost would be moderate durability would be high. Availability of replacement components should be reasonably good depending on chain design.

Pallet and Transfer Mechanism

Since the pallet and transfer mechanism were frequently interrelated, they were considered at the same time.

1. Option 1 consists of a sheet pallet (such as plywood) divided into lanes which each have a belt powered by a pulley or roller at each end of the pallet. Containers would be placed on the belt by the header and moved away from the header at a specified rate.
2. This option consists of a solid sheet which may be vibrated at a certain frequency and amplitude to carry containers either toward or away from the header. The pallet could be tilted to aid in such transfer. Pallets could be removed according to need and easily reattached by means of clamps.
3. A roller conveyer of relatively small rollers cold be mounted within the framework of a pallet. The conveyor could be powered or tilted to carry containers toward or away from the header.

The first option makes use of wide flexible belts and is therefore considered unacceptable for the reasons discussed under the header.

The second option would meet the needs of durability versus cost. It also allows for convenient handling of pallets since the plywood would be relatively light. Durability would depend on the type and thickness of protective coating.

The third option is relatively expensive as well as pallets being rather bulky and heavy thus, hard to handle. Adequate durability exists only if the rollers are equipped with sealed roller bearings.

For the reasons discussed the second option was selected due to the relative cost and the ease of handling.

APPENDIX B

LOADING DATA

TABLE III

RAW DATA FOR ONLOADING OF CONTAINERS USING VARIOUS CHAIN AND TRACTOR SPEEDS

Run No.	Spacing (ctr to ctr in container diameters)	Velocity Ratio	Ground Travel Time (sec. per 13.72 m)	Chain Travel Time (sec. per) 4.65 m)	Comments
1	1.0	.989	52.9	15.7	4th container was picked up low, was carried up sideways and dumped on pallet. Container was damaged (before?) and was replaced. 100 percent pickup of containers with slight slippage noted.
2	1.0	.968	52.1	15.8	Driver off-centered on #8 container. Other containers only marginally affected due to guards. #8 picked up crooked and was not released onto pallet properly. 100 percent of containers picked up.
3	1.0	.979	52.7	15.8	100 percent pickup with slight slippage of containers.
4	2.25	.894	47.8	15.7	#3 container tipped forward during pickup. No effect noted except at release onto pallet.

TABLE III (Continued)

Run No.	Spacing (ctr to ctr in container diameters)	Velocity Ratio	Ground Travel Time (sec. per 13.72 m)	Chain Travel Time (sec. per) 4.65 m)	Comments
5	2.25	.996	53.6	15.8	100 percent pickup with considerable slippage less than 2 1/2 cm.
6	2.25	.988	53.2	15.8	100 percent pickup with considerable slippage. Containers #1 and #4 slipped 5 cm but others less than 3 cm.

TABLE III (Continued)

Run No.	Spacing (ctr to ctr in container diameters)	Velocity Ratio	Ground Travel Time (sec. per 13.72 m)	Chain Travel Time (sec. per) 4.65 m)	Comments
1		1.01	27.2	7.9	Chain will not operate adequately--5 containes picked up then high speed of chain knocked container away and jammed containers in header sideways. Springs on the chains were badly bent as a result of operating at this speed. Both chains were replaced and repaired.

TABLE III (Continued)

Run No.	Spacing (ctr to ctr in container diameters)	Velocity Ratio	Ground Travel Time (sec. per 13.72 m)	Chain Travel Time (sec. per) 4.65 m)	Comments
1	Edge to edge	.998	34.0	10.0	11 containers picked up properly. #8 container slid, picked up wrong and pushed remaining containers out of line causing #12 container to tip over.
2	45.7 cm on container	1.03	34.9	10.0	100 percent pickup with no slippage.
3	45.7 cm on container	.986	33.6	10.0	100 percent pickup with slight slippage less than 2 cm on containers #5 and #6.
4	2.25	.992	33.5	9.9	100 percent pickup, no slippage.
5	1.0	1.00	33.8	9.9	100 percent pickup, no slippage.
6	1.0	.999	33.7	9.9	100 percent pickup, no slippage.

TABLE III (Continued)

Run No.	Spacing (ctr to ctr in container diameters)	Velocity Ratio	Ground Travel Time (sec. per 13.72 m)	Chain Travel Time (sec. per) 4.65 m)	Comments
1	2.25	1.198	40.8	10.0	100 percent pickup, no slippage.
2	1.0	1.183	40.3	10.0	100 percent pickup, no slippage.
3	1.0	1.189	40.5	10.0	100 percent pickup, no slippage.
4	1.0	1.16	39.6	10.0	100 percent pickup, no slippage.
5	2.25	1.25	42.5	10.0	100 percent pickup, no slippage.
6	2.25	1.19	40.6	10.0	100 percent pickup, no slippage.

TABLE III (Continued)

Run No.	Spacing (ctr to ctr in container diameters)	Velocity Ratio	Ground Travel Time (sec. per 13.72 m)	Chain Travel Time (sec. per) 4.65 m)	Comments
1	1.0	1.23	53.4	12.7 12.8	100 percent pickup, no slippage.
2	2.25	1.22	52.5	12.6	100 percent pickup, no slippage.
3	2.25	1.21	52.5	12.7	Container #5 slid down chain approximately 15 cm and #12 container tipped over onto pallet. Chain springs may be loosening and bending slightly.
4	1.0	1.22	52.6	12.6	100 percent pickup, no slippage.
5	1.0	1.23	52.7	12.6	100 percent pickup, no slippage.
6	2.25	1.23	53.0	12.6	Container #5 slid on chain.

APPENDIX C

UNLOADING DATA

TABLE IV

RAW DATA FOR UNLOADING OF CONTAINERS USING VARIOUS TRACTOR AND CHAIN VELOCITIES

Run No.		1		2		3	
Tractor Travel Time (sec)		16.0		16.3		16.9	
Chain Travel Time (sec)		32.1		32.8		32.8	
Pallet Location (cm)	Front Rear		177.2 177.2		174.6 183.5		179.1 178.4
		X	Y	X	Y	X	Y
Container Location (cm)		373.4	172.7	316.2	179.1	372.7	176.5
		431.8	97.2	372.1	176.5	419.1	174.6
		488.3	172.1	432.4	179.1	479.4	173.3
		539.1	172.1	500.4	178.4	548.0	174.0
		590.6	172.1	552.5	181.0	597.5	173.4
		634.4	172.7	657.9	182.9	727.1	174.0
		756.9	174.0	709.9	183.5	792.5	173.4
		826.8	174.0	773.4	185.4	854.1	172.7
		891.5	174.0	828.0	86.1	908.1	173.4
		960.8	175.3	899.2	188.6	965.8	169.5
		1012.8	177.2	958.9	188.0	1026.2	172.7
Pallet Location (cm)	Front Rear		175.9 193.0		192.4 207.6		167.6 431.2

Comments: Vibration of containers not working well.

TABLE IV (Continued)

Run No.		1		2		3	
Tractor Travel Time (sec)		20.5		23.1		20.2	
Chain Travel Time (sec per 4.65 m)		46.0		46.0		46.0	
Pallet Location (cm)	Front		177.8		226.1		168.3
	Rear		167.6		212.1		168.3
Container Location (cm)		X	Y	X	Y	X	Y
		499.1	161.9	304.8	206.4	490.2	167.0
		585.5	161.3	422.9	200.7	564.5	167.6
		660.4	159.4	496.6	196.9	643.3	167.0
		727.1	156.8	574.7	194.9	713.7	167.0
		805.2	156.2	649.6	191.8	787.4	165.7
		878.2	156.2	745.5	188.0	851.5	165.7
		941.1	153.7	822.3	186.7	929.6	168.3
		1005.8	153.0	899.8	185.4	1005.2	168.9
		1095.4	150.5	991.9	180.3	1076.3	168.9
		1162.1	49.9	1070.6	177.2	1141.7	170.8
		1237.6	149.2	1146.2	174.6	1231.9	171.5
		1313.8	150.5	1228.7	174.6	1304.3	173.4
Pallet Location (cm)	Front		148.0		171.5		175.3
	Rear		151.1		167.0		189.2

TABLE V

DATA CALCULATED FROM TABLE IV RAW DATA

Tractor Velocity (m/s)	0.40	0.39	0.39	0.40	0.40	0.40
Chain Velocity (m/s)	.145	.142	.142	0.101	0.101	0.101
Velocity Ratio	.363	.364	.364	.253	.253	.253
Container Spacings (cm)	58.4	55.9	46.4	86.4	118.1	74.9
	56.5	60.3	60.3	74.9	73.7	78.7
	50.8	67.9	68.6	66.7	78.1	70.5
	51.4	52.1	49.5	78.1	74.9	73.7
	43.8	51.4	56.5	73.0	95.9	74.3
	54.0	54.0	73.0	62.9	76.8	67.9
	68.6	52.1	65.4	64.8	77.5	75.6
	69.9	63.5	61.6	89.5	92.1	71.1
	64.8	54.6	54.0	66.7	94.0	65.4
	69.2	71.1	57.8	75.6	75.6	90.2
	52.1	59.7	60.3	76.2	82.6	72.5
$\Sigma\chi$ (cm)	639.5	642.6	653.4	814.8	939.3	814.7
$\Sigma\chi$ (cm^2)	37953.9	37990.8	39431.2	61088.9	82046.8	60762.1
$\overline{\chi}$ (cm)	58.1	58.4	59.4	74.1	85.4	74.1
S (cm)	8.8	6.7	7.9	8.6	13.6	6.5

TABLE V (Continued)

Tractor Velocity (m/s)	0.28	.30	.29	.29	.29	0.40
Chain Velocity (m/s)	.145	.142	.142	0.101	0.101	0.101
Velocity Ratio	.268	.250	.259	.359	.359	.306
Container Spacings (cm)	70.5	71.8	72.4	60.3	52.1	62.2
	80.0	72.4	76.2	58.4	54.0	59.7
	83.2	62.2	64.1	50.8	59.7	22.8
	71.1	72.4	61.6	54.6	57.2	59.1
	69.2	71.8	81.3	53.3	49.5	59.7
	66.0	60.3	64.8	51.4	56.5	67.3
	79.4	73.7	69.9	55.4	52.1	55.9
	77.5	76.2	66.0	50.8	52.1	55.2
	66.7	69.9	73.7	55.9	52.1	55.2
	67.3	67.9	63.5	53.3	60.3	71.8
	45.7	76.8	78.7	59.7	52.1	61.6
$\Sigma\chi$ (cm)	776.6	775.4	772.2	603.9	598.3	643.9
$\Sigma\chi$ (cm^2)	55869.6	54931.7	54659.9	33270.9	32665.5	39366.6
$\overline{\chi}$ (cm)	70.6	70.5	70.2	54.9	54.4	58.5
S (cm)	10.2	5.2	6.7	3.4	3.5	12.9

VITA

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