Impact of Cross-Aisles on Travel Distance in a Warehouse

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by
Saad H. ALBarrak
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CHAPTER I

PROBLEM STATEMENT

"Handling" cost constitutes a significant part of the overall cost of warehouse operation and the warehouse layout can have a great impact on the cost. Since reducing the distance travelled to retrieve items of an order will definitely result in lower handling cost, the warehouse layout should be a major consideration in the design of a warehouse system.

One of the important questions that must be addressed in warehouse layout design is "how many cross-aisles should be included in the layout design?" The inclusion of cross-aisles in the layout will surely result in more space requirement and therefore increase the area and warehouse perimeter costs such as the capital investment and maintenance costs, as well as some increase in travel distance. But cross-aisles can reduce the total distance travelled in multiple item picking and as a result reduce the total handling cost. The important point is that the advantages due to "cross-aisles" must outweigh their disadvantages.

In this study, four different layout designs
(different in terms of the number of cross-aisles only) are evaluated in terms of impact of "cross-aisles" on the average distance travelled in retrieving items (which has a direct impact on handling cost) of a specific order. The following four alternative layouts are considered:

<table>
<thead>
<tr>
<th>Layout #</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>with no cross-aisles</td>
</tr>
<tr>
<td>2</td>
<td>with one cross-aisle</td>
</tr>
<tr>
<td>3</td>
<td>with two cross-aisles</td>
</tr>
<tr>
<td>4</td>
<td>with three cross-aisles</td>
</tr>
</tbody>
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The effects of three different qualitative factors on the performance (in terms of travelled distance) of each alternative are investigated. Those factors are such as: items' aggregate demand distribution, order size distribution, items arrangement (view). The effect of change in the "magnitude of order size" (a quantitative factor) and warehouse size will also be examined. The objective of this study is a set of guidelines to assist the warehouse designer.
CHAPTER II

LITERATURE REVIEW

Many analysts have dealt with the problem of warehouse layout design in the past two decades. Among the earliest articles dealing with this problem are those by Francis (4) and Berry (3). Francis developed analytical models with which one can arrive at the dimensions of a rectangular warehouse (i.e. length*width) which will minimize the cost of items movement (handling costs) and warehouse perimeter costs. In his article, Francis also tried to respond to the question of the ratio of aisle space compared to the total warehouse space that will result in the least increase in total cost. However, Francis didn't deal with the details of aisles design. Berry (3) tried to identify the elements of warehouse layout. One of the elements that Berry looked into was the optimum number of aisles in a layout design. He developed a formula--derived from his general analytical model--which determines the optimum number of aisles for a given ratio of occupation cost of the building to the movement cost of goods stocked in the warehouse. Yet, for Berry's formula yield correct answers, the assumptions he
made in developing his model have to hold true. His strongest assumptions are that the cost of warehouse operation can be optimal based on the mean distance travelled to pick and store an item and average throughput for all items in the warehouse.

Many parameters must be evaluated before Berry's can be used. Some of these parameters such as the ratio of the building volume variable cost to traveling variable cost and the ratio of building area variable cost to travelling variable cost cannot be easily evaluated for a new warehouse since the data needed do not exist. In his concluding remarks, Berry pointed out the fact that even the simple assumptions he made in his model produced mathematically complex equations, and hence, if other factors were to be included in that model (i.e. item's demand distribution parameters, order size distribution parameters, etc.) the equations will be too complex to solve analytically.

Other articles which discussed the warehouse layout problem have considered the impact of goods storage assignment in minimizing the travelled distance in handling (1, 7, 8, 9, 12). Assignment approaches for optimal layout have been discussed by Francis & Mallette (10). Thornton, Francis and Lowe (5) warned that both the area taken up by goods as well as their relative frequency of handling (turnover) must be considered in order to solve the layout
problem of interest. Graves and White (6) analyzed the overall warehouse layout design in a case study using CRAFT (a layout planning computer program. Roberts & Reed (11) discussed the problem of optimal warehouse bay configuration, where optimality here is defined as the minimization of costs of handling and construction under the assumption of randomly assigned storage location. None of the aforementioned articles considered the impact of aisles on the materials handling cost.

Lately, Bassan, Roll and Rosenblatt (2) compared two configurations of shelves, taking in consideration the handling, area and perimeter costs. In their paper, they laid down some general preference rules depending on the ratio of the relevant costs. While they did not explicitly consider the impact of cross-aisles, one of the layouts they studied for both cases they considered (i.e. homogeneous & zoned warehouse) included a cross-aisle. Their work only compared the two layouts—in terms of their impact on handling, area, and perimeter costs for each of the above mentioned cases without concentrating on the impact of a specific factor on the costs. No prior studies were found that addressed the specific question of the impact of cross aisles on material handling cost that is the distance travelled in handling. This study will evaluate the impact of cross-aisles on material handling.
REFERENCES


CHAPTER III

SOLUTION APPROACH AND DESIGN

A. Method of Solution

The objective in this study is to explore the impact of cross-aisles on the travel distance incurred in items picking. In order to make the results of the study generally applicable, the impact of variations (encountered in practice) in the environment of the system upon the travel distance was studied. The following factors are considered "most influential" on the savings in travel distance that result from using cross-aisles in a warehouse layout plan:

(1) Stocked items' aggregate demand distribution function
(2) Order size distribution function
(3) Average order size
(4) Number of cross-aisles in a layout
(5) Item's arrangement (storage assignment)
(6) Warehouse size (storage capacity)

The first three are stochastic variables.

Based on results reported in the literature, an analytical model of this problem could be too complex to be solved. Even with simplifying assumptions and a
limited number of variables analytical models gave rise to complex equations. In addition, analytical models require the use of point estimates as expected value statistics and usually are not amenable to changes in the system environment, and hence, limits the generality of model results. According to Phillips:

For many years I have contended that if a system is designed and/or controlled by expected values, that system is doomed by failure, overdesign, inefficiency or all. The reason is clear: The long run acceptability of a system is more dependent upon system surges or variabilities than any other factor.

In his article, Phillips mentioned many reasons for preferring simulation over analytical models in analyzing material handling systems. Describing the flexibility of computer simulation, Phillips added: "Computer simulation models address a stochastic world that is described by probabilistic measures and is reflected by empirical density functions, probability density functions or process dependent state equations." Simulation allows an analyst to both incorporate variable phenomena in the model and study the behavior of the system under these influences. Since warehouse design problems have these properties simulation seems to be a promising method for solving the problem of this study.

Having decided to use a simulation model, the question of which simulation language to use had to be settled. FORTRAN language was used to simulate the system
under study for the following reasons:

(1) Since the system does not have any queuing phenomena as will be seen from the assumptions for any distinct process orientation except for the stochastic process generators which are relatively simple in the modeled system a process-oriented language like GPSS offers no advantages. Process-oriented languages are usually inflexible to fit specific system models like the system in this study. SLAM is one of the most recently developed languages which is highly efficient because it combines the three world views (process orientation, activity scanning orientation, and event orientation). Unfortunately only the process-oriented part of SLAM is available for this research.

(2) The simulation model to be used is relatively simple and does not need a special simulation language for its modeling.

(3) FORTRAN as a high-level language is very flexible and therefore efficient in modeling the system under study.

(4) The universal familiarity and availability of FORTRAN is another advantage.

A FORTRAN computer simulation model was developed for analyzing the problem under study which will be described in the next chapter.
B. Assumptions

The simulation model is based on the following assumptions:

1. The random number generators used produce perfectly random numbers (independent).

2. The studied system is time-independent because there is no queuing phenomena (waiting time, picking time, etc., are not considered). The study is only concerned with the travel distance incurred in items' picking and not in picking time.

3. All of the stocked items in the warehouse are of the same size, and hence the assigned storage space is the same for each item. The standard space is 4 x 3 unit².

4. Each item is assigned to a specific location in the warehouse according to its popularity. No item should have more than one location.

5. Each incoming order of size N will have N different items in it (no more than one unit ordered of the same item in a single order). Since this study is only concerned with travel distance, the travel to pick one item in a specific location will be the same even if more than one piece is ordered, because the travel will be to one location only.

6. The input/output point (door) of the warehouse
is located at its corner.

(7) Only "horizontal" movement is considered, since the aim is to reach the item's location. Vertical movement and distance is considered negligible. The picker can only travel either in parallel or orthogonal to the longitudinal walls of the warehouse.

(8) The warehouses considered in this study are approximately "square" in shape.

(9) The items' aggregate demand distribution and order size distribution functions are discrete; however, continuous distribution functions are used in the model which are assumed to efficiently approximate the discrete functions.

(10) The travel distance is the distance traversed to satisfy a specific order. Travel incurred in items' stocking or relocating is not considered.

(11) Each incoming order is expected to be satisfied because an infinite supply of stocked items is assumed.

C. Experimental Design

C.1 Factors and Response

This study is mainly interested in the six factors mentioned above. In order for the results of this study to have a wide range of applicability, a broad variation in the six factors was considered. Details on each factor
and the choice of factor levels are as follows:

a. Item's aggregate demand distribution:

This factor is a "qualitative" factor which is "fixed." Three different levels are assigned to this factor which are considered representative of practical situations. Those levels are:

1. Triangular distribution function.
2. Half-normal distribution function.
3. Uniform distribution function.

The third level was only an "extreme" case to help assess the impact of item's aggregate distribution on the response. All the three levels are qualitative.

b. Order size distribution:

This is another fixed qualitative factor. Two levels were assigned to it which were:

1. Uniform order size distribution.
2. Normal order size distribution.

c. Item's arrangement (storage assignment):

A fixed qualitative factor with two levels:

1. Zig-zag assignment.
2. Parallel assignment.

The factor and its levels will be described in the next chapter.

d. Average order size:

A fixed quantitative factor with 6 levels which
are:

1. Average order size = 1 item
2. Average order size = 2 items
3. Average order size = 10 items
4. Average order size = 25 items
5. Average order size = 50 items
6. Average order size = 75 items

The choice of the levels in this manner was due to the interest in covering the full range of fluctuation expected in practice. The first level is, of course, the minimum expected average order size (which is clearly intuitive). The other five levels were chosen empirically after trying a few simulation runs that indicated those specific levels will give a representative picture of the output variable fluctuation. Since this factor was believed to have a great influence on the system's response, 6 levels of order size were considered.

e. Number of cross-aisles in the layout:

This indeed is the most important factor (as it is clear from the objectives of the study). It is a fixed quantitative (discrete) factor. The levels of this factor were chosen to conform with objectives of the study, and they were:

1. Layout with one cross-aisle
2. Layout with two cross-aisles
3. Layout with three cross-aisles
Since the study explores "savings" in distance incurred in items picking, which is a relative measure, a "reference level" as a standard of comparison is needed. The reference level is the layout without cross-aisles.

f. Warehouse size:

Here warehouse size means the warehouse stocking capacity and not the literal (conventional) meaning of size. The warehouse size is a fixed quantitative factor. Three different warehouse sizes were considered, which are:

1. Small warehouse: with stocking capacity of 432 items (different items)
2. Medium warehouse: with stocking capacity of 864 items
3. Large warehouse: with stocking capacity of 4368 items

Since a relative measure is employed in this study (in comparison to the small warehouse) the three different levels of this factor are:

1. Warehouse size = 1 (small warehouse)
2. Warehouse size = 2 (medium warehouse)
3. Warehouse size = 10 (large warehouse)

The choice of the three levels is expected to cover the range of warehouse sizes found in practice.

g. The response:

A good performance measure for the system under
study could be the average distance travelled to pick all the items in an order. However, this measure cannot be used in comparing the different combinations of levels and factors because it will be different for each case. The average distance travelled per order for a 75 item average order size will clearly be much higher than the one for 1, 5, or 10 items average order size. A relative measure is needed, since the interest is in "savings" in travel distance. Saving in travel distance is considered to be the difference between the cumulative travelled distance incurred in picking items of all the orders in a simulation run using the layout without cross-aisles and the distance incurred when using an alternative layout (i.e., with one, two or three cross-aisles). In order to come up with a relative measure by which different combinations of factors and levels could be compared, the "percent reduction in travel distance as compared to the layout without cross-aisles (it is called Layout #1 throughout this study)" is considered the "RESPONSE" in the study's experimental design.

C.2 Experimental Design Model

The factors that will be considered for analysis in this study are summarized in Table III-1.
Table III-1

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
<th>Type</th>
<th>Characteristics</th>
<th>No. of levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Warehouse size (stocking capacity)</td>
<td>Quantitative</td>
<td>Fixed, input</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>Order size distribution</td>
<td>Qualitative</td>
<td>Fixed, exogenous input</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>Item's aggregate demand distribution</td>
<td>Qualitative</td>
<td>Fixed, exogenous input</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>Items arrangement</td>
<td>Qualitative</td>
<td>Fixed, input controllable</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>Average order size</td>
<td>Quantitative</td>
<td>Fixed, input</td>
<td>6</td>
</tr>
<tr>
<td>F</td>
<td>Number of cross-aisles</td>
<td>Quantitative</td>
<td>Fixed, input controllable</td>
<td>3</td>
</tr>
</tbody>
</table>
The analysis model will be as follows:

\[
Y_{ijkmn} = \bar{Y} + A_i + B_j + C_k + D_l + E_m + F_n + \\
(2\text{-Factors interactions}) + (3\text{-Factors interactions}) \\
+ (4\text{-Factors interactions}) + (5\text{-Factors interactions}) \\
+ (6\text{-Factors interactions}) + e_{ijklmn}
\]

where:

\[
Y_{ijkmn} = \text{percent reduction in travel distance (as compared to Layout #1) due to the combination of the } i^{th} \text{ level of A, } j^{th} \text{ level of B, } k^{th} \text{ level of C, } l^{th} \text{ level of D, } m^{th} \text{ level of E and the } n^{th} \text{ level of F.}
\]

\[
\bar{Y} = \text{is the constant portion of the true response "Y" that cannot be attributed to the measured factors or unmeasured parameters.}
\]

\[
A_i = \text{the true effect of the } i^{th} \text{ level of A on Y}
\]

\[
B_j = \text{the true effect of the } j^{th} \text{ level of B on Y}
\]

\[
C_k = \text{the true effect of the } k^{th} \text{ level of C on Y}
\]

\[
D_l = \text{the true effect of the } l^{th} \text{ level of D on Y}
\]

\[
E_m = \text{the true effect of the } m^{th} \text{ level of E on Y}
\]

\[
F_n = \text{the true effect of the } n^{th} \text{ level of F on Y}
\]

\[
P - \text{factor interactions} = \text{interaction effect of P factors}
\]

\[
(P = 2, 3, \ldots, 6)
\]

\[
e_{ijklmn} = \text{Error effect}
\]
C.3 Initial Conditions and Sample Size

C.3.1 Initial conditions:

The system under investigation is a time-independent system. There is no "learning effect" which is time dependent or a queuing phenomena simply because the study is concerned with the distance travelled in items' picking and not with how long it takes to do so. Therefore, initial conditions will have no effect on the system's performance because the situation is like a system which is always "empty" and ready to process any order. Transient effects are of no concern, no data will be discarded when estimating the system's parameters. The experimental problem reduces to one of selecting the sample size.

C.3.2 Sample size (simulation run length):

Mize and Cox confessed: "It is very desirable--and yet almost impossible--to determine sample size prior to the actual running of the simulations." Since a "hypothetical" system is being analyzed and no prior knowledge is available, several simulation runs were made to estimate the needed sample size. The response of the system--savings in travelled distance--is a relative measure which is exclusively a function of the average travelled distance per order. A good estimate of the average travelled distance per order will give a good estimate of the response value. The process of selecting
the sample size is based on the formula suggested by Mize and Cox for determining a preliminary sample size. To estimate the average distance travelled per order within 10 percent of the standard deviation of the true average, use

\[
    n = \left( \frac{\frac{Z_{\alpha/2}}{d}}{d} \right)^2 \text{ where } n \text{ is the sample size needed}
\]

\[
    \alpha = \text{probability of type 1 error} = 5\%
\]

\[
    d = \frac{\sigma}{\sqrt{10}}, \ Z_{\alpha/2} = 1.96 \text{ (for standard normal distribution)}
\]

and hence:

\[
    n = \left( \frac{1.96 \times \sigma}{\sqrt{10}} \right)^2 = 384
\]

A decision must be made on how long to run the simulation model to make an empirical estimate of the needed sample size. Since simulation models use large amounts of computer time, the entire factorial design which involves six factors with 864 combinations should not be run simply for the purpose of estimating the needed sample size. A decision must be made on the combination of factors and levels which should be run for achieving the above mentioned purpose. The assumption was made that the following factors had the greatest influence on the average distance travelled per order:
1. the number of cross-aisles
2. average order size
3. warehouse size
They are the quantitative factors in the study.

A representative combination of factors and levels was chosen to be:

1. Items' aggregate demand distribution (triangular) - one level
2. Order size distribution (uniform) - one level
3. Items arrangement (zig-zag) - one level
4. Average order size - 3 levels: 1, 20, 75
5. Number of cross-aisles - 4 levels: 0, 1, 2, 3
6. Warehouse size - 3 levels: small, medium and large

Total no. of combinations = 3 x 4 x 3 = 36

The simulation was run for 500 orders for each combination and average travelled distance was compared at 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 orders. Differences were tested using a t-test and no significant difference in the average distance travelled per order was found after 200 orders ($\alpha = 0.05$). In fact, for many combinations no significant difference was found well below 200 orders (i.e., 50, 100, 150). Therefore, a sample size of 200 orders was considered sufficiently large to make a good estimate of the system's response. The detailed results of this analysis are shown in the
C.4 Factorial Design

This investigation is the so-called "exploratory" type of experiment and not an "optimization" experiment. The main interest is in assessing the impact of cross-aisles on handling distance (i.e., handling cost) in a warehouse, but at the same time it is desired to explore how the other factors influence the impact of cross-aisles on travel distance. In reference to factorial design, Davies commented:

A considerable advantage is gained if the experiment is so designed that the effects of changing any one variable can be assessed independently of the others. One way of achieving this object is to decide on a set of values, or levels, for each of the factors to be studied and to carry out one or more trials of the process with each of the possible combinations of the levels of the factors. Such an experiment is termed a Factorial Experiment.8

Davies summed up the advantages of factorial design stating the following:

(a) When there are no interactions the factorial design gives the maximum efficiency in the estimation of the effects.

(b) When interactions exist, their nature being unknown, a factorial design is necessary to avoid misleading conclusions.

(c) In the factorial design the effect of a factor is estimated at several levels of the other factors, and the conclusions hold over a wide range of conditions.9

It should be clear by now that the factorial design
is well-suited for this investigation. However, complete factorial design involves large numbers of simulation runs which will require a large amount of computer time which is a disadvantage here. This question can be settled by estimating the required computer time needed for the 864 combinations of factors and levels. This means that 864 simulation runs are needed. This number looks very horrible and discouraging. To estimate the amount of computer time needed for the whole experiment, the simulation model was run for a number of combinations and from that, needed computer time was estimated. The simulation was run for the following combination:

1 level of factor A
1 level of factor B
2 levels of factor C
6 levels of factor D
4 levels of factor E
1 level of factor F

One run of the above combinations (48 combinations) took approximately 6 minutes of CPU time. Since a total of 864 runs is needed, then the total computer time can be calculated in the following manner:

\[
time\text{ needed} = 6\text{ min.} \times \frac{864}{48}
\]

\[
= 108\text{ minutes}
\]

\[
= 1.8\text{ hours}
\]
The above calculated time is very reasonable for an investigation of this size, and hence, a full factorial design was used.

C.5 Method of Data Analysis

Since the study conducted involves exploring the different effects of the factors, the "Analysis of Variance" suits the objectives. Lispon and Seth noted:

Analysis of variance is a powerful technique for analyzing experimental data involving quantitative measurements. It is particularly useful in factorial experiments where several independent sources of variation may be present.¹⁰

Naylor and Wonnacott, in their paper on "Methods for Analyzing Data from Computer Simulation Experiments" also added one more advantage of ANOVA when they mentioned: "The analysis of variance is a collection of techniques which are appropriate when the factors affecting the response are qualitative."¹¹ Three of the factors in this experiment are qualitative. Naylor and Wannacott also justified the use of ANOVA in analyzing computer simulation data despite their departure from the classical assumptions of the analysis of variance.¹² Duncan's multiple range test is used to test for significant differences between each factor's levels.
Notes


3Ibid.

4Ibid.


7Mize and Cox, p. 130.


9Ibid., p. 253.


12Ibid., p. 706.
CHAPTER IV

SYSTEM AND MODEL DESCRIPTION

A. The Warehouse Layout:

The warehouse configuration is shown in Figure IV-1. Only the plan view is considered here, because the investigation only considers the horizontal (planar) movements in the warehouse and no vertical movement is considered. All the racks in the warehouse are identical in dimensions and capacity, since all items are assumed to have the same size. Each item stock occupies a storage area of $3 \times 4 = 12$ squared units. All aisles and cross-aisles are assumed to be identical in width which is equal to 8 units. The warehouse had one door—8 units in width—which is located at the corner. The dimensions of the warehouse are approximately equal (square), and each additional cross-aisle requires an increase of 8 units in the width of the warehouse. The racks are all doublesided with access to both sides, except that racks adjacent to walls are single-sided, and half the width of the doublesided ones. In Figure IV-2 the items are shown assigned according to popularity, a typical layout of the storage area with the items arranged according to popularity is shown in Figure IV-3.
FIGURE IV-1

Alternative Layouts (Plan View)
FIGURE IV-1 (continued)
TABLE IV-1
Variables in Figure IV-1

<table>
<thead>
<tr>
<th></th>
<th>Small W.H.</th>
<th>Medium W.H.</th>
<th>Large W.H.</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>96</td>
<td>144</td>
<td>336</td>
</tr>
<tr>
<td>L</td>
<td>126</td>
<td>168</td>
<td>364</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
<td>12</td>
<td>26</td>
</tr>
</tbody>
</table>

FIGURE IV-2
Popularity Assignment
FIGURE IV-3

A Typical Layout of Storage Area and Items Assignment.
A.1 Definitions

Category: is defined as the segment of the warehouse containing all the items stored in any two opposite sides of racks and not separated by a cross-aisle. A "Category" here does not refer to any set of item characteristics and only refers to a location of a group of items in the warehouse. The inclusion of cross-aisles will result in more categories. In Figure IV-1-a (Layout #1--no cross-aisles) there are "C" categories, but in Figures IV-1-b, c and d (Layouts #2, 3 and 4) there are "2C," "3C," and "4C" categories respectively. The warehouse was divided into location categories only to facilitate the development of the travel distance computing algorithm.

Class: is the set of "categories" which have the same distance from the longitudinal wall of the warehouse. Like "categories", the inclusion of cross-aisles will result in more classes. In Layout #1 (no cross-aisles) only one class of categories is found because all the categories have the same distance from the longitudinal wall, but in Layout nos. 2, 3 and 4 there are 2, 3 and 4 classes respectively. Again, "class" here does not refer to item characteristics, it only refers to location.

The following assumptions were used in developing the computer model (relate to Figure IV-3).

(1) Each item has a storage area equal to 12
squared units (3 x 4).

(2) Point "a" is a picking point which is defined to be on the center line of the aisle and the center line through the opposing storage locations 1 and 2. Since both locations can be accessed from this point "a", the travel distance to pick from either location will be the same. The same relationship is true for each pair of storage locations on opposite sides of an aisle. Hereafter, the picking points a, b, c, etc. are designated as the centroids of the corresponding storage locations.

(3) Moving between adjacent centroid points (i.e. from point "a" to point "b") requires a move of four units.

(4) I/O is the input/output point and the picking of every order is assumed to start from I/O and end in I/O (roundtrip of the picker).

(5) The items are assumed to be assigned to popularity groups. The item location (in each category) nearest to the I/O point is designated as NFIRST. For example: Itmes no. 1, (N+1) and (2N+1) are NFIRST for their respective categories beginning at the end of the aisles closest to I/O.

B. The Variables

1. Items' aggregate demand distribution:

Stocked items in the warehouse are characterized by
their numbers which are indicative of their respective popularities. Every item is assigned an item number depending on its popularity—the item of the highest popularity designated as item number 1 and the item with the lowest popularity is assigned the number LN. In this investigation LN was set equal to: 432, 864 and 4368 for the small, medium and large warehouse respectively. Each item is assigned a unique number; that is, no two items have the same number even if they were equally popular.

Three distributions were used in this study, they are:

(a) Triangular: in which 25% of the stocked items account for 45% of the aggregate demand, i.e., (45/25).

(b) Half-Normal: in which 25% of the stocked items account for 52% of the aggregate demand (52/25).

(c) Uniform: in which 50% of the stocked items account for 50% of the aggregate demand (50/50). In this distribution all items are equally popular and item numbers are assigned randomly.

Figures IV-4 and IV-5 are the frequency histograms for the triangular and half-Normal distributions.

2. Order size distribution:

Each order consists of N different items, the value of N is designated as the order size. The following order size distributions were used in this study:

(a) Uniform distribution: in which the order size can be anywhere between 1 and N, where N is the maximum
PERCENTAGE BAR CHART

PERCENTAGE

24
21
18
15
12
9
6
3

TR MIDPOINT ITEM NO.-TRIANGULAR DISTRIBUTION

FIGURE IV-4
PERCENTAGE BAR CHART

PERCENTAGE

30

27

24

21

18

15

12

9

6

3

BN MIDPOINT ITEM NO.-HALFNORMAL DISTRIBUTION

FIGURE IV-5
possible order size.

(b) Normal distribution: To have a valid comparison between the two distributions, the normal distribution should include the same range of values as covered by the uniform distribution. Since the normal distribution is a symmetrical distribution, and 99% of the population lies between ±3 standard deviations, the mean equals N/2 and the standard deviation is 1/3 of the mean.

3. Storage Assignment:

Many policies for assignment of items to storage locations within a warehouse are used in practice today, such as assignment based on product popularity, assignment based on the size (volume) of the items stored and random assignment. The Cube-per-order assignment Index (COI) developed by Heskett (1) guarantees that the greatest stock-volume moves the shortest possible distance and is proved to be a highly efficient method (2, 3, 4).

The COI for an item is simply the quotient of the space which must be allocated for that item and the order frequency (popularity) for the item. It takes into account the item's space requirement as well as its popularity. Since in this study, all items are assumed to have the same size and therefore, having the same space requirement, the items' assignment or arrangement will be according to their popularity as shown in Figure IV-2. Two options are available for sequencing the items in
the warehouse, which are:

(1) Zigzag
(2) Parallel

The methods of arrangement are shown in Figures IV-6 and IV-7.

4. Other variables:

The other three input variables to the system are:

(a) Number of cross-aisles
(b) Average order size (mean value)
(c) Warehouse size (storage capacity)

Those are the quantitative factors which should be clear and need no further explanation.

C. **Picking Policy**

The picking policy will be as follows: The picker will pick the order in ascending item number sequence (the more popular items will have the lower item numbers). He will start from the input/output point (I/O in Figure 1) and pick the most popular item first, then the next most popular, and so on, until he picks the last (least popular) item in the order. He will then return to the input/output point.

D. **The Model**

D.1 - Algorithm Logic. The key function of the model is the travel distance computing algorithm. Figure IV-8 shows the round-trip route that will be travelled to
Zig-Zag Storage Sequence. NOTE: 40 Items Popularity Group. Number in Cell is Item Number.
Parallel Storage Sequence (see Figure 6 for Notes).
TD(L) = total travelled distance in order No. L
TD(L) = NDOOR 1 + NDBET + NDOOR 2
NITEM(1) = Item no. 1 in the order

**FIGURE IV-8**

Picker's round trip-order size=N
pick the items comprising any incoming order of size N. Figures IV-9 and IV-10 are the flowcharts of the calculating algorithm logic. Using the distance computing algorithm, the computer program calculates the distance travelled in each order and accumulates the total distance travelled in the 200 simulated orders for each combination of factors and levels.

D1.1 - Distance computing algorithm description (refer to Figure IV-9).

Block #1: Incoming order of size N is received.

Block #2: The N-items are sorted and arranged in ascending order with respect to the item number. Every item will be assigned a "picking sequence number" with the most popular item in the order assigned a picking sequence number of "1," the following example will clarify the procedure:

Example: Suppose an order of 5 items is received (N=5), where the items in the order are as follows:

- Item No. 405
- Item No. 61
- Item No. 352
- Item No. 5
- Item No. 7

The above items are then sorted and arranged in an ascending order with each one assigned a "picking sequence number" as follows:
1. Incoming Order with N Item

2. SORT the Items in an Ascending Order

3. Find the First Item Number
   Find its Category (SUBROUTINE CATEGO)
   Find the First Item in the Category NFIRST (SUBROUTINE CHECK)

4. Calculate the First Item's (in the Incoming Order) Distance from the I/O Point = NDOOR1 (SUBROUTINE DOOR)

5. YES
   
   NO

6. Total Distance Travelled in This Order TD(L) = 2 * NDOOR1

FIGURE IV-9
Distance Computing Algorithm
7. Calculate the Distance Travelled to Pick All Items Between 1, ..., N = NDBET

8. Calculate distance Between Item N and I/O Point = NDOOR2 (SUBROUTINE DOOR)

9. Total Travelled Distance in This Order
TD(L) = NDOOR1 + NDBET + NDOOR2

10. Accumulate Distance Travelled in All Orders = CTD

FIGURE IV-9 (continued)
Initialize NDBET = 0

Find Next Item Number
Find its Category (SUBROUTINE CATEGO)
Find the First Item in the Category
NFIRST (SUBROUTINE CHECK)

YES

Category of This Item = Last Item's Category?

NO

Calculate the Distance Between
the Two Items NDT Using Formula
of Statement No. 150 in the Program

Calculate the Distance
Between the Two Categories
of the Two Items ND4
(SUBROUTINE BETWEEN)

S3

S2

FIGURE IV-10

Computation of Distance Travelled Between Items
1, 2, ..., N-1, N (NDBET)
Find the Classes of the Two Categories KLASS1 & KLASS2 (SUBROUTINE CLASS)

Depending on the Values of KLASS1 & KLASS2
GO TO the Proper Formula (Statement No. 147, 148 or 149)
to Calculate the Distance Between the Two Items NDT

Accumulate Distance Travelled Between Items 1, . . . , N
NDBET = NDBET + NDT

Go to A to Pick the Next Item in the Order Until Item N is Reached

FIGURE IV-10 (continued)
The above items are then picked according to their picking sequence number.

Block #3: the multiple picking procedure will start here by identifying the 1st item number (which is item no. 5 in the last example). The item's category and the 1st item in that category (NFIRST) are identified by subroutines CATEGO and CHECK respectively.

Block #4: The distance between the I/O point and the 1st item picked is computed and designated as NDOOR1. Subroutine DOOR makes this computation.

Block #5: the order size "N" is checked here, and if N=1 control is transferred to Block #6. If N=1 (N>1), control is transferred to block #7.

Block #6: In this case, the order size is one item only and hence, the total travelled distance in the order (TD(L)) will be:

\[ TD(L) = 2 \times \text{NDOOR1} \]

where \( L = \text{Order Number} \)

Block #7: This block handles the multiple item orders case and computes the distance travelled between the 1st item and the last item picked in the order. This distance is called NDBET as shown in Figure IV-8. The
detailed flowchart for this block is shown in Figure IV-10.

**Block #8:** this block computes the distance travelled between the last item picked in the order and the I/O point which is called NDOOR2 as shown in Figure IV-8. Subroutine DOOR makes this computation.

**Block #9:** the total distance travelled in this order is computed as

\[ TD(L) = NDOOR1 + NDBET + NDOOR2 \]

**Block #10:** the cumulative travelled distance in all the orders is incremented here. The flowchart in figure IV-10 explains Block #7 as mentioned earlier.

To pick a multiple item order, one or more of the following kinds of moves are required:

1. **Door-to-item or item-to-door distance,** which is either the distance from the I/O point to the first item to be picked (NITEM(1)) or the distance from the last picked item (NITEM(N)) in the order to the I/O point. The two distances are called NDOOR1 and NDOOR2 and are calculated by subroutine DOOR in the computer model.

2. **Between items within category distance:** this distance is computed as the straight line between the two item locations. For example: in Figure IV-3, if the picker moves from point "a" (from which he either picked item 1 or 2 or both) to point "c" (to pick either item 5 or 6 or both) which is 2 locations away from "a", the traversed distance will be:
distance = 2 x 4 = 8 units,
since the distance between adjacent locations
is 4 units.

(3) Between categories distance: which is the
distance between the category of the item just picked
and the category of the next item to be picked. Subroutine
BTWEEN in the computer model calculates this distance.
NFIRST location defines the beginning of each category.

(4) Within category distance: which is the
distance travelled within the category either to move to
the first item's location or to move from the last item's
location--within the category--to outside this category.
A typical category layout is shown in Figure IV-11.

Subroutine DISTAN will calculate ND2 and ND3 in the
following way: If the item (just picked) is located at
point "b," then it can be moved out of its category either
along the direct ba or along direction bc.

\[ ba = ND2 \text{ (subroutine DISTAN)} = NDIR1 \text{ (main program)} \]
\[ bc = ND3 \text{ (subroutine DISTAN)} = NDIR2 \text{ (main program)} \]
NDIST = absolute value of (NFIRST - (item No.))
Distance between any two adjacent item locations =
4 units
NDIST/2 = No. of locations the item at "b" is away from
NFIRST location (division by 2 was necessary
because each location point is the same for the
items on opposite sides of the aisle.)
SL = Shelf Length
J = NFIRST--First Item in the Category
K = Last Item in Category
b = Location of the Item of Interest

FIGURE IV-11
Typical Category Layout
Hence: \[ ND2 = 4 \times (NDIST/2) \]
\[ ND3 = SL - ND2 - 4 \]

Integer variables were chosen to facilitate the calculation of distance to a location, as illustrated in the following example:

**Example**: (refer to Figure IV-11)

To move from location "b" (which is the location for both items \((J + 6)\) and item \((J + 7)\) to location "a" (location of item \(J\) which is NFIRST). Using the aforementioned formulae, if the item of interest (item which has just been picked or to be picked) was item \((J + 6)\), then:

\[ NDIST = |J - (J + 6)| = 6 \]
\[ NDIST/2 = 3 \]
\[ ND2 = 4 \times (NDIST/2) = 4 \times 3 = 12 \]

When the item of interest is item \((J + 7)\) which is equally distance from NFIRST:

\[ NDIST = |J - (J + 7)| = 7 \]
\[ NDIST/2 = 3.5 = 3 \text{ (since integer variables truncate fractions)} \]

and hence, again ND2 = 12, which is the correct distance.

**D.2 Travel discipline between two items:**

Suppose the picker has just picked item \(i\) (NITEM \((I)\)) in the order and wants to move to pick the next item
i + 1 (NITEM(I + 1)). One of the four following situations can happen: (refer to Figure IV-12).

(1) The next item (NITEM(I + 1)) is in the same category. An example of this situation is moving from point "b1" to point "b2" in Figure IV-12. The travel distance here is equal to x3" and is computed by statement no. 150 in the computer program in the same way as was described earlier.

(2) The next item (NITEM(I + 1)) belongs to a category which is in the same class as that of the item just picked NITEM(I). An example of this situation is shown in Figure IV-12. Moving from the item at location "a" to the item at location "a1" where the two respective categories belong to the same class (class 1). Two routes are possible here in order to arrive at location "a1" from location "a", which are:

- route 1: move along $X_1 \rightarrow Y_1$ and $X'_1$
- route 2: move along $X_2 \rightarrow Y_2$ and $X'_2$

route 1 distance = $X_1 + Y_1 + X'_1$
route 2 distance = $X_2 + Y_2 + X'_2$

The model computes the two distances and uses the shorter of the two to move from location "a" to location "a1";

(3) The next item NITEM(I + 1) is located in a category of a higher class than item's NITEM(I) category.
FIGURE IV-12
Travel Discipline Between Two Items
(Types of Moves)
An example of this case can be seen in Figure IV-12 when the picker moves from location "b" to location "c_1". In this case there is only one shortest route that can be followed which is $\text{X}_4 \rightarrow \text{Y}_3 \rightarrow \text{X'}_3$. The model computes the distance as equal to $\text{X}_4 + \text{Y}_3 + \text{X'}_3$.

(4) The last possible situation is when item NITEM $(i+1)$ is located in a category which has a lower class than item (NITEM$(i)$) category. In Figure IV-12, an example of this situation can be: moving from location "d" to location "c_1." Location "d" is in class 4, while location "x_1" is in class 3. Again, there is one shortest route to follow in this case which is route $\text{X}_5 \rightarrow \text{Y}_4 \rightarrow \text{X'}_4$ and the travel distance will be $\text{X}_5 + \text{Y}_4 + \text{X'}_4$. Note here that what is meant by "one shortest route" is any route that will result in the least possible travel distance between the two items of interest and not simply the only route, because there could be many routes which satisfy this criterion. In all of the four different situations just mentioned, distance $X$ (i.e., $\text{X}_1$, $\text{X'}_1$, $\text{X}_2$, $\text{X'}_2$, $\text{X}_3$, $\text{X}_4$, ... etc.) which are the "within category travel distance" will always be computed by subroutine DISTAN as explained earlier. This distance is either ND2 or ND3 in Figure IV-8 (the same notation ND2 and ND3 are used in DISTAN). The "between categories distance"--the $Y$ distance in Figure IV-12--such as $\text{Y}_1$, $\text{Y}_2$, $\text{Y}_3$ and $\text{Y}_4$ will be computed by subroutine BTWEEN. A detailed description of the computer program is given in Appendix B.
Notes


CHAPTER V
RESULTS & DISCUSSION

Data generated by the computer program were analyzed by SAS (Statistical Analysis System) computer package. The multiple classification analysis of variance -ANOVA- was used to evaluate the effect of each of the six factors mentioned earlier in the study on the response which is "the percent reduction in travel distance." Duncan's multiple range test was employed to evaluate the effects of different levels within each of the six factors. Table V-1 is the analysis of variance table.

Factors Main Effect:

As can be seen from table V-1, the most influential factors are:

1. The warehouse size (factor A)
2. The average order size (factor E)
3. The number of cross-aisles (factor F).

The above mentioned factors are all quantitative.
The other three qualitative factors which are: order size distribution, items demand distribution and items storage assignment (arrangement) sequence (factors B, C and D respectively) have turned out to have far less effect than the quantitative factors mentioned above.
## Table V-1

### Analysis of Variance Procedure (ANOVA)

#### Dependent Variable: Y  
**Percent Reduction in Travel Distance**

<table>
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<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>P &gt; F</th>
<th>Significant Effect</th>
</tr>
</thead>
<tbody>
<tr>
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<td>952791.79274018</td>
<td>14726.10787131</td>
<td>194.52</td>
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<tr>
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</table>

#### ANOVA

<table>
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<tr>
<th>Source</th>
<th>DF</th>
<th>ANOVA SS</th>
<th>F-Value</th>
<th>P &gt; F</th>
<th>Significant Effect</th>
</tr>
</thead>
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<tr>
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</tr>
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<td>0.49</td>
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</tr>
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<td>8.09</td>
<td>0.0001</td>
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<td>134.73150061</td>
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</table>
The F-values of the quantitative factors (A, E & F) are very much larger than the F-values of the qualitative factors (B, C and D). Although the qualitative factors have all passed the F-test of significance (their effects are significantly different from zero at the 1% confidence level), their contributions to the total variation (sum of squares) were very small in comparison to the contributions of the quantitative factors.

The main factor of interest in this study, the number of cross-aisles, is far less influential than the other two quantitative factors.

But one should bear in mind that one level of this factor (layout with no cross-aisles) was excluded from the analysis because it was a reference level employed to measure the relative response—the percent reduction in travel distance as compared to the layout without cross-aisles. If this reference level is included in the analysis, the percent reduction in travel distance (the response) for no cross-aisles will always be zero for any combination of factors and levels, and would be a misleading measurement of the response variable. The inclusion of the reference level would undoubtedly contribute significantly to the total variation in the model, and increase the influence of factor F (number of cross-aisles). This result is intuitive and can be predicted from the of ANOVA and Duncan's multiple range
The increase in warehouse size will imply an increase in the rack's length, which in turn will result in longer travel distance between items (if the items do not belong to same popularity group). As a consequence, the warehouse size will greatly influence the travel distance between items since longer racks mean more travel to reach the far items. When the warehouse size was varied from 1-to-10 (the large warehouse area is 10 times the small warehouse area), this variation greatly influenced the travel distance (as well as the savings in travel distance). The above argument explains why warehouse size was the most important factor in terms of impact on reduction in travel distance. The average order size was expected to have the highly significant effect on the response as indicated in the ANOVA table. The more items in an order, the more moves required to pick the order. As a consequence, the travel distance increases with order size.

**Interactions Between Factors:**

Out of the 57 different interactions, only 19 had a significant effect on the response variable (1% significance level). 18 out of the 19 significant interactions involved at least one of the quantitative factors (A, E or F) and the 1st order interactions among
the quantitative factors (interactions AF, AE and EF) were the most significant. This result further emphasizes the great influence of the quantitative factors on the system response as compared to the influence of the qualitative factors.

Effects of Levels Within Each Factor:

(Refer to table V-2 which shows the results of Duncan's multiple range test):

A. Warehouse Size:

The large warehouse (size=10) is the most important level within this factor, followed by the medium warehouse (size=2) and lastly the small warehouse (size=1). The test results imply that the three levels are significantly different from each other. Since the large warehouse has the largest rack length, the large size has the greatest influence on savings in travel distance. This result follows from the earlier argument that longer racks require longer travel distance than shorter racks.

B. Order size distribution:

This factor included the two levels (qualitative) which are: uniform and normal distributions. Duncan's multiple range test implies that the two levels are significantly different from each other (Alpha=0.01). The test also indicated that the 2nd level (normal distribution) is more significant than the 1st level
### TABLE V-2

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE Y

Y = PERCENT REDUCTION IN TRAVEL DISTANCE DUE TO CROSS-AISLES

MEANS WITH THE SAME GROUPING ARE NOT SIGNIFICANTLY DIFFERENT

**ALPHA = 0.01  DF = 31752  MS = 78.0442**

<table>
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<th>GROUPING LETTER</th>
<th>MEAN</th>
<th>N</th>
<th>LEVEL</th>
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<td>B</td>
<td>6.63945</td>
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<td>2</td>
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<td></td>
<td>C</td>
<td>1.35437</td>
<td>10800</td>
<td>1</td>
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<td>ORDER SIZE</td>
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<td>16200</td>
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</tr>
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<td>16200</td>
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</tr>
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<td>ITEMS DEMAND</td>
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<td>6.25912</td>
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<td>50</td>
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<td></td>
<td>E</td>
<td>3.20198</td>
<td>5400</td>
<td>75</td>
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<td>F</td>
<td>-0.65372</td>
<td>5400</td>
<td>1</td>
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<tr>
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<td>B</td>
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<tr>
<td></td>
<td>C</td>
<td>6.23100</td>
<td>10800</td>
<td>3</td>
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50 Observations—out of the 200 collected observations at each combination of factors and levels—were used for this test. This will not influence the results of the test because the system is a non-transient stable system. The ANOVA results when using 200 observations and the results when using 50 observations were approximately the same.
(uniform distribution). If the average order size is too small (i.e. 1 item/order), the cross-aisles will have no advantage since on the average only one item will be picked and most of the time no travel between items is required. At the other extreme, if the order size is too large the picker will travel to most of the locations in the warehouse, and cross-aisles will only result in excess travel distance. In order to maximize utility of cross-aisles the order size must be modest (from 5-25 items based on the results of this study). When the order size distribution is normal, most of the orders will be near average in size, and will fall within the modest range. When the order size distribution is uniform, order size will have an equal chance of falling anywhere within the whole range of possible values, and therefore the chances of having a small, modest or large order size are the same. For this reason the normal order size distribution had a greater effect on the response variable than the uniform distribution.

C. Items demand distribution:

Duncan's range test implies that the three levels (triangular, half-normal and uniform distribution) are significantly different from each other. The most significant level was the triangular distribution followed by the uniform and half-normal distributions. This result suggests that if the items of an order are far apart, the
cross-aisles provide a greater advantage. The characteristic shape of each distribution is shown in FIGURES IV-4 & IV-5. If the demand distribution is half-normal, more of the items in an order will be from the 1st 30% of the items, than for either of the other distributions. If the items are close to each other in popularity, they are close physically and less traveling is needed between items, and cross-aisles are less advantageous. In the cases of the triangular and uniform distributions of items demand, the items in a given order will tend to be further apart than in the case of the half-normal distribution. As a consequence, travel between items, and hence, cross-aisles' impact on savings in travel distance will be enhanced.

Following the same argument, one would expect the uniform distribution level to be the most significant of the three levels of item demand distribution. However, it should be noticed that with the uniform distribution of item demand, the items of any order will be much more uniformly distributed through the warehouse than the two other cases. As the order size increases, the chance that the picker will travel to many locations in the warehouse will be higher. The higher the probability of the picker going to every location, the less advantageous cross-aisles will be. The uniform items demand distribution will maximize the probability of "almost going
everywhere in the warehouse" and therefore the triangular distribution had more impact on savings in travel distance—as a result of using cross-aisle—than did the uniform distribution.

Despite the fact that the three distribution levels were shown to be significantly different from each other, from a practical point of view there is very little difference amongst the mean values of the three of them as indicated in table V-2, and for this reason, the items demand distribution turned out to be of very little importance as compared to other factors in the study.

D. Items arrangement (storage assignment):

The parallel sequence assignment method was more significant—in terms of reduction in travel distance—than the zig-zag sequence method. When the parallel sequence method is employed, the more popular items will be closer to the I/O point, and less distance will be traversed to pick an order than in the case of zig-zag sequence method. FIGURE V-1 will help in clarifying the above argument. As in the case of the item demand distribution, for practical purposes the difference between the mean values of the two methods is very small as indicated in table V-2.

E. Average order size:

Duncan's range test indicated that the descending order of importance of the 6 levels of order size was:
Most popular category in each popularity group.

NOTE: Shaded sections are those of the more popular items.
10, 5, 25, 50, 75 & 1 items/order. As mentioned earlier in the discussion, when the average order size is too small—i.e. 1 item/order—cross-aisles will only be causing more travel distance. Also in the case of large order sizes, since the picker will be going to almost every location in the warehouse, cross-aisles will only result in excessive travel distance. In order to obtain maximum utility from the cross-aisles the average order size should fall within the range of 5 and 25 items/order as indicated by this study. The most important level 10, and followed by the levels of 5 and 25 items/order. This result further emphasizes the modest range of order sizes within which the advantages of cross-aisles will be maximal.

F. The number of cross-aisles:

As indicated by table V-2, the 1 cross-aisle level is the most significant amongst the three levels of this factor, followed by the 2 cross-aisles and the 3 cross-aisles levels respectively. FIGURES V-2 through V-7 are a representative sample of the graphs (in Appendix A) showing variation of order size versus the variation in percent reduction in travel distance encountered for all the cases investigated in this study. The results obtained for all the combinations of factors and levels were highly consistent as indicated by the graphs in FIGURE V-2 through V-7 and the set of graphs supplied in
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS- AISLE , 2=2 CROSS- AISLES, ----- ETC.

AVERAGE ORDER SIZE

FIGURE V-2
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = ZIG-ZAG
1 = 1 CROSS-AISLE, 2 = 2 CROSS-AISLES, --- ETC.

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<th>22.5</th>
<th>20.0</th>
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<th>15.0</th>
<th>12.5</th>
<th>10.0</th>
<th>7.5</th>
<th>5.0</th>
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<th>-15.0</th>
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MID-POINT DISTANCE

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</table>

FIGURE V-3
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = MEDIUM (864 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = ZIG-ZAG
1=1 CROSS-AISLE, 2=2 CROSS-AISLES, .... ETC.

\begin{center}
\begin{tabular}{c|c}
\hline
Average Order Size & Percent Reduction \\
\hline
0 & 27.5 \\
5 & 25.0 \\
10 & 22.5 \\
15 & 20.0 \\
20 & 17.5 \\
25 & 15.0 \\
30 & 12.5 \\
35 & 10.0 \\
40 & 7.5 \\
45 & 5.0 \\
50 & 2.5 \\
55 & 0.0 \\
60 & -2.5 \\
65 & -5.0 \\
70 & -7.5 \\
75 & -10.0 \\
80 & -12.5 \\
85 & -15.0 \\
\hline
\end{tabular}
\end{center}

\textit{Average Order Size}

\textit{Figure V-4}
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = MEDIUM (864 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = PARALLEL
1 = 1 CROSS-AISLE, 2 = 2 CROSS-AISLES, ...... ETC.

PERCENT REDUCTION

\[
\begin{array}{cccccccccccc}
0 & 5 & 10 & 15 & 20 & 25 & 30 & 35 & 40 & 45 & 50 & 55 & 60 & 65 & 70 & 75 \\
\hline
-15.0 & -12.5 & -10.0 & -7.5 & -5.0 & -2.5 & 0.0 & 2.5 & 5.0 & 7.5 & 10.0 & 12.5 & 15.0 & 20.0 & 25.0 & 27.5 \\
\end{array}
\]

AVERAGE ORDER SIZE

FIGURE V-5
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS-AISLE, 2=2 CROSS-AISLES, ... ETC.

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<tr>
<th>PERCENT REDUCTION</th>
<th>ORDER SIZE</th>
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</thead>
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AVERAGE ORDER SIZE

FIGURE V-6
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = ZIG-ZAG
1=1 CROSS-AISLE, 2=2 CROSS-AISLES, .... ETC.

PERCENT REDUCTION IN TRAVEL DISTANCE

<table>
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<tr>
<th>Percent Reduction</th>
<th>Frequency</th>
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<tr>
<td>-15.0</td>
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AVERAGE ORDER SIZE

FIGURE V-7
Appendix A. A major finding of this study is that—in general—at least 80% of the reductions in travel distance can be accomplished by using one cross-aisle only.

In the small warehouse, 1 cross-aisle was always superior to the two other levels for all the combinations of factors and levels. For the medium warehouse, 1 and 2 cross-aisles levels were comparable but the maximum extra savings accomplished by employing 2 cross-aisles over 1 cross-aisle was somewhere between 1.5 - 2.8%, which is small and most probably will not make up for the extra cost of adding a cross-aisle. For many of the cases, the difference between savings furnished by using 2 cross-aisles and those furnished by using 1 cross-aisle is negligible (in the order of 1%).

For the large warehouse, the 2 cross-aisles level was superior to the other levels in most if not all of the cases. In the very few cases in which the 3 cross-aisles level was superior to the 2 cross-aisles level, the difference between the two is very negligible (fractions of percent). The interesting finding is that even in the large warehouse, most of the reduction in travel distance (80-87% of the maximum possible reduction) can be accomplished by using only 1 cross-aisle. In all the cases investigated (for the large warehouse), the maximum difference between savings made by 2 cross-aisles (or 3 cross-aisles) and savings made by 1 cross-aisle was
approximately 3.2%. From the above discussion it can be seen that in all the cases investigated in this study, at least 82% of the maximum possible savings in travel distance (as a result of using cross-aisles) can be accomplished by using 1 cross-aisle, in the large warehouse. The following example may make the acceptance of the above stated result more appealing.

**Example:** (related to FIGURE V-8)

As can be seen from FIGURE V-8, cross-aisles will only reduce the distance travelled in the Y-direction and will have no impact on the distance travelled in the X-direction. Suppose the picker has just picked up the item at location "b" in FIGURE V-8-a, and he wants to move to the next item's location at point "bl". The total distance travelled between the two items will be equal to \( bc + ccl + clbl \). If the picker was in location "a" and wanted to move to "al", the total travel distance will be equal to \( ac + ccl + clal \). If the cross-aisle is added as shown in FIGURE V-8-b, and if the picker wanted to travel from "a" to "al" (in FIGURE V-8-b) the total distance will equal \( ad + dda + dlal \). If the picker wanted to move from "b" to "bl", the distance will be \( bd + ddl + dlbbl \). The travel in the X-direction which is \( ccl \) (in FIGURE V-8-a) and \( ddl \) (in FIGURE V-8-b) is the same and has not been affected by the cross-aisle, but the travel in the Y-direction has been reduced significantly. If more than
(a) No Cross-Aisles

(b) One Cross-Aisle

FIGURE V-8
FIGURE V-8 (continued)
one cross-aisle is added as shown in FIGURE V-8-c, and the picker wanted to move from "b" to "bl", the travel distance will equal be + eel + elbl. If he was moving from "a" to "al", the travel distance will be ae + eel + elal. For the case of moving from point "b" to "bl", the 2nd cross-aisle was a disadvantage because it resulted in more travel distance since the picker had to cross the cross-aisle as depicted by FIGURE V-8, but for the case of moving from "a" to "al" the 2nd cross-aisle was advantageous because of the reduction in travel distance encountered. The addition of the 1st cross-aisle was an advantage to both cases. Extrapolating the findings from this experiment implies that the 1st cross-aisle will almost always bring about some reduction in distance (in multiple item picking - N > 1), while the addition of a 2nd and 3rd cross-aisle might be advantageous in terms of savings in travel distance. The simple argument given above will help in understanding the more significant impact of the 1 cross-aisle level over the other levels.
Conclusions:

The following conclusions can be drawn based on the results of this study:

(1) The most important factors which influence savings in material handling distance when cross-aisles are used in a warehouse are:
   a) The warehouse size
   b) Average order size
   c) Number of cross-aisles

The study also shows that other factors such as: items demand distribution and order demand distribution are far less important than the above mentioned factors in terms of their impact on savings in material handling distance accomplished by using cross-aisles. No strong conclusions can be made about the items storage assignment method, because the study only considered a narrow variation within the well known method of popularity assignment.

(2) In the range of warehouse sizes considered in this study, 1 cross-aisle accomplishes 80% of the maximum possible savings in travel distance which could be achieved by either two or three cross-aisles.
(3) Maximal savings in travel distance can be achieved if the order size falls within the range of 5 to 25 items/order and cross-aisles are used.

(4) The warehouse designer can make use of the design table (Table VI-1) which was developed based on the results of this study. The design table in combination with the relevant costs (additional cross-aisle construction & per unit distance material handling costs) should help the warehouse designer in making a good decision as to the number of cross-aisles in the warehouse layout.

Recommendations:

(1) Future studies on the optimum number of cross-aisles should concentrate mainly on two important factors identified in this investigation which are:

--- Warehouse size (storage capacity)

--- Average order size

Regarding the average order size, more levels should be assigned to this factor, and a functional relationship established among average order size, number of cross-aisles and the percent savings in travel distance for a given size of a warehouse. This study discourages any attempt to explore the advantages of including more than three cross-aisles in a warehouse layout.

(2) The model for this study should be expanded to permit
<table>
<thead>
<tr>
<th>Average Order Size</th>
<th>1 Cross-Aisle</th>
<th>2 Cross-Aisles</th>
<th>3 Cross-Aisles</th>
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<tr>
<td></td>
<td>Range</td>
<td>Avg.</td>
<td>Range</td>
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<td></td>
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<td>1.08</td>
<td>-1.99 - 1.13</td>
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<td>10.55</td>
<td>7.66 - 10.67</td>
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<td>5.64</td>
<td>1.74 - 4.16</td>
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<td>-1.57</td>
<td>-2.93 - 3.67</td>
</tr>
<tr>
<td>75</td>
<td>-4.82 - 2.5</td>
<td>-0.24</td>
<td>-9.51 - 3.67</td>
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<tr>
<td>Medium 24,000 Sq. ft.</td>
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<td>2.29</td>
<td>-0.09 - 1.47</td>
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<tr>
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<td>14.04</td>
<td>13.10 - 16.16</td>
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<td>14.57</td>
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<td>-0.71 - 2.79</td>
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</table>

Percent Savings in Travel Distance Through Using Cross-Aisles
### Table VI-1 (continued)

<table>
<thead>
<tr>
<th>Warehouse Size</th>
<th>Average Order Size</th>
<th>1 Cross-Aisle</th>
<th>2 Cross-Aisles</th>
<th>3 Cross-Aisles</th>
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</thead>
<tbody>
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<td>3.46 - 5.18</td>
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<td>12.77 - 17.51</td>
<td>15.17</td>
<td>14.62 - 19.67</td>
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</table>
exploring the impact of other variations of the warehouse environment on the savings in travel distance through using cross-aisles. Some important variations that should be considered are: storage assignment method, variable item size and per item storage area allocation.

(3) Establish a functional relationship between rack aisle facing length and number of cross-aisles that will achieve maximum (and economically sound) savings in distance.

(4) This investigation has only explored an approximately fixed, square physical layout because the variation was only in the number of cross-aisles in the alternative layouts. The impact of the variations in the length to width ratio of the warehouse on the optimum number of cross-aisles should be assessed.

(5) The model was evaluated on the basis that the items were picked in the order in which they were sorted. This heuristic method was not intended to result in a shortest route. It will be worthwhile to explore the impact of cross-aisles when a shortest route algorithm is used to determine the picking sequence. Since the study has shown that cross-aisles have the greatest benefit in travel distance for orders in the range 5 to 25 items, the shortest route methods such as the travelling salesman algorithm, should be tested with orders in this size range. The computational requirements for shortest route
algorithms are reasonable for tours containing fewer than 25 nodes (items).
REFERENCES


APPENDIX A

GRAPHICAL AND TABULATED RESULTS
FIGURE A-1
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = ZIG-ZAG
1=1 CROSS-AISLE, 2=2 CROSS-AISLES, .... ETC.

PERCENT REDUCTION IN TRAVEL DISTANCE

27.5 +
25.0 +
22.5 +
20.0 +
17.5 +
15.0 +
12.5 +
10.0 +
7.5 +
5.0 +
2.5 +
0.0 +
-2.5 +
-5.0 +
-7.5 +
-10.0 +
-12.5 +
-15.0 +

--- +--- +--- +--- +--- +--- +--- +--- +--- +--- +--- +--- +--- +--- +--- +---
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

AVERAGE ORDER SIZE
FIGURE A-2
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS-AISLE , 2=2 CROSS-AISLES,.....ETC.

PERCENT REDUCTION IN TRAVEL DISTANCE

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<th></th>
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AVERAGE ORDER SIZE

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
FIGURE A-3

PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = ZIG-ZAG
1=1 CROSS-AISLE, 2=2 CROSS-AISLES,......ETC.

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0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

AVERAGE ORDER SIZE
FIGURE A-4

PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS-AISLE, 2=2 CROSS-AISLES,.....ETC.

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AVERAGE ORDER SIZE
FIGURE A-5
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = ZIG-ZAG
1 = 1 CROSS-AISLE, 2 = 2 CROSS-AISLES, .... ETC.

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```

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

AVERAGE ORDER SIZE
FIGURE A-6
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS-AISLE, 2=2 CROSS-AISLES, .... ETC.
FIGURE A-7
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT#1 (NO CROSS-AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = ZIG-ZAG
1=1 CROSS-AISLE, 2=2 CROSS-AISLES, .... ETC.

| P |   27.5 + |
| E |   25.0 + |
| C |   22.5 + |
| E |   20.0 + |
| R |   17.5 + |
| D |   15.0 + |
| U |   12.5 + |
| C |   10.0 + |
| T |   7.5 + |
| O |   5.0 + |
| N |   2.5 + |
| T |   0.0 + |
| R |  -2.5 + |
| A |  -5.0 + |
| V |  -7.5 + |
| E | -10.0 + |
| H | -12.5 + |
| N | -15.0 + |

---

0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

AVERAGE ORDER SIZE
FIGURE A-8

PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT#1 (NO CROSS-AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = PARALLEL

1=1 CROSS-AISLE, 2=2 CROSS-AISLES, ... ETC.

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AVERAGE ORDER SIZE

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
FIGURE A-9
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = ZIG-ZAG
1 = 1 CROSS-AISLE, 2 = 2 CROSS-AISLES, .... ETC.

PERCENT REDUCTION

| 27.5 + |
| 25.0 + |
| 22.5 + |
| 20.0 + |
| 17.5 + |
| 15.0 + |
| 12.5 + |

AVERAGE ORDER SIZE

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
FIGURE A-10
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = PARALLEL
1 = 1 CROSS-AISLE, 2 = 2 CROSS-AISLES, .....

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</tr>
</tbody>
</table>
FIGURE A-11
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = ZIG-ZAG
1 = 1 CROSS- AISLE, 2 = 2 CROSS- AISLES, .... ETC.

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AVERAGE ORDER SIZE

2  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

AVG. ORDER SIZE
FIGURE A-12
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = SMALL (432 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS-AISLE, 2=2 CROSS-AISLES, .... ETC.

\[
\begin{array}{cccccccccccccccccc}
\text{AVERAGE ORDER SIZE} & 0 & 5 & 10 & 15 & 20 & 25 & 30 & 35 & 40 & 45 & 50 & 55 & 60 & 65 & 70 & 75 \\
\text{PERCENT REDUCTION} & -15.0 & -12.5 & -10.0 & -7.5 & -5.0 & -2.5 & 0.0 & -2.5 & 5.0 & 10.0 & 12.5 & 15.0 & 20.0 & 22.5 & 25.0 & 27.5 \\
\end{array}
\]
**FIGURE A-13**

**PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT#1 (NO CROSS-CHAISELS)**

WAREHOUSE SIZE = MEDIUM (864 ITEMS STOCKED)

ORDER SIZE DISTRIBUTION = UNIFORM

ITEMS DEMAND DISTRIBUTION = TRIANGULAR

ITEMS ARRANGEMENT = ZIG-ZAG

1=1 CROSS-CHAILE, 2=2 CROSS-CHAILES, .... ETC.

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**O 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75**
FIGURE A-14
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = MEDIUM (864 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = PARALLEL
1 = 1 CROSS-AISLE, 2 = 2 CROSS-AISLES, .... ETC.

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<tr>
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| 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 |

AVERAGE ORDER SIZE
FIGURE A-15
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = MEDIUM (964 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = ZIG-ZAG
1 = 1 CROSS- AISLE, 2 = 2 CROSS- AISLES, .... ETC.

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<th>PERCENT REDUCTION</th>
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<tbody>
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Average Order Size

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
FIGURE A-16
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = MEDIUM (864 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS-AISLE, 2=2 CROSS-AISLES,......ETC.

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0  5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

AVG.

ORDER SIZE
FIGURE A-17
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = MEDIUM (864 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = ZIG-ZAG
1 = 1 CROSS- AISLE, 2 = 2 CROSS- AISLES, ... ETC.

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0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
**Figure A-18**

Percent Reduction in Travel Distance Compared to Layout #1 (No Cross-Aisles)

Warehouse Size = Medium (864 Items Stocked)

Order Size Distribution = Uniform

Items Demand Distribution = Uniform

Items Arrangement = Parallel

1 = 1 Cross-Aisle, 2 = 2 Cross-Aisles, ... Etc.

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Average Order Size

0  5  10  15  20  25  30  35  40  45  50  55  60  65  70  75
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = MEDIUM (864 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = ZIG-ZAG
1=1 CROSS-AISLE, 2=2 CROSS-AISLES, ..... ETC.

PERCENT REDUCTION

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AVERAGE ORDER SIZE

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
FIGURE A-20
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS AISLES)

WAREHOUSE SIZE = MEDIUM (364 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS AISLE, 2=2 CROSS AISLES,.....ETC.

PERCENT REDUCTION IN TRAVEL DISTANCE

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</table>

AVERAGE ORDER SIZE

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
FIGURE A-21
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-ALISES)

WAREHOUSE SIZE = MEDIUM (864 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = ZIG-ZAG
1 = 1 CROSS-ALISLE, 2 = 2 CROSS-ALISLES,.... ETC.

PERCENT REDUCTION

17.5 + 2
15.0 + 1 2
12.5 + 3 1
10.0 + 2 1
7.5 + 3
5.0 + 2 1
2.5 + 1
0.0 + 2
-2.5 + 3
-5.0 +
-7.5 +
-10.0 +
-12.5 +
-15.0 +

---+---+---+---+---+---+---+---+---+---+---+---+---+---
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

AVERAGE ORDER SIZE
**Figure A-22**

Percent Reduction in Travel Distance Compared to Layout #1 (No Cross-Aisles)

Warehouse Size = Medium (964 Items Stocked)

Order Size Distribution = Normal

Items Demand Distribution = Half-Normal

Items Arrangement = Parallel

1 = 1 Cross-Aisle, 2 = 2 Cross-Aisles, .... Etc.

<table>
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<th>-5.0+</th>
<th>-7.5+</th>
<th>-10.0+</th>
<th>-12.5+</th>
<th>-15.0+</th>
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</table>

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Average Order Size

```
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
```
FIGURE A-23
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = MEDIUM (864 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = ZIG-ZAG
1=1 CROSS-AISLE, 2=2 CROSS-AISLES, ...ETC.

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<th>PERCENT REDUCTION</th>
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AVERAGE ORDER SIZE

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
FIGURE A-24
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = MEDIUM (864 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS-AISLE , 2=2 CROSS-AISLES,... ETC.

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0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

AVERAGE ORDER SIZE
FIGURE A-25

PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = ZIG-ZAG
1=1 CROSS-AISLE , 2=2 CROSS-AISLES,......ETC.

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27.5 + |
25.0 + |
22.5 + |
20.0 + |
17.5 + |
15.0 + |
12.5 + |
10.0 + |
 7.5 + |
 5.0 + |
 2.5 + |
 0.0 + |
-2.5 + |
-5.0 + |
-7.5 + |
-10.0 + |
-12.5 + |
-15.0 + |
```

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0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

AVERAGE ORDER SIZE
FIGURE A-26
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = PARALLEL
1 = 1 CROSS-AISLE, 2 = 2 CROSS-AISLES, .... ETC.

PERCENT REDUCTION

27.5 +
25.0 + 3
22.5 +
20.0 + 3 1 3
17.5 + 1 1
15.0 + 2
12.5 + 3
10.0 +
7.5 +
5.0 + 2
2.5 + 3
0.0 +
-2.5 +
-5.0 +
-7.5 +
-10.0 +
-12.5 +
-15.0 +

--------------------------
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

AVERAGE ORDER SIZE
FIGURE A-27
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = ZIG-ZAG

1 = 1 CROSS- AISLE, 2 = 2 CROSS- AISLES, ..... ETC.

PERCENT REDUCTION IN TRAVEL DISTANCE

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-2.5 +
-5.0 +
-7.5 +
-10.0 +
-12.5 +
-15.0 +

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
FIGURE A-28
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = PARALLEL
1 = 1 CROSS-AISLE, 2 = 2 CROSS-AISLES, .... ETC.

AVERAGE ORDER SIZE
FIGURE A-29
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = ZIG-ZAG
1=1 CROSS-AISLE, 2=2 CROSS-AISLES, ... ETC.

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FIGURE A-30
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT#1 (NO CROSS-AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = UNIFORM
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS-AISLE, 2=2 CROSS-AISLES,.....ETC.

PERCENT REDUCTION

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AVERAGE ORDER SIZE

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
FIGURE A-31
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = ZIG-ZAG
1 = 1 CROSS-AISLE, 2 = 2 CROSS-AISLES, ..... ETC.

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FIGURE A-32
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = TRIANGULAR
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS- AISLE, 2=2 CROSS- AISLES, ...... ETC.

PERCENT REDUCTION IN TRAVEL DISTANCE

27.5 +
25.0 + 3
22.5 +
20.0 + 3 1
17.5 + 2 1
15.0 +
12.5 +
10.0 +
7.5 +
5.0 + 2
2.5 +
0.0 +
-2.5 +
-5.0 +
-7.5 +
-10.0 +
-12.5 +
-15.0 + 3

--- + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + -
AVERAGE ORDER SIZE

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
FIGURE A-33
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED
TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = ZIG-ZAG
1=1 CROSS-Aisle , 2=2 CROSS-AISLES, ... ETC.

PERCENT REDUCTION IN TRAVEL DISTANCE

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0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
AVERAGE ORDER SIZE
FIGURE A-34
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS-AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = HALF-NORMAL
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS-AISLE, 2=2 CROSS-AISLES, ...... ETC.

PERCENT REDUCTION IN TRAVEL DISTANCE

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AVERAGE ORDER SIZE
FIGURE A-35
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT #1 (NO CROSS- AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = ZIG-ZAG
1=1 CROSS- AISLE , 2=2 CROSS- AISLES, .... ETC.

PERCENT REDUCTION

\[
\begin{array}{ccc}
& 27.5 & + \\
& 25.0 & + & 3 & 3 \\
& 22.5 & + & 2 \\
& 20.0 & + & 3 & 1 & 1 \\
& 17.5 & + & 1 \\
& 15.0 & + & 3 \\
& 12.5 & + & 1 \\
& 10.0 & + \\
& 7.5 & + \\
& 5.0 & + & 2 \\
& 2.5 & + & 3 \\
& 0.0 & + \\
& -2.5 & + \\
& -5.0 & + \\
& -7.5 & + \\
& -10.0 & + \\
& -12.5 & + \\
& -15.0 & + \\
\end{array}
\]

AVERAGE ORDER SIZE

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
FIGURE A-36
PERCENT REDUCTION IN TRAVEL DISTANCE COMPARED TO LAYOUT#1 (NO CROSS-AISLES)

WAREHOUSE SIZE = LARGE (4368 ITEMS STOCKED)
ORDER SIZE DISTRIBUTION = NORMAL
ITEMS DEMAND DISTRIBUTION = UNIFORM
ITEMS ARRANGEMENT = PARALLEL
1=1 CROSS-AISLE, 2=2 CROSS-AISLES,......ETC.

PERCENT REDUCTION IN TRAVEL DISTANCE

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**Table A-1**

**WAREHOUSE CAPACITY = 432 ITEMS**
**ORDER SIZE DISTRIBUTION IS UNIFORM**
**LAYOUT1: NO CROSS AISLE**
**LAYOUT2: ONE CROSS AISLE**
**LAYOUT3: TWO CROSS AISLES**
**LAYOUT4: THREE CROSS AISLES**
**WA = EFFECTIVE AVERAGE ORDER SIZE**
**SER = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE**
**ITEMS DERIVED DISTRIBUTION IS TRIANGULAR**

**ITEMS ARRANGEMENT: SHORT-LONG**

**NO. OF SIMULATED ORDERS = 200**

**SUMMARY OF RESULTS:**

---

**Note:** The table presents data on warehouse layout configurations, order sizes, and travel distances. It compares different layout scenarios with varying order sizes, reporting the average number of iterations, average distance per order, standard deviation, and other statistical measures relevant to warehouse efficiency. The results indicate improvements in travel distance and reductions in standard error across different configurations, reflecting the impact of layout optimizations on operational efficiency.
Table A-2

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WAREHOUSE CAPACITY = 412 ITEMS
ORDER SIZE DISTRIBUTION IS UNIFORM
LAYOUT: NO CROSS AISLE
LAYOUT: TWO CROSS AISLES
EACH = EXPECTED AVERAGE ORDER SIZE
5% = THE STANDARD ERROR OF THE MEAN
STD ERR = THE STANDARD ERROR OF THE MEAN

ITEMS DEMAND DISTRIBUTION IS TRIANGULAR

ITEMS ARRANGEMENT: PARALLEL

Summary of Results:

---

No. of Simulated Orders = 200
Table A-3

WAREHOUSE CAPACITY = 432 ITEMS
ORDER SIZE DISTRIBUTION IS UNIFORM
LAYOUT1: NO CROSS AISLE
LAYOUT2: ONE CROSS AISLE
LAYOUT3: THREE CROSS AISLES
EOQS = EXPECTED AVERAGE ORDER SIZE
SEM = THE STANDARD ERROR OF THE MEAN
STD RED = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE

ITEMS ARRANGED DISTRIBUTION IS HALF-NORMAL

SUMMARY OF RESULTS:

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Table A-5

WAREHOUSE CAPACITY = 432 ITEMS
ORDER SIZE DISTRIBUTION IS UNIFORM
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LAYOUT2: ONE CROSS AISLE
LAYOUT3: TWO CROSS AISLES
LAYOUT4: THREE CROSS AISLES
ENS = THE STANDARD ERROR OF THE MEAN
STD RED = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE
ITEMS DEMAND DISTRIBUTIONS IS UNIFORM

ITEMS ARRANGED: ZIG-ZAG

SUMMARY OF RESULTS:

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### Table A-6

**WAREHOUSE CAPACITY = 432 ITEMS**

**ORDER SIZE DISTRIBUTION IS UNIFORM**

**LAYOUT-1: NO CROSS AISLE**

**LAYOUT-2: TWO CROSS AISLES**

**LAYOUT-3: THREE CROSS AISLES**

**SEAS = EXPECTED AVERAGE ORDER SIZE**

**STD RED = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE**

**ITEM DEMAND DISTRIBUTION IS UNIFORM**

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Table A-7

WAREHOUSE CAPACITY = 432 ITEMS
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LAYOUT: 2 NO CROSS AISLES
LAYOUT: 1 TWO CROSS AISLES
LAYOUT: 1 THREE CROSS AISLES
EAOS = EXPECTED AVERAGE ORDER SIZE
STD ERR = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE
ITEMS DEMAND DISTRIBUTION IS TRIANGULAR

ITEMS ARRANGEMENT: 25-EAG
NO. OF SIMULATED ORDERS = 200
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WAREHOUSE CAPACITY = 433 ITEMS
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LAYOUT3: 20% CROSS AISLE
LAYOUT4: 50% CROSS AISLE
BASE = EXPECTED AVERAGE ORDER SIZE
STD = THE STANDARD ERROR OF THE MEAN
STD. ERR = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE

ITEMS DEMAND DISTRIBUTION IS TRIANGULAR

ITEMS ARRANGEMENT : PARALLEL

NO. OF SIMULATED ORDERS = 200
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Table A-10

WAREHOUSE CAPACITY = 403 ITEMS
ORDER SIZE DISTRIBUTION IS NORMAL
LAYOUT 1: NO CROSS AISLES
LAYOUT 2: ONE CROSS AISLE
LAYOUT 3: TWO CROSS AISLES
LAYOUT 4: THREE CROSS AISLES
EADS = EXPECTED AVERAGE ORDER SIZE
STD = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE
ITEMS DEMAND DISTRIBUTION IS HALF-NORMAL

ITEMS ARRANGED = PARALLEL

NUMBER OF SIMULATION RUNS = 200

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**Table A-12**

WAREHOUSE CAPACITY = 432 ITEMS
ORDER SIZE DISTRIBUTION IS NORMAL
LAYOUT1: NO CROSS AISLE
LAYOUT2: ONE CROSS AISLE
LAYOUT3: TWO CROSS AISLES
LAYOUT4: THREE CROSS AISLES
BAGS = EXPECTED AVERAGE ORDER SIZE
STD = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE

ITEMS DEMAND DISTRIBUTION IS UNIFORM

ITEMS ARRANGEMENT : PARALLEL

NO. OF SIMULATED ORDERS = 200

SUMMARY OF RESULTS:

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**ITEMS ARRANGEMENT:** SIG-TAG

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**WAREHOUSE CAPACITY = 964 ITEMS**  
**ORDER SIZE DISTRIBUTION IS UNIFORM**  
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**LAYOUT B: ONE CROSS AISLE**  
**LAYOUT C: TWO CROSS AISLES**  
**EACH EXPECTED AVERAGE ORDER SIZE**  
**SER = THE STANDARD ERROR OF THE MEAN**  
**STD RED = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE**  
**ITEMS DEMAND DISTRIBUTION IS HALF-NORMAL**

**ITEMS ARRANGEMENT : SIG-1AG**

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**SUMMARY OF RESULTS :**

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**NO. OF SIMULATED ORDERS = 200**

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**NOTE:** The table includes the following columns:
- **CASE:** The case number.
- **EOGS:** The expected order generation size.
- **LAYOUT:** The layout type (A, B, C).
- **AVG ITEM NO:** The average number of items per order.
- **AVG DISTANCE/ORDER:** The average distance per order.
- **STD DEV:** The standard deviation.
- **SER:** The standard error of the mean.
- **COM DISTANCE:** The cumulative distance.
- **% REDUCTION:** The percentage reduction in travel distance.
- **STD RED:** The standard deviation of the percent reduction.
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Table A-18

WAREHOUSE CAPACITY = 864 ITEMS
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LAYOUT2: 432 CROSS AISLES
LAYOUT3: 864 CROSS AISLES
PLUS = EXPECTED AVERAGE ORDER SIZE
STD = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE

ITEMS DEMAND DISTRIBUTION IS UNIFORM

ITEMS ARRANGEMENT = PARALLEL

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SOVRANT OF RESULTS:
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WAREHOUSE CAPACITY = 666 ITEMS
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LAYOUT 2: TWO CROSS AISLES
YIELD = EFFECTS AVERAGE ORDER SIZE
STD = THE STANDARD DEVIATION OF THE MEAN
STD RED = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE
ITEMS DEMAND DISTRIBUTION IS TRIANGULAR

ITEMS ARRANGED: ZIG-ZAG

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SUMMARY OF RESULTS:

NO. OF SIMULATED ORDERS = 200
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**WAREHOUSE CAPACITY X 864 ITEMS**

**ORDER SITE DISTRIBUTION IS NORMAL**

**LAYOUT 1: MC CROSS AISLE**

**LAYOUT 2: JC CROSS AISLE**

**LAYOUT 3: INTERM CROSS AISLES**

**STD = THE STANDARD DEVIATION OF THE mean**

**SEM = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE**

**ITEMS ARRANGED: A PARALLEL**

**NO. OF SIMULATED ORDERS = 200**

**ITEMS DEPARED: DISTRIBUTION IS HALF-NORMAL**
### Table A-23

**BARRETTAS CAPACITY = 440 ITEMS**

**ORDER SIZE DISTRIBUTION IS NORMAL**

**LAYOUT 1: NO CROSS AISLE**

**LAYOUT 2: ONE CROSS AISLE**

**LAYOUT 3: TWO CROSS AISLES**

**LAYOUT 4: THREE CROSS AISLES**

**PAS = EXPECTED AVERAGE ORDER SIZE**

**STD Dev = THE STANDARD DEVIATION OF THE PARENT REDUCTION IN TRAVEL DISTANCE**

**ITEMS DEMAND DISTRIBUTION IS UNIFORM**

**ITEMS ARRANGED BY: SIG-EAG**

**SUMMARY OF RESULTS:**

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**WAREHOUSE CAPACITY = 964 ITEMS**

**ORDER SIZE DISTRIBUTION IS NORMAL**

**LAYOUT1 = BC CROSS AISLE**

**LAYOUT2 = FC CROSS AISLE**

**LAYOUT3 = TWO CROSS AISLES**

**LAYOUT4 = THREE CROSS AISLES**

**NO. = EXPECTED AVERAGE ORDER SIZE**

**STD ERR = THE STANDARD ERROR OF THE MEAN**

**STY RED = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE**

**ITEMS OPPAARD DISTRIBUTION IS UNIFORM**

**ITEMS ARRANGEMENT = PARALLEL**

**NO. OF SIMULATED ORDERS = 200**

**SUMMARY OF RESULTS**

**Note:** The table presents various configurations of warehouse layouts and order sizes, along with corresponding average item numbers, average distance per order, standard error, standard current distance, percent reduction, and standard error results. The data is organized in a tabular format with columns for each variable, allowing for a clear comparison of different layout and order size scenarios. The table highlights the reduction in travel distance when different arrangements are considered.
## Table A-25

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### Summary of Results:

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### Summary of Results

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| NO. OF SIMULATED ORDERS = 200 |

---

**Warehouse Capacity:** 4368 items

**Order Size Distribution:** Uniform

**Layout 1:** No Cross Aisle

**Layout 2:** Long Cross Aisle

**Layout 3:** Short Cross Aisle

**Layout 4:** Three Cross Aisles

**EOQ:** Expected average order size

**STD:** Standard deviation of the mean

**STD Err.:** Standard deviation of the 95% confidence interval

**Items Demand Distribution:** Triangular
### Table A-27

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Table A-30

WAREHOUSE CAPACITY = 1960 ITEMS
ORDER SIZE DISTRIBUTION IS UNIFORM

ITEMS DEMAND DISTRIBUTION IS UNIFORM
ITEMS ARRANGEMENT: PARALLEL

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**Summary of Results:**

| Vol. of simulated orders = 200 |

**WAREHOUSE CAPACITY = 368 ITEMS**

**ORDER SIZE DISTRIBUTION IS NORMAL**

**LAYOUT1: NO CROSS AISLES**

**LAYOUT2: 50 CROSS AISLES**

**LAYOUT3: 100 CROSS AISLES**

**LAYOUT4: THREE CROSS AISLES**

**DEV = STANDARD ERROR OF THE MEAN**

**STD RED = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE**

**ITEMS DEMAND DISTRIBUTION IS TRIANGULAR**

**ITEMS ARRANGEMENT: PARALLEL**
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**Table A-35**

- **WAREHOUSE CAPACITY = 616 SETS**  
- **ORDER SIZE DISTRIBUTION IS NORMAL**  
- **LAYOUT1: NO CROSS ISLE**  
- **LAYOUT2: ONE CROSS ISLE**  
- **LAYOUT3: TWO CROSS ISLES**  
- **LAYOUT4: THREE CROSS ISLES**  
- **EANS = EXPECTED AVERAGE ORDER SIZE**  
- **STD = THE STANDARD DEVIATION OF THE PERCENT REDUCTION IN TRAVEL DISTANCE**  
- **ITEMS DEMAND DISTRIBUTION IS UNIFORM**  
- **ITEMS ARRANGEMENT: BIC-ZAC**  
- **NO. OF SIMULATED ORDERS = 200**
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<td>597.203</td>
<td>26.716</td>
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<td>24.203</td>
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<td>26.716</td>
<td>3782.120</td>
<td>24.203</td>
<td>34.988</td>
<td>6.998</td>
</tr>
</tbody>
</table>
APPENDIX B

DESCRIPTION OF THE COMPUTER PROGRAM
DESCRIPTION OF THE COMPUTER PROGRAM:

Refer to FIGURE B.1 (the flowchart of the main program):

Block No. 1: Start

Block No. 2: A two-iteration DO loop. In each iteration one level of the order size distribution is used as an input variable.

Block No. 3: A three-iteration DO loop, in each iteration one level of the items aggregate demand distribution is used as an input variable to the system.

When LDEMND = 1 - triangular distribution will be used
When LDEMND = 2 - half-normal distribution will be used
When LDEMND = 3 - uniform distribution will be used

Block No. 4: A two-iteration DO loop. One level of items arrangement will be used as an input variable in each iteration.

When ISIGN = 1 - Zigzag arrangement will be used
When ISIGN = 2 - Parallel arrangement will be used

Block No. 5: A six-iteration DO loop. In each iteration, one of the six levels of the average order size is used as an input parameter.

* Some blocks are skipped in the description because they are very clear from the flowchart.

** In FIGURE B.1 (Flowchart):

1. Block no. is the number over the upper left corner of each block.

2. Numbers between the brackets are statement numbers in the computer program.
FIGURE B.1

Main Program Flowchart
initialize
CTD = 0.0
NSUM = 0.0
ITMSUM = 0.0
IX = 15011

CALL ORDER OSIZE1 OR OSIZE2
generate order size
N

NSUM = NSUM + N

CALL DEMAND
generate ordered items numbers

FIGURE B.1 (continued)
FIGURE B.1 (continued)
FIGURE B.1 (continued)

21

N = 1

YES

GO TO 120

NO

IK = 1, NM

JM = N - IK

J = 1, JM

NITEM(J) < NITEM(J + 1)

YES

GO TO 70

NO

NTEMP = NITEM(J)
NITEM(J) = NITEM(J + 1)
NITEM(J + 1) = NTEMP

CONTINUE

D

FIGURE B.1 (continued)
FIGURE B.1 (continued)
CALL CHECK

CALL DOOR

NDOOR1 = ND1

N = 1

initialize NDBET = 0

ID = 2,N

ITMNUM = NITEM(ID - 1)
ICT = ICAT(ID - 1)

FIGURE B.1 (continued)
CALL CHECK
CALL DISTAN

NDIR1(1) = ND2
NDIR2(1) = ND3

ITMNUM = NITEM(ID)

CALL CATEGO

ICAT(ID) = ICT

ICAT(ID) = ICAT(ID - 1)

NX1 = ICAT(ID - 1)
NX2 = ICAT(ID)

FIGURE B.1 (continued)
\[ \text{NDT} = \text{NDIR}_2(1) + \text{NDIR}_1(2) + \text{ND}_4 \]

\[ \text{ND}_5 = \text{NDIR}_1(1) + \text{NDIR}_1(2) \]

\[ \text{ND}_6 = \text{NDIR}_2(2) + \text{NDIR}_2(2) \]

\[ \text{NDT} = \text{NDIR}_1(1) + \text{NDIR}_2(2) + \text{ND}_4 \]

\[ \text{NDT} = \text{ND}_5 + \text{ND}_4 \]

\[ \text{NO} \]

\[ \text{H} \]

\[ \text{H}_2 \]

\[ \text{GO TO 3} \]

\[ \text{NDT} = \text{ND}_6 + \text{ND}_4 \]

\[ \text{YES} \]

\[ \text{ND}_5 \leq \text{ND}_6 \]

\[ \text{H}_1 \]

\[ \text{FIGURE B.1 (continued)} \]

\[ \text{NDT} = 4 \cdot \left(\left[\frac{\text{NFIRST} - \text{NITEM(ID) - 1}}{2}\right]\right) \]

\[ \text{NDT} = 4 \cdot \left(\left[\frac{\text{NFIRST} - \text{NITEM(ID)}}{2}\right]\right) \]
64
NDT = \text{ABS}(NDT1) - \text{ABS}(NDT2)

(3)
NDBET = NDBET + NDT

(130)
CONTINUE

(180)
\begin{align*}
NDBET &= 0 \\
\text{NDOOR2} &= \text{NDOOR1}
\end{align*}

(190)
\begin{align*}
\text{ITMNUM} &= \text{NITEM}(N) \\
\text{ICT} &= \text{ICAT}(N)
\end{align*}

GO TO 190

GO TO 199

FIGURE B.1 (continued)
71 CALL CHECK
    CALL DOOR
72 NDOOR2 = ND1
73 (199) \( TD(L) = NDOOR1 + NDBET + NDOOR2 \)
74 (200) \( CTD = CTD + TD(L) \)
75 \( RED(M,L) = ((TD(1,L) - TD(M,L))/TD(1,L)) \times 100. \)
76 CONTINUE

FIGURE B.1 (continued)
\[
\text{ITMAVG}(KASE,M) = \frac{ITMSUM}{NSUM}
\]
\[
\text{SIMRUN} = L,M
\]
\[
\text{AVGTD}(KASE,M) = \frac{CTD}{SIMRUN}
\]
\[
\text{AVGRED} = \frac{((\text{AVGTD}(KASE,1) - \text{AVGTD}(KASE,M))/\text{AVGTD}(KASE,1))}{100}
\]
\[
\text{calculate}
\]
\[
\text{STD}(KASE,M) = \sqrt{\frac{SXX}{(SIMRUN - 1)}}
\]
\[
\text{SEM}(KASE,M) = \frac{\text{STD}(KASE,M)}{\sqrt{\text{SIMRUN}}}
\]
\[
\text{STDRED} = \sqrt{\frac{SXXR}{(SIMRUN - 1)}}
\]

WRITE

KASE = Level no. of the avg. order size
EAOS = Expected Avg. Order Size
M = Layout No.
ITMAVG = Avg. item no. in all the orders
AVGTD(KASE,M) = Avg. travel distance/order
STD(KASE,M) = Std. dev. of travel distance/order
CTD = Cumulative travel distance in all orders
AVGRED = Avg. percent reduction in travel distance
STDRED = Std. dev. of percent reduction in travel distance

FIGURE B.1 (continued)
FIGURE B.1 (continued)
Block No. 6: The control of the routine is transferred to subroutine SIZE which will provide the expected average order size EAOS depending on the value of KASE in the previous block.

Block No. 7: A four-iteration DO loop. In each iteration one of levels of the number of cross-aisles will be used as an input variable, where:

M = 1 stands for Layout #1 (no cross-aisles)
M = 2 stands for Layout #2 (one cross-aisle)
M = 3 stands for Layout #3 (two cross-aisles)
M = 4 stands for Layout #4 (three cross-aisles)

Block No. 8: All values of:

CTD = cumulative travelled distance (in all orders)
NSUM = total number of items ordered in all the orders
ITMSUM = the sum of item numbers which have been ordered
are initialized.

Block No. 9: A two-hundred iteration loop representing the 200 simulated orders, where L here indicated the order number. The distance computing algorithm will start functioning after this block to accumulate the distance travelled in multiple items picking for all the orders.

Block No. 10: The control of the routine is transferred to subroutine OSIZE1 or OSIZE2 which randomly generate an order size ~ according to the specific parameters supplied earlier (EAOS and distribution kind).

Block No. 11: A summation block which will accumulate the total number of the ordered items.
Block No. 12: An N-iteration loop. In each iteration one item will be generated as an ordered item in this specific order.

Block No. 13: The control of the routine is transferred to subroutine DEMAND which will randomly generate an item number ITEM according to the distribution specified by LDEMN (Block 2).

Block No. 14: Assigns the randomly generated item number to one of the items in the order.

Blocks No. 15-19: In these blocks it is made sure that there will be no replication of any item in the order (no more than one item from the same type can be ordered in a single order). If any item number is regenerated, control will be transferred back to subroutine DEMAND to generate another different item number.

Block No. 21: This block checks if the order size = 1. If N (order size) = 1, then there is no need for sorting the items (next step), and control is transferred to statement No. 120. If N > 1, then sorting is needed, and the routine will continue to the next step.

Blocks No. 22-28: In these blocks the items of the order are sorted and arranged in an ascending order.

Blocks No. 30 and 31: Item numbers are accumulated.

Block No. 32: The first item in the order NITEM (1) is set equal to ITMNUM.

Block No. 33: Control is transferred to subroutine CATEGO which will inform the main routine of the category of item NITEM (1).

Block No. 35: After knowing the item's category, control is transferred to subroutine CHECK which will find the first item in the category NFIRST.
Block No. 36: The item's category and NFIRST, which were just found, will be inputed to subroutine DOOR which will calculate the distance from the door (I/O point) to the first item in the orders NDOOR1.

Block No. 38: The order size N is checked. If there is only one item in this order, control is transferred to statement No. 180. If N is greater than 1, the routine will continue to the next step.

Block No. 39: NDBET is initialized. NDBET is the distance travelled between the items 1, 2, . . . , N in the order, where item N is the last picked item.

Block No. 40: A loop of N-1 iterations through which the distances travelled between items 1, 2, . . . , N is computed and accumulated to find NDBET. (Refer back to FIGURE IV-8).

Blocks No. 41 and 42: Input values are specified, and then control is transferred to subroutine CHECK to find NFIRST for the item just picked and then control is transferred to subroutine DISTAN which calculates the distance to move this item to the edge of its category using either of the two possible directions. Those distances are ND2 and ND3 which are calculated as explained earlier (refer to FIGURE IV-11).

Block No. 44: Here, the next item of interest if specified (next item to be picked).

Blocks No. 45 and 46: Control is transferred to subroutine CATEGO which will provide the item's category. ITMNUM is the input to subroutine CATEGO.
Block No. 47: A check is made whether the next item to be picked is located within the same category of the item just picked. If it is in the same category, control is transferred to statement No. 150 which will compute the travel distance between the two items for this special case.

Block No. 48: Categories of the last item picked and the next item to be picked are specified and used as input arguments to subroutine BETWEEN.

Block No. 49: Control is transferred to subroutine BETWEEN which will compute the distance between the two categories of the two items (ND4).

Block No. 51: Subroutines CHECK and DISTAN are called to find NFIRST (the first item in the category of the item to be picked) and hence, the within category travel distance (for the item to be picked) will be computed by DISTAN.

Block No. 52: The values of ND2 and ND3 are started as NDIR 1 (2) and NDIR 2 (2), which are the distances to reach the item from both directions as explained earlier in FIGURE IV-8.

Block No. 53: A check is made on the value of M (which is the Layout No.). If M = 1 (Layout #1) there will be one class only, and hence, control is transferred to Statement No. 148 which will compute the distance travelled between the two items for this case. If M > 1, the routine continues to the next step.

Block No. 54: Subroutine CLASS is called to identify the classes of the items' categories, namely: KLASS 1 and KLASS 2.
Blocks No. 55-62: KLASS 1 is the class of just-picked item's category and KLASS 2 is the class of the category of the next item to be picked. If KLASS 1 and KLASS 2 are equal, control is transferred to Statement No. 148 which will compute the distance between the two items using both the possible routes between them. In Blocks 60-62 the minimum of the two distances will be used as the value of NDT (shortest possible travel distance between the two items). If KLASS 1 and KLASS 2 are not equal, control is transferred to either of the two Statements No. 147 and 149 which will compute NDT in the proper manner as explained earlier in FIGURE IV-12. After computing the proper NDT, control is transferred to Statement No. 3 where NDBET is incremented.

Blocks No. 63 and 64: NDT is computed for the special case of having the two items in the same category.

Block No. 65: After finding the proper NDT, NDBET (distance travelled between items 1, 2, . . . , N) is incremented.

Block No. 68: This is Statement No. 180 which will handle the special case of having one item only in the order. It is clear here that NDBET = 0 and the total distance travelled in this order can be computed by doubling NDOOR 1 (which is the distance--from the I/O point--travelled to pick up the first item). NDOOR 2 (distance from the last item picked in the order to the I/O point) will be equal to NDOOR 1.

Blocks No. 70-72: The last item picked in the order is identified and subroutines CHECK and DOOR are called to compute the distance from this item back to I/O point which is NDOOR 2.
Block No. 73: The total distance travelled to retrieve the items of Order No. L is computed according to the formula of Statement No. 199.

Block No. 74: The cumulative travelled distance in all the orders is accumulated.

Block No. 75: The percent reduction in travel distance in this order is computed, where

\[ \text{RED}(M,L) = \text{percent reduction in travel distance in the } M^{th} \text{ Layout at the } L^{th} \text{ order} \]

Block No. 76: Marks the end of the travel distance computing algorithm for all the orders.

Block No. 77: The following parameters are computed (or assigned):

\[ \text{ITMAVG} (KASE, M) = \text{average it no. in all the orders} \]

\[ \text{SIMRUN} = \text{simulation run length} \]

\[ \text{AVGTD} (KASE, M) = \text{average travelled distance per order} \]

\[ \text{AVGRED} = \text{average percent reduction in travel distance} \]

Block No. 78:

\[ \text{STD} (KASE, M) = \text{standard deviation of travel distance per order} \]

\[ \text{SEM} (KASE, M) = \text{standard error of the mean travel distance per order} \]

\[ \text{STDRED} = \text{standard deviation of percent reduction in travel distance} \]

Block No. 79: The results of each simulation run are printed out. Each simulation run represents one combination of factors and levels.

Blocks No. 80-85: Are self-evident as can be seen in the flowchart in FIGURE B.1.
Subroutines:

1. DISTAN: Computes the within category distances as explained earlier and depicted in FIGURE IV-11.

2. DOOR: Computes the distance from the I/O point to the location of the first item in the order as well as the distance from the last item to the I/O point. The distance from any item's location to the I/O point consists of:
   (a) distance travelled within the items category (in the I/O point direction).
   (b) between categories distance, where I/O lies on the center line of Category No. 1.
   (c) distance from item's category class to I/O point (N1, or N2, or N3 in FIGURE B.2)

FIGURES B.2 and B.3 will help in understanding the logic of the algorithm which is very simple in concept. The important variables in the algorithm are:

ND1 = the total distance from the item's location to the I/O point

ICT = the item's Category No.

NFIRST = the first item number in the item's category

NDD = the distance between the first item in the category and the item of concern (within category distance)

N1, N2, and N3 - as depicted in FIGURE B.2

3. BETWEEN: This subroutine transfers the control of the routine to the proper subroutine (among BTW1 and BTW2) which computes the distance between categories of items. The control transfer depends on the value of M (Layout No.).
TABLE B.1
Variables on FIGURE B.2

<table>
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<tr>
<th>W.H Size</th>
<th>Layout</th>
<th>N1</th>
<th>N2</th>
<th>N3</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2</td>
<td>62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
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<td>86</td>
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<td>182</td>
<td></td>
</tr>
<tr>
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<td>126</td>
<td>246</td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>4</td>
<td>98</td>
<td>190</td>
<td>282</td>
</tr>
</tbody>
</table>

FIGURE B.2

Between Classes Distances (Subroutine Door)
assign values N1, N2 and N3

NDD = (NFIRST - ITMNUM)/2

ICT > 3C + 1

ICT > 2C + 1

ICT > C + 1

YES

NO

YES

NO

YES

NO

S3

FIGURE B.3
SUBROUTINE DOOR Flowchart
FIGURE B.3 (continued)
4. BTW1 and BTW2: Values of the items' categories are fed to either
BTW1 or BTW2 (depending on M). The subroutine assigns a class
number to each item's category, and depending on the difference
between the two categories, control is transferred to the proper
formula (through a computed GO TO) which in turn computes the
distance between the two categories. Variables in the subroutine
are defined as follows:

NX1 = category of the first item
NX2 = category of the other item
NA(I) = category class
NBOTH = control variable for the computed GO TO statement
NX3 = distance between the two categories

5. CLASS: This subroutine simply provides the class numbers for the
main routine (KLASS 1 and KLASS 2).

6. RAND: A random number generator which generates uniformly dis-
tributed random numbers between 0 and 1. The random number
generator used in the model was the one provided by Gillet.¹

7. DEMAND: Depending on the value of LDEMND, this subroutine trans-
fers the control to the specific "items aggregate demand distri-
bution" generator.

8. TRIANG: A process generator which randomly generates a number
(i.e. item number) from a triangular distribution. Using the
inverse transform technique, the number (X) can be generated
using the formula developed in the following manner:

¹Gillet, B.E., "Introduction to Operations Research: A Computer
\[ f(x) = \text{triangular probability density function} \]

\[ f(x) = 1 - \frac{x}{2} \quad 0 \leq x \leq 2 \]

\[ F(x) = \int_{0}^{x} f(x) \, dx = x - \frac{x^2}{4} \]

Setting \( r = x - \frac{x^2}{4} \) where \( r \) is a uniform random number between 0 and 1.

Solving for \( x \):
\[ x - \frac{x^2}{4} - r = 0 \]

Multiplying through by -4 and rearranging the terms:
\[ x^2 - 4x + 4r = 0 \]

Solving the above equation for \( x \):
\[ x = \frac{4 \pm \sqrt{16 - 16r}}{2} \]
\[ = \frac{4 \pm 4 \sqrt{1 - r}}{2} = 2 \pm 2 \sqrt{1 - r} \]

One root of the equation can be accepted because it is within the limits of \( x \) \((0 \leq x \leq 2)\) which is:
\[ x = 2 - 2 \sqrt{1 - r} = 2 (1 - \sqrt{1 - r}) \quad \text{(A)} \]

by entering random numbers in (A) where \( 0 \leq r \leq 1 \), triangularly distributed random numbers can be generated between 0 and 2.

8. **HNORM**: Is a process generator which generates half-normally distributed random numbers. This process generator can be developed by using a normal random number generator with a
zero mean - \( u = 0 \) -, and changing the negative half of the generated distribution to a positive one. This change will double the area of the positive half (since the normal distribution is symmetrical around the mean), and hence producing a half-normal distribution.

9. SIZE: This subroutine will provide the parameters of the order size distribution to the OSIZE subroutine. If the order size distribution is uniform, the subroutine will only provide the average order size \( EX \) since the lower limit--minimum value--of the distribution is zero. If the order size distribution is normal, then the subroutine will provide the mean--average order size--and the standard deviation which is always made to be equal to one-third of the mean as explained earlier.

10. OSIZE1 and OSIZE2: Are process generators which will randomly generate an order size according to the parameters provided by the SIZE subroutine. The generated random number can come from a uniform distribution (OSIZE1) which can be developed by making use of the RAND subroutine, or can come from a normal distribution (OSIZE2). The normal distribution generator used in the model was Naylor, Balintfy, Burdick and Chu.²

11. CHECK, CHECK 1, CHECK 2, . . . , and CHECK 6: CHECK subroutines are data subroutines which provide NFIRST value to the main routine whenever it is called. CHECK is only a "control transfer"

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²Naylor, T.H., Balintfy, J.L., Burdick, D.S. and Kong Chu, 
subroutine, which will transfer the control to the appropriate subroutine among CHECK 1, . . . , CHECK 6 to obtain NFIRST (first item in a category). The transfer of control depends on the values of M (Layout Number) and ISIGN (item arrangement pattern).

12. CATEGO, CATEG 1, . . . , CATEG 7: Are also data subroutines which provide the "Category Number" for any item in the warehouse. CATEGO is the control transfer subroutine which calls the appropriate subroutine among CATEG 1, . . . , CATEG 7 depending on the values of M (Layout Number) and ISIGN (item arrangement pattern).
**LEGEND OF VARIABLES IN THE PROGRAM:**

- **NSI** = NUMBER OF STOCKED ITEMS
- **NS** = WAREHOUSE SIZE (1 FOR SMALL, 2 FOR MEDIUM & 10 FOR LARGE)
- **NOSD** = ORDER SIZE DISTRIBUTION TYPE
- **NOSD** = 1 ........ UNIFORM ORDER SIZE DISTRIBUTION
- **NOSD** = 2 ........ NORMAL ORDER SIZE DISTRIBUTION
- **NITEM(N)** = N-TH ITEM NUMBER
- **ICAT(N)** = THE CATEGORY OF THE N-TH ITEM
- **LM** = TOTAL NUMBER OF SIMULATED ORDERS (SIMULATION RUN LENGTH)
- **M** = LAYOUT NO. (M=1 ... NO CROSS AISLES, M=2 .... 1 CROSS AISLE, .... ETC.)
- **RED(M,L)** = PERCENT REDUCTION IN TRAVEL DISTANCE (TD(M,L)) = TOTAL TRAVELLED DISTANCE
- **LDENND** = 2 .......... HALF ZIGZAG ITEMS DEMAND DISTRIBUTION
- **LDENND** = 3 .......... UNIFORM ITEMS DEMAND DISTRIBUTION
- **NITEM(200)**, **ICAT(200)**, **NDIR1(100)**, **NDIR2(100)**, **RED(5, 250)**, **TD(5, 250)**, **AVGT(15, 6)**, **STD(15, 6)**, **ITMAVG(15, 5)**, **SEM(15, 5)**, **RD(432)**, **ISIGN=1, 2**

*DIMENSION NITEM(200), ICAT(200), NDIR1(100), NDIR2(100), RED(5, 250), TD(5, 250), AVGT(15, 6), STD(15, 6), ITMAVG(15, 5), SEM(15, 5)*

WRITE(6, 101) NSI

101 FORMAT("1", "WAREHOUSE CAPACITY= ", "ITEMS", "/", "1X")

WRITE(6, 102)

102 FORMAT("1X", "SEM = THE STANDARD ERROR OF THE MEAN")
WRITE(6,103)
103 FORMAT(1X,"STD RED = THE STANDARD DEVIATION OF THE PERCENT REDUCTION")
IF(LDEMN.D.EQ.1) WRITE(6,97)
97 FORMAT(0","ITEMS DEMAND DISTRIBUTION IS TRIANGULAR")
IF(LDEMN.D.EQ.2) WRITE(6,98)
98 FORMAT(0","ITEMS DEMAND DISTRIBUTION IS HALF-NORMAL")
IF(NOSD.EQ.1) WRITE(6,299)
299 FORMAT(0","ORDER SIZE DISTRIBUTION IS UNIFORM")
IF(NOSD.EQ.2) WRITE(6,399)
399 FORMAT(0","ORDER SIZE DISTRIBUTION IS NORMAL")
IF(ISIGN.EQ.1) WRITE(6,175)
175 FORMAT(0","ORDER ARRANGEMENT : ZIG-ZAG")
IF(ISIGN.EQ.2) WRITE(6,185)
185 FORMAT(0","ORDER ARRANGEMENT : PARALLEL")
WRITE(6,104)
104 FORMAT(36X,33("=",))
WRITE(6,515)LM
515 FORMAT(/,36X,"NO. OF SIMULATED ORDERS = ",I5)
WRITE(6,616)
616 FORMAT(36X,32("=",))
WRITE(6,444)
444 FORMAT(0",2X,"SUMMARY OF RESULTS : ")
WRITE(6,445)
445 FORMAT(1X,22("=",))
WRITE(6,745)
WRITE(6,515)
515 FORMAT(/,36X,"LEVEL NO. OF THE AVERAGE ORDER SIZE")
WRITE(6,616)
616 FORMAT(36X,32("=",))
WRITE(6,444)
444 FORMAT(0",2X,"SUMMARY OF RESULTS : ")
WRITE(6,445)
445 FORMAT(1X,22("=",))
WRITE(6,745)
WRITE(6,515)
515 FORMAT(/,36X,"AVG ORDER SIZE HAS SIX LEVELS WHICH ARE :")
WRITE(6,616)
616 FORMAT(36X,32("=",))
WRITE(6,444)
444 FORMAT(0",2X,"SUMMARY OF RESULTS : ")
WRITE(6,445)
445 FORMAT(1X,22("=",))
WRITE(6,745)
C KASE=4 ................. AVG ORDER SIZE = 25 ITEMS/ORDER
C KASE=5 ................. AVG ORDER SIZE = 50 ITEMS/ORDER
C KASE=6 ................. AVG ORDER SIZE = 75 ITEMS/ORDER

DO 777 KASE=1,6
       749 FORMAT(1X,121("="))
C SUBROUTINE SIZE PROVIDES THE AVG ORDER SIZE EX
C CALL SIZE(KASE,EX,STDX)
EAOS=EX
Eaos = THE EXPECTED AVERAGE ORDER SIZE
STDX = THE STD DEV OF ORDER SIZE IN THE NORMAL DISTRIBUTION
C THIS DO LOOP TAKES CARE OF CHANGING THE WAREHOUSE LAYOUT
C ACCORDING TO THE VALUE OF M (LAYOUT NO.)
C
DO 999 M=1,4
THE TRAVEL DISTANCE COMPUTATION STARTS HERE BY INITIALIZING :
C CTD (CUMULATIVE TRAVELLED DISTANCE),
C NSUM = SUM OF ORDER SIZES
C ITMSUM = SUM OF THE ORDERED ITEM NO.S'
C IX = THE SEED NUMBER
C
CTD=0.0
NSUM=0
ITMSUM=0
IX=15011
DO 111 L=1,LM
C
OSIZE1 RANDOMLY GENERATES AN ORDER SIZE FROM A UNIFORM DIST
OSIZE2 RANDOMLY GENERATES AN ORDER SIZE FROM A NORMAL DIST.
C
IF(NOSD.EQ.1) CALL OSIZE1(IX,EX,N)
IF(NOSD.EQ.2) CALL OSIZE2(IX,EX,STDX,N)

WHLO0810
WHLO0820
WHLO0830
WHLO0840
WHLO0850
WHLO0860
WHLO0870
WHLO0880
WHLO0890
WHLO0900
WHLO0910
WHLO0920
WHLO0930
WHLO0940
WHLO0950
WHLO0960
WHLO0970
WHLO0980
WHLO0990
WHLO1000
WHLO1010
WHLO1020
WHLO1030
WHLO1040
WHLO1050
WHLO1060
WHLO1070
WHLO1080
WHLO1090
WHLO1100
WHLO1110
WHLO1120
WHLO1130
WHLO1140
WHLO1150
WHLO1160
WHLO1170
WHLO1180
WHLO1190
WHLO1200
NSUM = NSUM + N
NM = NM + 1

This coming loop generates N item numbers (ordered items)
where N is the randomly generated order size

DO 30 I = 1, N
   40 CALL DEMAND(LDEMAND, IX, ITEM)
   NITEM(I) = ITEM
   IF(I .EQ. 1) GO TO 30
   IM = I + 1
   DO 50 K = 1, IM
      THIS COMING LOOP ASSURES THAT THE SAME ITEM IS NOT
      GENERATED TWICE IN THE SAME ORDER. IF THE SAME ITEM
      IS GENERATED AGAIN IN ORDER, CONTROL IS TRANSFERRED
      BACK TO THE DEMAND SUBROUTINE TO GENERATE A DIFFERENT
      ITEM NO.
      IF(NITEM(I) .EQ. NITEM(K)) GO TO 40
      50 CONTINUE
   30 CONTINUE
IF(N .EQ. 1) GO TO 120

IF N = 1, there is no need for sorting the items of the order
therefore the sorting procedure is avoided.... if N > 1
the next few lines will sort the items and arrange them
in ascending order

DO 60 IK = 1, NM
   JM = N + 1
   DO 70 J = 1, JM
      IF(NITEM(J) .LT. NITEM(J+1)) GO TO 70
   60 CONTINUE
   NTMP = NITEM(J)
   NITEM(J) = NITEM(J+1)
   NITEM(J+1) = NTMP
CONTINUE
CONTINUE
DO 100 I=1,N
100 ITMSUM=ITMSUM+NITEM(I)
ITMNUM=I
CALL CATEGO(ITMNUM,ICT,M,ISIGN)

C CATEGO SUBROUTINE WILL CALL THE PROPER DATA SUBROUTINE OUT
OF CATEG1 , ......, CATEG7 TO IDENTIFY THE THE CATEGORY OF
THE FIRST ITEM IN THE ORDER

ICAT(1)=ICT
CALL CHECK(ISIGN,ICT,NFIRST,M)

AFTER THE ITEMS CATEGORY IS IDENTIFIED, THE FIRST ITEM IN
THE PROPER DATA SUBROUTINE OUT OF CHECK1, ........,CHECK6
DEPENDING ON THE LAYOUT NO. (M) AND THE ITEMS ARRANGEMENT
METHOD (ISIGN)

CALL DOOR(NFIRST,ICT,ITMNUM,ND1,M)

SUBROUTINE DOOR COMPUTES THE DISTANCE FROM THE I/O POINT (DOOR)
TO THE FIRST ITEM IN THE ORDER NITEM(1). THIS DISTANCE=NDOR1

NDOR1=ND1
IF(N.EQ.1) GO TO 180

IF THE ORDER SIZE N =1 THERE IS NO NEED TO COMPUTE THE
DISTANCE TO OTHER ITEMS. THE TRAVELLED DISTANCE IN THIS
CASE WILL BE = 2*NDOR1

IF N > 1 , THE DISTANCE BETWEEN NITEM(1),NITEM(2), ......,
.......NITEM(N-1) AND NITEM(N) IS COMPUTED IN THE FOLLOWING STEPS ** ** ** THIS DISTANCE IS CALLED NDBET ** ** **
NDGET=0
NDGET IS INITIALIZED, AND COMPUTED BY THE DO LOOP
DO 130 ID=2,N
THE LOOP STARTS BY IDENTIFYING THE LAST PICKED ITEM,
WHICH IS NITEM(ID*1), THEN THE ITEMS CATEGORY IS IDENTIFIED
BY SUBROUTINE CATEGO, THE 1ST ITEM IN THE CATEGORY (NFIRST)
IS THEN IDENTIFIED BY SUBROUTINE CHECK.

ITMNUM=NITEM(ID*1)
ICT=ICAT(ID+1)
CALL CHECK(ISIGN,ICT,NFIRST,M)
NOW SUBROUTINE DISTAN IS CALLED TO COMPUTE THE TRAVEL DISTANCE
NEEDED TO MOVE TO THE ITEMS LOCATION FROM THE BEGINNING OF ITS
CATEGORY, OR TO MOVE FROM THE ITEMS LOCATION (AFTER PICKING THE
ITEM) TO EITHER END OF THE CATEGORY. SINCE THERE ARE ALWAYS TWO
POSSIBLE DIRECTIONS TO MOVE EITHER INTO A CATEGORY OR OUT OF IT
DISTAN WILL ALWAYS PROVIDE THE MAIN ROUTINE WITH THE TRAVEL
DISTANCES ARE DESIGNATED AS NDIR1 & NDIR2.

CALL DISTAN(NFIRST,ITMNUM,ND2,ND3,M)
NDIR1(1)=ND2
NDIR2(1)=ND3
THE DISTANCE BETWEEN THE LAST PICKED ITEM (NITEM(ID)) TO THE
ITEM TO BE PICKED NOW WILL CONTINUE HERE BY IDENTIFYING THE
ITEM TO BE PICKED, ITS CATEGORY AND ITS NFIRST

ITMNUM=NITEM(ID)
CALL CATEGO(ITMNUM,ICT,M,ISIGN)
ICAT(ID)=ICT
IF THE CATEGORY OF THIS ITEM IS THE SAME ONE OF THE LAST PICKED
ITEM, THEN THERE IS NO TRAVEL BETWEEN CATEGORIES, AND THE
TRAVEL IS ONLY BETWEEN THE TWO ITEMS IN THE SAME CATEGORY
(WITHIN CATEGORY DISTANCE), STATEMENT NO. 150 IN THE
MAI~
ROUTINE COMPUTES THE DISTANCE BETWEEN THE TWO ITEMS.

IF(ICAT(ID).EQ.ICAT(ID+1)) GO TO 150
NX1=ICAT(ID+1)
NX2=ICAT(ID)

THE DISTANCE BETWEEN CATEGORIES OF THE TWO ITEMS OF CONCERN IS
COMPUTED BY SUBROUTINE BTWEEN

CALL BTWEEN(NX1,NX2,NX3,M)
ND4=NX3
CALL CHECK(ISIGN,ICT,NFIRST,M)
CALL DISTANCE(NFIRST,ITMNUM,ND2,ND3,M)
NDIR1(2)=ND2
NDIR2(2)=ND3

IF THERE IS NO CROSS AISLES (M=1), THERE WILL ONLY BE 1 CLASS
OR CLASS NO. 1 ......... THE CONTROL IS THEN TRANSFERRED TO
STATEMENT NO. 148 WHICH WILL COMPUTE THE DISTANCE FOR THIS CASE

IF(M.EQ.1) GO TO 148

IF THERE ARE CROSS AISLES , THEN THE CLASS OF THE ITEMS CATEGORY
NEEDS TO BE IDENTIFIED BY SUBROUTINE CLASS.

CALL CLASS(NX1,NX2,KLASS1,KLASS2)

DEPENDING ON THE SITUATION ENCOUNTERED, CONTROL WILL BE
TRANSFERRED TO THE PROPER SECTION OF THE ROUTINE TO MAKE THE
NECESSARY COMPUTATIONS AS WAS EXPLAINED EARLIER USING FIGURE
IV-12 IN CHAPTER IV.

IF(KLASS1+KLASS2)147,148,149
147 NDT=NDIR2(2)+NDIR1(2)+ND4
GO TO 3
149 NDT=NDIR1(2)+NDIR2(2)+ND4
GO TO 3
148 NDT=NDIR1(2)+NDIR1(2)
ND6=NDIR2(1)+NDIR2(2)
IF(ND5*ND6)1,1,2
1 NDT=ND4+ND4  
GO TO 3  
2 NDT=ND6+ND4  
GO TO 3  
150 NDT1=4*((NFIRST*NITEM(ID))/2)  
NDT2=4*((NFIRST*NITEM(ID))/2)  
IF(NDT1)4,5,5  
4 NDT1=NDT1  
5 CONTINUE  
IF(NDT2)6,7,7  
6 NDT2=NDT2  
7 NDT=NDT1+NDT2  
IF(NDT)8,9,9  
9 NDT=NDT  
9 CONTINUE  
3 NDBET=NDBET+NDT  
130 CONTINUE  
C THE COMPUTATION OF NDBET ENDS HERE  
C GO TO 190  
C IF THERE IS 1 ITEM IN THE ORDER (N=1) THEN NDBET=0  
C AND NDOOR1 WILL EQUAL NDOOR2 (THE DISTANCE FROM THE LAST  
C ITEM IN THE ORDER TO THE I/O POINT)  
C GO TO 199  
180 NDBET=0  
NDOOR2=NDOOR1  
IF(N>1) THEN AFTER COMPUTING NDBET, THE DISTANCE FROM THE  
LAST ITEM PICKED IN THE ORDER TO THE I/O POINT NEEDS TO BE  
COMPUTED (NDOOR2), THIS DISTANCE IS COMPUTED BY SUBROUTINE  
DOOR .........  
190 ITMNUM=NITEM(N)  
ICT=ICAT(N)  
CALL CHECK(ISIGN,ICT,NFIRST,M)  
CALL DOOR(NFIRST,ICT,ITMNUM,N1,M)  
NDOOR2=N1
THE TOTAL DISTANCE TRAVELLED IN THIS ORDER (TD(M,L)) IS COMPUTED

THE DISTANCE TRAVELLED IN EACH ORDER IS ACCUMULATED

THE PERCENT REDUCTION IN TRAVEL DISTANCE IN THIS ORDER

THE TRAVEL DISTANCE FOR ALL THE ORDERS (200) ENDS HERE ......

THE NEXT STEPS COLLECT THE STATISTICS NEEDED FOR THE WHOLE SIMULATION RUN OF 200 ORDERS

IT MAVG(KASE, M) = IT MSUM/NSUM
SIMRUN=LM
AVGTD(KASE, M) = CTD/SIMRUN
AVGRED=((AVGTD(KASE,1) - AVGTD(KASE, M))/AVGTD(KASE,1))*100.0
SXX=0.0
SXXR=0.0
DO 112 I=1,LM
XX=(TD(M,I) - AVGTD(KASE, M))**2
SXXR=SXXR+XXR
112 XX=(TD(M,I) - AVGTD(KASE, M))**2
SXXR=SXXR+XXR

STD(KASE, M) = SQRT(SXX/(SIMRUN*1.0))
SEM(KASE, M) = STD(KASE, M)/SQRT(SIMRUN)
STDRED=SQRT(SXXR/(SIMRUN*1.0))

WRITE(6,746) KASE, EAOS, M, ITMAVG(KASE, M), AVGTD(KASE, M), STD(KASE, M), SEM(KASE, M), STDRED

GO TO 999

END
SUBROUTINES Used For The Small Warehouse:

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SUBROUTINE SIZE (KASE, EX, STDX)
DIMENSION AV(6), SD(6), KA(6)
DATA KA(1,2,3,4,5,6),/ DATA AV(1,5,10,25,50,75,/
DATA SD(33,1.66,3.33,8.33,16.66,25,/
DO 10 I=1,6
10 IF (KASE.EQ.KA(I)) EX=AV(I)
DO 11 I=1,6
11 IF (KASE.EQ.KA(I)) STDX=SD(I)
RETURN
END

SUBROUTINE OSIZE2 (IX, EX, STDX, N)
1 SUM=0.0
DO 5 I=1,12
CALL RAND (IX, IT, YFL)
IX=IX
=YFL
5 SUM=SUM+R
X=STDX*(SUM-6.0)+EX
XMAX=2.0*Y
IF (X.LT.0.0) GO TO 1
IF (X.GE.XMAX) GO TO 1
Y=Y+1.0
RETURN
END

SUBROUTINE OSIZE1 (IX, EX, N)
CALL RAND (IX, IT, YFL)
IX=IX
T=2.0*EX
W=4.0+1.0
RETURN
END

SUBROUTINE DEMAND (LD, MND, IX, IT, WM)
IF (LD.EQ.MND.1) CALL TRIANG (IX, IT, WM)
IF (LD.EQ.MND.2) CALL HNORM (IX, IT, WM)
IF (LD.EQ.MND.3) CALL UNIFRM (IX, IT, WM)
RETURN
END

SUBROUTINE HNORM (IX, IT, WM)
X=0.0
STDX=0.3333
1 SUM=0.0
DO 5 I=1,12
CALL RAND (IX, IT, YFL)
IX=IX
=YFL
5 SUM=SUM+R
X=STDX*(SUM-6.0)+EX
IF (X.LT.0.0) X=-X
IF (X.GE.1.0) GO TO 1
ITEM=32.*X+1.0
RETURN
END

SUBROUTINE UNIFRM (IX, IT, WM)
1 CALL RAND (IX, IT, YFL)
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IF (YFL.GE.1.) GO TO 1
ITEM=432.*YFL+1.0
RETURN
END

SUBROUTINE DOOR (NFIRST, ICT, ITNUM, ND1, M)
IF (M.EQ.2) N1=62
IF (M.EQ.3) N1=66
IF (M.EQ.3) N2=66
IF (M.EQ.4) N1=38
IF (M.EQ.4) N2=68
IF (M.EQ.4) N3=102
ND1=(NFIRST-ITNUM)/2
IF (ND1.LT.0) GO TO 700
GO TO 1
600
700 ND1=ND
701 IF (ICT.GE.28) GO TO 705
IF (ICT.GE.19) GO TO 704
IF (ICT.GE.10) GO TO 702
ND1=ND1+16*(ICT-10)+1
GO TO 703
702 ND1=ND1+16*(ICT-10)+1
GO TO 703
704 ND1=ND1+16*(ICT-19)+N2
GO TO 703
705 ND1=ND1+16*(ICT-28)+N3
RETURN
END

SUBROUTINE DISTAN (NFIRST, ITNUM, ND2, ND3, M)
NDIST=NFIRST-ITNUM
IF (NDIST.LT.0) GO TO 600
GO TO 700
500
600 ND2=ND1-NDIST
601 ND3=ND1-ND2
RETURN
END

SUBROUTINE CLASS (NX1, NX2, K1, K2, K3, K4, K5)
DIMENSION IC(2), K(2), NCAT(5), NP(5)
IC(1)=NX1
IC(2)=NX2
DATA NCAT/0,9,19,27,36/
DATA NP/1,2,3,4,5/
DO 100 I=1,2
DO 100 J=1,5
IF (IC(I).GE.NCAT(J)) K(I)=NP(J)
100 CONTINUE
K1=K(I)
K2=K(I)
RETURN
END

SUBROUTINE TRIANG (IX, ITEM)
CALL RAND(IX, IY, YFL)
IY=IY
E=YFL
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ITEM = 432. * (1. - SQRT(1. - R)) + 1.
RETURN
END

SUBROUTINE RAND (IX, IY, IFL)
  IX = IX * 65539
  IF (IX) 5, 5, 6
  IY = IY + 2147483647 * 1
  IFL = IY
  RETURN
END

SUBROUTINE BETWEEN (NX1, NX2, NX3)
  CALL BTW1 (NX1, NX2, NX3)
  CALL BTW2 (NX1, NX2, NX3)
RETURN
END

DIMENSION IC (2), NA (2)
IC (1) = NX1
IC (2) = NX2
DO 100 I = 1, 2
  IF (IC (I) .LE. 9) NA (I) = 1
  IF (IC (I) .GT. 9) NA (I) = 2
  IF (IC (I) .GT. 18) NA (I) = 3
100 CONTINUE
NBCH = NA (1) - NA (2) + 3
GO TO (10, 20, 30, 40, 50), NBCH
10 NY3 = 14 * (NX2 - 18) - RX1) + 52
GO TO 60
20 NY3 = 14 * (NX2 - 9) - RX1) + 12
GO TO 60
30 NY3 = 14 * (NX2 - RX1) + 12
GO TO 60
40 NY3 = 14 * (NX2 - (RX1 - 9)) + 12
GO TO 60
50 NY3 = 14 * (NX2 - (NX1 - 18)) + 52
GO TO 60
60 RETURN
END

SUBROUTINE BTW2 (NX1, NX2, NX3)
  DIMENSION IC (2), NA (2)
  IC (1) = NX1
  IC (2) = NX2
  DO 100 I = 1, 2
    IF (IC (I) .LE. 9) NA (I) = 1
    IF (IC (I) .GT. 9) NA (I) = 2
    IF (IC (I) .GT. 18) NA (I) = 3
100 CONTINUE
NBCH = NA (1) - NA (2) + 4
GO TO (10, 20, 30, 40, 50, 60, 70), NBCH
10 NY3 = 14 * (NX2 - 27) - RX1) + 76
GO TO 60
20 NY3 = 14 * (NX2 - 18) - RX1) + 44
GO TO 60
30 NY3 = 14 * (NX2 - 9) - RX1) + 12
GO TO 80
40 NX3=14*(NX2-NX1)+12
GO TO 80
50 NX3=14*(NX2-(NX1-9))+12
GO TO 80
60 NX3=14*(NX2-(NX1-18))+4
GO TO 80
70 NX3=14*(NX2-(NX1-27))+76
80 RETURN

END

SUBROUTINE CATG1(ITNUM, ICT)
DIMENSION NCAT(20), ITEM(20)
DATA NCAT/9,8,7,6,5,4,3,2,1/
DATA ITEM/432,384,336,288,240,192,144,96,48/ 
DO 100 I=1,9
IF (ITNUM.LE. ITEM(I)) ICT=NCAT(I)
100 CONTINUE
RETURN
END

SUBROUTINE CATG2(ITNUM, ICT)
DIMENSION NCAT(50), ITEM(50)
DATA NCAT/16,9,8,17,16,7,6,15,14,5,4,3,2,1,10,9,8,7,6,5,4,3,2,1/
DATA ITEM/432,408,384,360,336,312,288,264,240,216,192,168,144,120,96,72,48,24/ 
DO 100 I=1,19
IF (ITNUM.LE. ITEM(I)) ICT=NCAT(I)
100 CONTINUE
RETURN
END

SUBROUTINE CATG3(ITNUM, ICT)
DIMENSION NCAT(50), ITEM(50)
DATA NCAT/432,408,384,360,336,312,288,264,240,216,192,168,144,120,96,72,48,24/ 
DO 100 I=1,19
IF (ITNUM.LE. ITEM(I)) ICT=NCAT(I)
100 CONTINUE
RETURN
END

SUBROUTINE CATG4(ITNUM, ICT)
DIMENSION NCAT(50), ITEM(50)
DATA ITEM/432,416,400,384,368,352,336,320,304,288,272,256,240,224/
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*208, 192, 176, 160, 144, 128, 112, 96, 80, 64, 48, 32, 16/
DATA NCAT(27), 19, 5, 9, 17, 25, 15, 6, 15, 24, 23, 14, 5, 13, 22, 21, 12, 11/
*I1, 20, 19, 10, I/
DO 100 I=1,27
IF (ITEMU.LE. ITEM(I)) ICT=NCAT(I)
100 CONTINUE
RETURN
END
SUBROUTINE CATG5(ITEMU, ICT)
DIMENSION NCAT(50), ITEM(50)
DATA NCAT(27, 19, 9, 17, 25, 15, 6, 15, 24, 23, 14, 5, 13, 22, 21, 12, 11/
*I1, 20, 19, 10, I/
DO 100 I=1,27
IF (ITEMU.LE. ITEM(I)) ICT=NCAT(I)
100 CONTINUE
RETURN
END
SUBROUTINE CATG6(ITEMU, ICT)
DIMENSION NCAT(50), ITEM(50)
DATA ITEM(432, 416, 400, 384, 368, 352, 336, 320, 304, 288, 272, 256, 240, 224,
*208, 192, 176, 160, 144, 128, 112, 96, 80, 64, 48, 32, 16/
DC 100 I=1,27
IF (ITEMU.LE. ITEM(I)) ICT=NCAT(I)
100 CONTINUE
RETURN
END
SUBROUTINE CATG7(ITEMU, ICT)
DIMENSION NCAT(50), ITEM(50)
DATA ITEM(432, 420, 408, 396, 384, 372, 360, 348, 336, 324, 312, 300, 288, 276,
*264, 252, 240, 228, 216, 204, 192, 180, 168, 156, 144, 132, 120, 108, 96, 84, 72,
*60, 48, 36, 24, 12/
DATA NCAT(36, 27, 16, 9, 8, 17, 26, 35, 24, 25, 16, 6, 15, 23, 32, 32, 23, 14, 5,
*13, 22, 31, 30, 21, 11, 3, 2, 11, 20, 29, 28, 19, 10, 1/
DO 100 I=1,36
IF (ITEMU.LE. ITEM(I)) ICT=NCAT(I)
100 CONTINUE
RETURN
END
SUBROUTINE CHECK(ISIGN, ICT, NFIRST, N)
IF (M.EQ.3) GO TO 1
IF (M.NE.4) GO TO 2
IF (ISIGN.EQ.1) CALL CHECK1(ICT, NFIRST)
IF (ISIGN.EQ.2) CALL CHECK2(ICT, NFIRST)
GO TO 3
1 IF (ISIGN.EQ.1) CALL CHECK3(ICT, NFIRST)
IF (ISIGN.EQ.2) CALL CHECK4(ICT, NFIRST)
GO TO 3
2 IF (ISIGN.EQ.1) CALL CHECK5(ICT, NFIRST)
IF (ISIGN.EQ.2) CALL CHECK6(ICT, NFIRST)
3 RETURN
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END
SUBROUTINE CHECK1 (ICT, NFIRST)
DIMENSION NCAT (50), NF (50)
DATA NCAT/18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1/
DATA NF/409, 360, 313, 266, 217, 168, 121, 72, 25, 385, 384, 289, 288, 193, 192, S
*97, 96, 1/
DC 100 I=1, 19
IF (ICT.EQ. NFST) NFST=37
100 CONTINUE
RETURN
END
SUBROUTINE CHECK2 (ICT, NFIRST)
IF (ICT.GE. 10) GO TO 1
NFST=48*(ICT-1)+1
GO TO 2
1 NFST=48*(ICT-10)+25
2 RETURN
END
SUBROUTINE CHECK3 (ICT, NFIRST)
DIMENSION NCAT (50), NF (50)
DATA NCAT/27, 26, 25, 24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1/
DATA NF/417, 352, 321, 256, 225, 160, 129, 64, 43, 401, 368, 305, 272, 209, 176, S
*113, 80, 17, 385, 384, 289, 288, 193, 192, 97, 96, 1/
DC 100 I=1, 27
IF (ICT.EQ. NFST) NFST=47
100 CONTINUE
RETURN
END
SUBROUTINE CHECK4 (ICT, NFIRST)
IF (ICT.GE. 19) GO TO 2
IF (ICT.GE. 10) GO TO 1
NFST=48*(ICT-1)+1
GO TO 3
1 NFST=48*(ICT-10)+17
GO TO 3
2 NFST=48*(ICT-19)+33
3 RETURN
END
SUBROUTINE CHECK5 (ICT, NFIRST)
DIMENSION NCAT (50), NF (50)
DATA NCAT/421, 349, 325, 252, 229, 156, 133, 60, 37, 209, 360, 313, 264, 217, 168, S
*212, 72, 25, 397, 372, 301, 276, 205, 180, 109, 94, 12, 385, 384, 289, 288, 193, S
*192, 97, 96, 1/
DATA NF/36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 24, 23, 22, 21, 20, 19, 18, S
*17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1/
DC 100 I=1, 36
100 IF (ICT.EQ. NFST) NFST=46
RETURN
END
SUBROUTINE CHECK6 (ICT, NFIRST)
IF (ICT.GE. 29) GO TO 1
IF (ICT.GE. 19) GO TO 2
IF (ICT.GE. 10) GO TO 3
NFST=48*(ICT-1)+1
GO TO 4
1 NFIRST=49*(ICT-29)+37
GO TO 4
2 NFIRST=49*(ICT-19)+25
GO TO 4
3 NFIRST=48*(ICT-10)+13
\& RETURN
END
SUBROUTINES Used for the Medium Warehouse:

FILE: MEDIUM FORTRAN A

SUBROUTINE SIZE(KASE,EX,STDX)
DIMENSION AV(6),SD(6),FA(6)
DATA FA/1,2,1,4,6,6/
DATA AV/1,5,10,25,50,125,/
DATA SD/33,1.66,3.33,8.33,16.66,33.33,/
DO 10 I=1,6
10 IF(KASE.EQ.FA(I)) EX=AV(I)
DO 11 I=1,6
11 IF(KASE.EQ.FA(I)) STDX=SD(I)
RETURN
END

SUBROUTINE OSIZE2(IX,EX,STDX,N)
1 SUM=0.0
DO 5 I=1,12
CALL PAND(IX,IX,YFL)
IX=IX
P=YFL
5 SUM=SUM+P
Y=STDX*(SUM-6.0)+P
YMAX=2.0*EX
IF(IX.LT.0.0) GO TO 1
IF(Y.LT.YMAX) GO TO 1
Y=Y+1.0
RETURN
END

SUBROUTINE OSIZE3(IX,EX,STDX,N)
CALL PAND(IX,IX,YFL)
IX=IX
T=2.0*EX
Y=1.0*YFL+1.0
RETURN
END

SUBROUTINE DEMAND(DD,IX,ITEM)
IF(DD.LE.1.0) CALL TRIANG(IX,ITEM)
IF(DD.EQ.2.0) CALL UNIFRM(IX,ITEM)
IF(DD.EQ.3.0) CALL NORM(IX,ITEM)
RETURN
END

SUBROUTINE UNIFRM(IX,ITEM)
1 CALL PAND(IX,IX,YFL)
IX=IX
IF(YFL.GT.1.0) GO TO 1
ITEM=8*YFL*YFL+1.0
RETURN
END

SUBROUTINE NORM(IX,ITEM)
EX=0.0
STDX=0.3333
1 SUM=0.0
DO 5 I=1,12
CALL PAND(IX,IX,YFL)
IX=IX
P=YFL
5 SUM=SUM+P
Y=STDX*(SUM-6.0)+Y
RETURN
END
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IP (X,LT.G.0) X=-X
IP (X,GE.1.) GO TO 1
ITEM=864.*X+1.0
RETURN
END

SUBROUTINE DISTAN (FIRST,ITNUM,MC2,ND3,*)
NDIST=WIST-IT IN
IF (NDIST.LT.0) GO TO 500
GO TO 600
500 NDIST=-NDIST
600 ND3=ND2+NDIST/2
ND3=146/M-4-02
RETURN
END

SUBROUTINE TRIANG (IX,ITEM)
CALL RAND (IX,IX,YFL)
IX=IT
F=YFL
ITEM=864.*(1.-SORT(1.-R))+.1
RETURN
END

SUBROUTINE RAND (IX,IX,YFL)
IX=IX*5539
IF (IX) 5,6,6
5 IX=IX+2137483647+1
6 YFL=YFL*.4656613357-9
RETURN
END

SUBROUTINE DOP (FIRST,ICT,ITNUM,ND1,*)
IF (M. EQ.2) N1=99
IF (M. EQ.3) N2=99
IF (M. EQ.4) N1=99
IF (M. EQ.5) N2=99
IF (M. EQ.6) N3=99
ND3=(FIRST-ITNUM)/2
IF (ND3.LT.0) GO TO 700
GO TO 701
700 ND3=-ND3
701 IF (ICT.GE.37) GO TO 705
IF (ICT.GE.25) GO TO 704
IF (ICT.GE.13) GO TO 702
ND1=ND3+14*(ICT-1)+6
GO TO 703
702 ND1=ND3+14*(ICT-13)+91
GO TO 703
703 IF (ICT.GE.25) GO TO 704
IF (ICT.GE.13) GO TO 702
ND1=ND3+14*(ICT-13)+93
GO TO 703
703 RETURN
END

SUBROUTINE BETWEEN (NX1,NX2,NX3,*)
IF (M. LE.3) CALL BET1 (NX1,NX2,NX3)
IF (M. GE.4) CALL BET2 (NX1,NX2,NX3)
RETURN
END

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IP (X,LT.G.0) X=-X
IP (X,GE.1.) GO TO 1
ITEM=864.*X+1.0
RETURN
END

SUBROUTINE DISTAN (FIRST,ITNUM,MC2,ND3,*)
NDIST=WIST-IT IN
IF (NDIST.LT.0) GO TO 500
GO TO 600
500 NDIST=-NDIST
600 ND3=ND2+NDIST/2
ND3=146/M-4-02
RETURN
END

SUBROUTINE TRIANG (IX,ITEM)
CALL RAND (IX,IX,YFL)
IX=IT
F=YFL
ITEM=864.*(1.-SORT(1.-R))+.1
RETURN
END

SUBROUTINE RAND (IX,IX,YFL)
IX=IX*5539
IF (IX) 5,6,6
5 IX=IX+2137483647+1
6 YFL=YFL*.4656613357-9
RETURN
END

SUBROUTINE DOP (FIRST,ICT,ITNUM,ND1,*)
IF (M. EQ.2) N1=99
IF (M. EQ.3) N2=99
IF (M. EQ.4) N1=99
IF (M. EQ.5) N2=99
IF (M. EQ.6) N3=99
ND3=(FIRST-ITNUM)/2
IF (ND3.LT.0) GO TO 700
GO TO 701
700 ND3=-ND3
701 IF (ICT.GE.37) GO TO 705
IF (ICT.GE.25) GO TO 704
IF (ICT.GE.13) GO TO 702
ND1=ND3+14*(ICT-1)+6
GO TO 703
702 ND1=ND3+14*(ICT-13)+91
GO TO 703
703 IF (ICT.GE.25) GO TO 704
IF (ICT.GE.13) GO TO 702
ND1=ND3+14*(ICT-13)+93
GO TO 703
703 RETURN
END

SUBROUTINE BETWEEN (NX1,NX2,NX3,*)
IF (M. LE.3) CALL BET1 (NX1,NX2,NX3)
IF (M. GE.4) CALL BET2 (NX1,NX2,NX3)
RETURN
END
RETURN
END
SUBROUTINE BT1(NX1,NX2,NX3)
DIMENSION IC(2), NA(2)
IC(1) = NX1
IC(2) = NX2
DO 100 I = 1, 2
IF (IC(1), LE, 12) NA(I) = 1
IF (IC(1), GE, 12) NA(I) = 2
IF (IC(2), LE, 24) NA(I) = 3
100 CONTINUE
NBOTH = NA(1) - NA(2) + 3
GO TO (10, 20, 30, 40, 50, 60, 70), NBOTH
10 NX3 = 14*(NX2-24)-NX1) + 68
GO TO 60
20 NX3 = 14*(NX2-12)-NX1) + 12
GO TO 60
30 NX3 = 14*(NX2-NX1) + 12
GO TO 60
40 NX3 = 14*(NX2-(NX1-12)) + 12
GO TO 60
50 NX3 = 14*(NX2-(NX1-24)) + 68
GO TO 60
RETURN
END
SUBROUTINE BT2(NX1,NX2,NX3)
DIMENSION IC(2), NA(2)
IC(1) = NX1
IC(2) = NX2
DO 100 I = 1, 2
IF (IC(1), LE, 12) NA(I) = 1
IF (IC(1), GE, 12) NA(I) = 2
IF (IC(2), LE, 24) NA(I) = 3
IF (IC(2), LE, 36) NA(I) = 4
100 CONTINUE
NBOTH = NA(1) - NA(2) + 3
GO TO (10, 20, 30, 40, 50, 60, 70), NBOTH
10 NX3 = 14*(NX2-36)-NX1) + 100
GO TO 60
20 NX3 = 14*(NX2-24)-NX1) + 56
GO TO 60
30 NX3 = 14*(NX2-12)-NX1) + 12
GO TO 60
40 NX3 = 14*(NX2-NX1) + 12
GO TO 60
50 NX3 = 14*(NX2-(NX1-12)) + 12
GO TO 60
60 NX3 = 14*(NX2-(NX1-24)) + 56
GO TO 60
70 NX3 = 14*(NX2-(NX1-36)) + 100
GO TO 60
RETURN
END
SUBROUTINE CLASS(NX1,NX2,KLASS1,KLASS2)
DIMENSION IC(2), K(2), NCAT(5), NR(5)
IC(1) = NX1
IC(2) = NX2
```fortran
DATA NCAT/0,1,2,3,4,5/  
DATA NF/1,2,3,4,5/  
DO 100 I=1,5  
DO 100 J=1,5  
IF (IC(I).GT.TC(J)).K(I).NE.N(J)  
100 CONTINUE  
KCLASS1=K(1)  
KCLASS2=K(2)  
RETURN  
END  
SUBROUTINE CATEG(ITEMNUM,ICT,ISIGN)  
IF (ISIGN.EQ.2) GO TO 111  
IF (M.EQ.1) CALL CATEG1(ITEMNUM,ICT)  
IF (M.EQ.2) CALL CATEG2(ITEMNUM,ICT)  
IF (M.EQ.3) CALL CATEG3(ITEMNUM,ICT)  
IF (M.EQ.4) CALL CATEG4(ITEMNUM,ICT)  
GO TO 112  
111 IF (M.EQ.1) CALL CATEG1(ITEMNUM,ICT)  
IF (M.EQ.2) CALL CATEG2(ITEMNUM,ICT)  
IF (M.EQ.3) CALL CATEG3(ITEMNUM,ICT)  
IF (M.EQ.4) CALL CATEG4(ITEMNUM,ICT)  
RETURN  
END  
SUBROUTINE CATEG1(ITEMNUM,ICT)  
DIMENSION NCAT(15),ITEM(15)  
DATA ITEM/964,292,792,762,684,648,684,648,612,576,540,504,468,432,396/  
DATA NCAT/12,11,10,9,8,7,6,5,4,3,2,1/  
DO 100 I=1,12  
100 IF (ITEMUM.LE.ITEM(1)).ICT=NCAT(I)  
RETURN  
END  
SUBROUTINE CATEG2(ITEMNUM,ICT)  
DIMENSION NCAT(25),ITEM(25)  
DATA ITEM/964,292,792,756,720,684,648,612,576,540,504,468,432,396/  
*360,324,288,252,216,180,144,108,72,36/  
DATA NCAT/24,12,22,11,10,2,21,9,20,19,7,6,18,17,5,4,16,15,12,14,3,1/  
*360,324,288,252,216,180,144,108,72,36/  
DATA NCAT/24,12,22,11,10,2,21,9,20,19,7,6,18,17,5,4,16,15,12,14,3,1/  
*360,324,288,252,216,180,144,108,72,36/  
100 IF (ITEMUM.LE.ITEM(1)).ICT=NCAT(I)  
RETURN  
END  
SUBROUTINE CATEG3(ITEMNUM,ICT)  
DIMENSION NCAT(40),ITEM(40)  
DATA ITEM/964,840,316,792,762,684,648,576,540,504,468,432,396/  
*288,252,216,180,144,108,72,36/  
DATA NCAT/24,12,22,11,10,2,21,9,20,19,7,6,18,17,5,4,16,15,12,14,3,1/  
*360,324,288,252,216,180,144,108,72,36/  
100 IF (ITEMUM.LE.ITEM(1)).ICT=NCAT(I)  
RETURN  
END  
SUBROUTINE CATEG4(ITEMNUM,ICT)  
DIMENSION NCAT(60),ITEM(60)  
DATA ITEM/964,840,316,792,762,684,648,576,540,504,468,432,396/  
*288,252,216,180,144,108,72,36/  
DATA NCAT/24,12,22,11,10,2,21,9,20,19,7,6,18,17,5,4,16,15,12,14,3,1/  
*360,324,288,252,216,180,144,108,72,36/  
100 IF (ITEMUM.LE.ITEM(1)).ICT=NCAT(I)  
RETURN  
END
```
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*144,120,96,72,48,24/
DATA NCAT/12,24,36,35,23,11,10,22,34,33,21,9,8,20,32,31,19,7,6,18/
*30,25,17,5,4,16,29,27,15,3,2,14,26,25,13,1/
DC 100 I=1,36
100 IF (ITNUM.LE.ITEM(I)) ICT=NCAT(I)
      RETURN
END
SUBROUTINE CATEG (ITNUM,ICT)
DIMENSION NCAT(40),ITEM(50)
DATA ITEM/864,846,828,810,792,774,756,738,720,702,684,666,648,630/
* 612,594,576,558,540,522,504,486,468,450,432,414,396,378,360,342/
* 324,306,288,270,252,234,216,198,180,162,144,126,108,90,72,54,36/
* 18/
DATA NCAT/12,24,36,48,47,35,23,11,10,22,34,33,21,9,8,23,22,8,31,19,7,6,18/
*30,25,17,5,4,16,29,27,15,3,2,14,26,25,13,1/
DC 100 I=1,36
100 IF (ITNUM.LE.ITEM(I)) ICT=NCAT(I)
      RETURN
END
SUBROUTINE CATEG (ITNUM,ICT)
DIMENSION NCAT(50),ITEM(50)
DATA ITEM/864,846,828,810,792,774,756,738,720,702,684,666,648,630/
* 612,594,576,558,540,522,504,486,468,450,432,414,396,378,360,342/
* 324,306,288,270,252,234,216,198,180,162,144,126,108,90,72,54,36/
* 18/
DATA NCAT/12,24,36,48,47,35,23,11,10,22,34,33,21,9,8,23,22,8,31,19,7,6,18/
*30,25,17,5,4,16,29,27,15,3,2,14,26,25,13,1/
DC 100 I=1,36
100 IF (ITNUM.LE.ITEM(I)) ICT=NCAT(I)
      RETURN
END
SUBROUTINE CHECK (ISIGN,ICT,NFFirst)
IF (ISIGN.EQ.3) GO TO 1
IF (ISIGN.EQ.4) GO TO 2
IF (ISIGN.EQ.0.1) CALL CHECK1 (ICT,NFFirst)
IF (ISIGN.EQ.0.2) CALL CHECK2 (ICT,NFFirst)
GO TO 3
1 IF (ISIGN.EQ.1) CALL CHECK3 (ICT,NFFirst)
IF (ISIGN.EQ.0.1) CALL CHECK5 (ICT,NFFirst)
GO TO 3
2 IF (ISIGN.EQ.0.1) CALL CHECK6 (ICT,NFFirst)
IF (ISIGN.EQ.0.2) CALL CHECK7 (ICT,NFFirst)
GO TO 3

3 RETURN
END
SUBROUTINE CHECK1(ICT, NFIRST)
DIMENSION NCAT(25), ITEM(25)
DATA ITEM/829, 757, 684, 613, 540, 466, 396, 325, 252, 181, 108, 37, 264, 721,
*720, 577, 576, 433, 432, 289, 288, 145, 144, 1/
DATA NCAT/24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4
*720, 577, 576, 433, 432, 289, 288, 145, 144, 1/
DO 100 I=1, 25
1 IF (ICT .EQ. NCAT(I)) NFIRST=ITEM(I)
RETURN
END
SUBROUTINE CHECK2(ICT, NFIRST)
IF (ICT .GE. 13) GO TO 1
IF (N FIRST .EQ. 72 * (ICT - 1) + 1) GO TO 2
1 N FIRST = 72 * (ICT - 13) + 37
RETURN
END
SUBROUTINE CHECK3(ICT, NFIRST)
DIMENSION NCAT(40), ITEM(40)
DATA ITEM/916, 769, 672, 625, 528, 481, 384, 337, 240, 193, 96, 49, 840, 745,
*696, 601, 552, 457, 408, 371, 264, 169, 120, 25, 864, 721, 720, 557, 576, 433,
*632, 299, 288, 145, 144, 1/
DATA NCAT/36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 24, 23, 22, 21, 20, 19, 18,
*17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1/
DO 100 I=1, 36
100 IF (ICT .EQ. NCAT(I)) NFIRST=ITEM(I)
RETURN
END
SUBROUTINE CHECK4(ICT, NFIRST)
IF (ICT .GE. 25) GO TO 2
IF (ICT .GE. 13) GO TO 1
IF (N FIRST .EQ. 72 * (ICT - 1) + 1) GO TO 3
1 N FIRST = 72 * (ICT - 13) + 25
GO TO 3
2 N FIRST = 72 * (ICT - 25) + 49
RETURN
END
SUBROUTINE CHECK5(ICT, NFIRST)
DIMENSION NCAT(50), ITEM(50)
DATA ITEM/910, 775, 666, 631, 522, 487, 379, 343, 234, 197, 90, 55, 829, 757,
*694, 517, 469, 396, 325, 252, 181, 106, 37, 846, 739, 702, 595, 558, 451,
DATA NCAT/48, 47, 46, 45, 44, 43, 42, 41, 40, 39, 38, 37, 36, 35, 34, 33, 32, 31, 30,
*29, 28, 27, 26, 25, 24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8,
*7, 6, 5, 4, 3, 2, 1/
DO 100 I=1, 48
100 IF (ICT .EQ. NCAT(I)) NFIRST=ITEM(I)
RETURN
END
SUBROUTINE CHECK6(ICT, NFIRST)
IF (ICT .GE. 37) GO TO 3
RETURN
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IF (ICT .GE. 25) GO TO 3
IF (ICT .GE. 13) GO TO 1
NFIRST=72*(ICT-1)+1
GO TO 4
1 NFIRST=72*(ICT-1)+19
GO TO 4
2 NFIRST=72*(ICT-25)+37
GO TO 4
3 NFIRST=72*(ICT-37)+55
4 RETURN
END
SUBROUTINES Used For the Large Warehouse:

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SUBROUTINE SIZE (KASE, EX, STDX)
DIMENSION AV(6), SE(6), KA(6)
DATA FA/1,2,3,4,5,6/
DATA AV/1.5,10,25,50,75,/
DATA SD/33,1.66,3.33,8.33,16.66,25. /
DO 10 I=1,6
10 IF(KASE.EQ.KA(I)) TX=AV(I)
DO 11 I=1,6
11 IF(KASE.EQ.KA(I)) STDX=SD(I)
RETURN
END
SUBROUTINE OSIZE2 (IX, EX, STDX, N)
SUM=0.0
DO 5 I=1,12
CALL PAND(IX,IX,YFL)
IX=IX
N=N+1.0
5 SUM=SUM+?X=STDX*(SUM-.6)+EX
YMAX=2.*EX
IF(Y,X.LT.0.0) GO TO 1
IF(Y,X.GT.X*MAX) GO TO 1
N=N+1.0
RETURN
END
SUBROUTINE OSIZE1 (IX,EX,Y)
CALL PAND(IX,IX,YFL)
IX=IX
Y=YFL
N=N+1.0
RETURN
END
SUBROUTINE DEMAND (DD,IX,ITEM)
IF(DD.LT.1.0) CALL TRIANG(IX,ITEM)
IF(DD.GT.2.0) CALL HANG(IX,ITEM)
IF(DD.GT.3.0) CALL UNIFR(IX,ITEM)
RETURN
END
SUBROUTINE UNIFR (IX,ITEM)
1 CALL PAND(IX,IX,YFL)
IX=IX
IF(YFL.GE.1.1) GO TO 1
ITEM=3333.*YFL+1.0
RETURN
END
SUBROUTINE HANG (IX,ITEM)
EX=0.0
STDX=0.3333
DO 5 I=1,12
CALL PAND(IX,IX,YFL)
IX=IX
Y=YFL
5 SUM=SUM+?X=STDX*(SUM-.6)+EX
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IF (X.LT.0.0) Y=-X
IF (X.LE.1.0) GO TO 1
ITEM=436.4*X+1.0
RETURN
END

SUBROUTINE DISTANT(MFIRST,ITNUM,ND2,ND3,M)

NDD=MFIRST-ITNUM
IF (NDD.LT.1) GO TO 500
GO TO 600
500 NDD=NDD
IF (NDD.LT.700) GO TO 600
600 NDD=2*(NDD/2)
ND=336/NDD-ND2
RETURN
END

SUBROUTINE TRIANG(IX,ITEM)
CALL RAND(IX,IX,YFL)
IX=IT
X=YFL
ITEM=436.4*(1.-SQRT(1.-B)) + 1.
RETURN
END

SUBROUTINE BAND(IX,IX,YFL)
IX=IT
X=YFL
YFL=YFL-.4656613359
RETURN
END

SUBROUTINE DOOR(MFIRST,ICT,ITNUM,ND1,M)
IF (M.EQ.2) M1=102
IF (M.EQ.3) M1=126
IF (M.EQ.4) M1=246
IF (M.EQ.4) M1=282
IF (M.EQ.3) M2=102
IF (M.EQ.4) M2=246
ND=(MFIRST-ITNUM)/7
ND=ND+14*(ICT-1)+6
GO TO 703
700 ND=ND-NDD
701 IF (ICT.GE.79) GO TO 705
IF (ICT.GE.53) GO TO 704
IF (ICT.GE.27) GO TO 702
ND=ND+14*(ICT-1)+6
GO TO 703
702 ND=ND+14*(ICT-79)+N1
GO TO 703
704 ND=ND+14*(ICT-27)+N2
GO TO 703
705 ND=ND+14*(ICT-79)+N3
RETURN
END

SUBROUTINE BETWEEN(N1,N2,N3,7)
IF (M.EQ.3) CALL BTW1(N1,N2,N3)
IF (M.EQ.4) CALL BTW2(N1,N2,N3)
RETURN
END

SUBROUTINE BTW1(NX1,NX2,NX3)
DIMENSION IC(2),NA(2)
IC(1)=NX1
IC(2)=NX2
DO 100 I=1,2
IF (IC(I).LE.26) NA(I)=1
IF (IC(I).GT.52) NA(I)=3
IF (IC(I).GT.52) NA(I)=3
100 CONTINUE
NBTM=NA(1)-NA(2)+3
GO TO (10,20,30,40,50),NBOTH
10 NX3=14*((NX2-52)-NX1)+132
GO TO 60
20 NX3=14*((NX2-26)-NX1)+12
GO TO 60
30 NX3=14*(NX2-NX1)+12
GO TO 60
40 NX3=14*(NX2-(NX1-26))+12
GO TO 60
50 NX3=14*(NX2-(NX1-52))+132
GO TO 60
RETURN
END

SUBROUTINE BTW2(NX1,NX2,NX3)
DIMENSION IC(2),NA(2)
IC(1)=NX1
IC(2)=NX2
DO 100 I=1,2
IF (IC(I).LE.26) NA(I)=1
IF (IC(I).GT.52) NA(I)=3
IF (IC(I).GT.78) NA(I)=4
100 CONTINUE
NBTM=NA(1)-NA(2)+4
GO TO (10,20,30,40,50,60,70),NBOTH
10 NX3=14*((NX2-78)-NX1)+196
GO TO 80
20 NX3=14*((NX2-52)-NX1)+104
GO TO 80
30 NX3=14*((NX2-26)-NX1)+12
GO TO 80
40 NX3=14*(NX2-NX1)+12
GO TO 80
50 NX3=14*(NX2-(NX1-26))+12
GO TO 80
60 NX3=14*(NX2-(NX1-52))+104
GO TO 80
70 NX3=14*(NX2-(NX1-78))+196
GO TO 80
RETURN
END

SUBROUTINE CLASS(NX1,NX2,KLASS1,KLASS2)
DIMENSION IC(2),K(2),NCAT(5),NF(5)
IC(1)=NX1
IC(2)=NX2
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* 31,5,30,4,29,3,28,2,27,1/
DC 100 I=1,52
100 IF (ITEMUM.LE. ITEM (I)) I=NCAT (I)
RETURN
END
SUBROUTINE CATEG (ITEMUM, ICT)
DIMENSION NCAT (80), ITEM (80)
DATA ITEMUM/36,4,43,2,452,6,4256,4200,4144,4088,4032,3976,3920,3964,3908/,
*3752,3696,3640,3584,3528,3472,3416,3360,3304,3248,3192,3136,3080/
*3024,2968,2912,2856,2800,2744,2688,2632,2576,2520,2464,2408,2352/
*2296,2240,2194,2148,2102,2056,1996,1920,1856,1792,1728,1664,1600/
*1536,1472,1408,1344,1280,1216,1152,1088,1024,960,896,832,768/
*704,640,576,512,448,384,320,256,192,128,64,0/
DATA DATAUM/26,52,78,77,5,1,25,4,29,76,75,70,64,56,48,40,36,30,25,20,15/
*10,6,5,4,3,2,2,1,1/  DC 100 I=1,79
100 IF (ITEMUM.LE. ITEM (I)) I=NCAT (I)
RETURN
END
SUBROUTINE CATEG5 (ITEMUM, ICT)
DIMENSION NCAT (104), ITEM (104)
DATA ITEMUM/36,4,43,2,452,6,4256,4200,4144,4088,4032,3976,3920,3964,3908/
*3752,3696,3640,3584,3528,3472,3416,3360,3304,3248,3192,3136,3080/
*3024,2968,2912,2856,2800,2744,2688,2632,2576,2520,2464,2408,2352/
*2296,2240,2194,2148,2102,2056,1996,1920,1856,1792,1728,1664,1600/
*1536,1472,1408,1344,1280,1216,1152,1088,1024,960,896,832,768/
*704,640,576,512,448,384,320,256,192,128,64,0/
DATA DATAUM/10,6,5,4,3,2,2,1,1/  DC 100 I=1,78
100 IF (ITEMUM.LE. ITEM (I)) I=NCAT (I)
RETURN
END
SUBROUTINE CATEG104 (ITEMUM, ICT)
DIMENSION NCAT (104), ITEM (104)
DATA ITEMUM/36,4,43,2,452,6,4256,4200,4144,4088,4032,3976,3920,3964,3908/
*3752,3696,3640,3584,3528,3472,3416,3360,3304,3248,3192,3136,3080/
*3024,2968,2912,2856,2800,2744,2688,2632,2576,2520,2464,2408,2352/
*2296,2240,2194,2148,2102,2056,1996,1920,1856,1792,1728,1664,1600/
*1536,1472,1408,1344,1280,1216,1152,1088,1024,960,896,832,768/
*704,640,576,512,448,384,320,256,192,128,64,0/
DATA DATAUM/10,6,5,4,3,2,2,1,1/  DC 100 I=1,104
100 IF (ITEMUM.LE. ITEM (I)) I=NCAT (I)
RETURN

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DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERS

END

SUBROUTINE CATEG(ITEMNUM, ICT)

DIMENSION NCAIT(104), ITEM(104)

DATA ITEM(4368, 4326, 4284, 4242, 4200, 4158, 4116, 4074, 4032, 3990, 3948), LARIO2790
* 3906, 3864, 3822, 3780, 3738, 3696, 3654, 3612, 3570, 3528, 3486, 3444, 3402, LARIO2800
* 3360, 3318, 3276, 3234, 3192, 3150, 3106, 3064, 3022, 2980, 2938, 2896, 2854, LARIO2810
* 2814, 2772, 2730, 2688, 2646, 2604, 2562, 2520, 2478, 2436, 2394, 2352, 2310, LARIO2820
* 2268, 2226, 2184, 2142, 2100, 2058, 2016, 1974, 1932, 1890, 1848, 1806, 1764, LARIO2830
* 1722, 1680, 1638, 1596, 1554, 1512, 1470, 1428, 1386, 1344, 1302, 1260, 1218, LARIO2840
* 1176, 1134, 1092, 1050, 1008, 966, 924, 882, 840, 798, 756, 714, 672, 630, 588, LARIO2850
* 546, 504, 462, 420, 378, 336, 294, 252, 210, 168, 126, 84, 42/ LARIO2860

DATA NCAIT(104), 78, 52, 26, 103, 77, 51, 25, 102, 76, 50, 24, 101, 75, 49, 23, 120, LARIO2870
* 74, 48, 22, 99, 73, 47, 21, 96, 22, 66, 41, 15, 92, 66, 40, 14, 91, 55, 39, 13, 90, 64, LARIO2880
* 38, 12, 89, 63, 37, 11, 88, 62, 36, 10, 87, 61, 35, 8, 86, 69, 34, 8, 85, 59, 33, 7, 84, LARIO2890
* 50, 32, 57, 31, 5, 22, 56, 30, 4, 81, 55, 29, 3, 60, 54, 28, 2, 79, 53, 27, 11/ LARIO2890

DO 100 I = 1, 104

100 IF (ITEMNUM .LE. ITEM(I)) IACT = NCAIT(I)

RETURN

END

SUBROUTINE CHECK (ISIGN, ICT, NFIRST, T)

IF (T .EQ. 3) GO TO 1

IF (T .EQ. 4) GO TO 2

IF (ISIGN .EQ. 1) CALL CHECK1 (ICT, NFIRST)

IF (ISIGN .EQ. 2) CALL CHECK2 (ICT, NFIRST)

GO TO 3

1 IF (ISIGN .EQ. 1) CALL CHECK3 (ICT, NFIRST)

IF (ISIGN .EQ. 2) CALL CHECK4 (ICT, NFIRST)

GO TO 3

2 IF (ISIGN .EQ. 1) CALL CHECK5 (ICT, NFIRST)

IF (ISIGN .EQ. 2) CALL CHECK6 (ICT, NFIRST)

RETURN

END

SUBROUTINE CHECK1 (ICT, NFIRST)

DIMENSION NCAIT(52), ITEM(52)

DATA ITEM(4229, 4177, 3946, 3715, 3484, 3253, 3022, 2791, 2560, 2329, 2108, 1877, LARIO3100
* 1646, 1415, 1184, 953, 722, 491, 260, 129, 96, 65, 32, 19, 6, 3/ LARIO3110
* 2152, 2017, 1882, 1747, 1612, 1477, 1342, 1207, 1072, 937, 802, 667, 532, 401, LARIO3120
* 278, 245, 212, 179, 146, 113, 80, 47, 14, 7, 1/ LARIO3130

DATA NCAIT(52), 51, 49, 47, 45, 43, 41, 39, 37, 35, 33, 31, 29, 27, 25, 23, 21, 19, 17, LARIO3140
* 15, 13, 11, 9, 7, 5, 3, 1/ LARIO3150

DO 100 I = 1, 52

100 IF (ICT .EQ. NFIRST) NFIRST = I

RETURN

END

SUBROUTINE CHECK2 (ICT, NFIRST)

IF (ICT .EQ. 27) GO TO 1

IF (NFIRST .EQ. 168 * (ICT - 1)) + 1

GO TO 2

1 NFIRST = 168 * (ICT - 27) + 95

2 RETURN

END
FILE: LARGE FORTRAN A

END

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LARG3660
APPENDIX C

EMPIRICAL ESTIMATION OF THE NEEDED SAMPLE SIZE
The Student's t-test was used to compare the average travel distance/order for a number of different simulation run lengths as mentioned earlier in Chapter III. The following pages contain a sample of the results of this analysis because the complete set of results is very extensive.

LEGEND:

T-STATISTIC(X,Y) = The t statistic for the difference between the avg. distance when the simulation run length is X and the avg. distance when the simulation run length is Y.

CASE = 1 .......... Avg. order size = 1 item/order
CASE = 2 .......... Avg. order size = 25 items/order
CASE = 3 .......... Avg. order size = 75 items/order.

Alpha = 0.05
ITEMS ARRANGEMENT: ZIG-ZAG

WAREHOUSE CAPACITY = 432 ITEMS

NO. OF SIMULATED ORDERS = 500

COMPARISON OF DIFFERENT MEANS OF TRAVELLED DISTANCE RESULTING FROM DIFFERENT SIMULATION RUN LENGTHS

H0 = THE TWO MEANS ARE EQUAL

<table>
<thead>
<tr>
<th>CASE</th>
<th>LAYOUT</th>
<th>NO. OF SIMULATED ORDERS</th>
<th>AVG DISTANCE/ORDER</th>
<th>STD DEV</th>
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<td>1</td>
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<td>56</td>
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CALCULATION OF T-STATISTIC:

T-STATISTIC(100, 50) = -0.33253  ACCEPT H0
T-STATISTIC(150, 50) = -0.52926  ACCEPT H0
T-STATISTIC(200, 50) = -0.66394  ACCEPT H0
T-STATISTIC(250, 50) = -1.08551  ACCEPT H0
T-STATISTIC(300, 50) = -1.24602  ACCEPT H0
T-STATISTIC(350, 50) = -1.40187  ACCEPT H0
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**Calculation of T-Statistic:**

- T-STATISTIC(100, 50) = -0.26431, ACCEPT H0
- T-STATISTIC(150, 50) = -0.53532, ACCEPT H0
- T-STATISTIC(200, 50) = -0.65556, ACCEPT H0
- T-STATISTIC(250, 50) = -1.16387, ACCEPT H0
- T-STATISTIC(300, 50) = -1.31761, ACCEPT H0
- T-STATISTIC(350, 50) = -1.44133, ACCEPT H0
- T-STATISTIC(400, 50) = -1.12456, ACCEPT H0
- T-STATISTIC(450, 50) = -1.16640, ACCEPT H0
- T-STATISTIC(500, 50) = -1.10543, ACCEPT H0
- T-STATISTIC(150, 100) = -0.29103, ACCEPT H0
- T-STATISTIC(200, 100) = -0.42703, ACCEPT H0
- T-STATISTIC(250, 100) = -1.00908, ACCEPT H0
T-STATISTIC(300, 200) = -1.10762 \text{ ACCEPT } H_0

T-STATISTIC(350, 200) = -1.33146 \text{ ACCEPT } H_0

T-STATISTIC(400, 200) = -0.83703 \text{ ACCEPT } H_0

T-STATISTIC(450, 200) = -0.92777 \text{ ACCEPT } H_0

T-STATISTIC(500, 200) = -1.00506 \text{ ACCEPT } H_0

T-STATISTIC(300, 250) = -0.22926 \text{ ACCEPT } H_0

T-STATISTIC(350, 250) = -0.43877 \text{ ACCEPT } H_0

T-STATISTIC(400, 250) = -0.10174 \text{ ACCEPT } H_0

T-STATISTIC(450, 250) = 0.02085 \text{ ACCEPT } H_0

T-STATISTIC(500, 250) = -0.05043 \text{ ACCEPT } H_0

T-STATISTIC(350, 300) = -0.21067 \text{ ACCEPT } H_0

T-STATISTIC(400, 300) = 0.36164 \text{ ACCEPT } H_0

T-STATISTIC(450, 300) = 0.28238 \text{ ACCEPT } H_0

T-STATISTIC(500, 300) = 0.22145 \text{ ACCEPT } H_0

T-STATISTIC(550, 300) = -0.60366 \text{ ACCEPT } H_0

T-STATISTIC(400, 350) = 0.52701 \text{ ACCEPT } H_0

T-STATISTIC(450, 350) = -0.45753 \text{ ACCEPT } H_0

T-STATISTIC(500, 350) = 0.09449 \text{ ACCEPT } H_0

T-STATISTIC(550, 400) = 0.17081 \text{ ACCEPT } H_0

T-STATISTIC(500, 450) = -0.06464 \text{ ACCEPT } H_0

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<th>CASE</th>
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CALCULATION OF T-STATISTIC:

T-STATISTIC(100, 50) = 0.10579 \text{ ACCEPT } H_0

T-STATISTIC(150, 50) = 0.90773 \text{ ACCEPT } H_0
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**Calculation of T-statistic:**

| T-STATISTIC(100, 50) = 0.09259 | ACCEPT H0 |
| T-STATISTIC(150, 50) = 1.08959 | ACCEPT H0 |
| T-STATISTIC(200, 50) = 1.64313 | ACCEPT H0 |
| T-STATISTIC(250, 50) = 1.96930 | *** REJECT H0 *** |
| T-STATISTIC(300, 50) = 2.22645 | *** REJECT H0 *** |
| T-STATISTIC(350, 50) = 2.26433 | *** REJECT H0 *** |
| T-STATISTIC(400, 50) = 2.40644 | *** REJECT H0 *** |
| T-STATISTIC(450, 50) = 2.55736 | *** REJECT H0 *** |
| T-STATE(TIC | \( (500, 50) \) | 2.45593 | \( \text{REJECT } H_0 \) | |\( (150, 100) \) | 1.24639 | \( \text{ACCEPT } H_0 \) | |\( (200, 100) \) | 1.96059 | \( \text{REJECT } H_0 \) | |\( (250, 100) \) | 2.41474 | \( \text{REJECT } H_0 \) | |\( (300, 100) \) | 2.78667 | \( \text{REJECT } H_0 \) | |\( (350, 100) \) | 2.85998 | \( \text{REJECT } H_0 \) | |\( (400, 100) \) | 3.07019 | \( \text{REJECT } H_0 \) | |\( (450, 100) \) | 3.27772 | \( \text{REJECT } H_0 \) | |\( (500, 100) \) | 3.15865 | \( \text{REJECT } H_0 \) | |\( (200, 150) \) | 0.70631 | \( \text{ACCEPT } H_0 \) | |\( (250, 150) \) | 1.15087 | \( \text{ACCEPT } H_0 \) | |\( (300, 150) \) | 1.57117 | \( \text{ACCEPT } H_0 \) | |\( (350, 150) \) | 1.63538 | \( \text{ACCEPT } H_0 \) | |\( (400, 150) \) | 1.86231 | \( \text{ACCEPT } H_0 \) | |\( (450, 150) \) | 2.06229 | \( \text{REJECT } H_0 \) | |\( (500, 150) \) | 1.92410 | \( \text{ACCEPT } H_0 \) | |\( (250, 200) \) | 0.44600 | \( \text{ACCEPT } H_0 \) | |\( (300, 200) \) | 0.89460 | \( \text{ACCEPT } H_0 \) | |\( (350, 200) \) | 0.94879 | \( \text{ACCEPT } H_0 \) | |\( (400, 200) \) | 1.18651 | \( \text{ACCEPT } H_0 \) | |\( (450, 200) \) | 1.38453 | \( \text{ACCEPT } H_0 \) | |\( (500, 200) \) | 1.22515 | \( \text{ACCEPT } H_0 \) | |\( (300, 250) \) | 0.46732 | \( \text{ACCEPT } H_0 \) | |\( (350, 250) \) | 0.51239 | \( \text{ACCEPT } H_0 \) | |\( (400, 250) \) | 0.75866 | \( \text{ACCEPT } H_0 \) | |\( (450, 250) \) | 0.95695 | \( \text{ACCEPT } H_0 \) | |\( (500, 250) \) | 0.78028 | \( \text{ACCEPT } H_0 \) | |\( (350, 300) \) | 0.03165 | \( \text{ACCEPT } H_0 \) | |\( (400, 300) \) | 0.27562 | \( \text{ACCEPT } H_0 \) | |\( (450, 300) \) | 0.46648 | \( \text{ACCEPT } H_0 \) |
\[
\begin{align*}
T\text{-STATISTIC}(500, 300) &= 0.27399 & \text{ACCEPT H}_0 \\
T\text{-STATISTIC}(400, 350) &= 0.25341 & \text{ACCEPT H}_0 \\
T\text{-STATISTIC}(450, 350) &= 0.45166 & \text{ACCEPT H}_0 \\
T\text{-STATISTIC}(500, 350) &= 0.25079 & \text{ACCEPT H}_0 \\
T\text{-STATISTIC}(450, 400) &= 0.19577 & \text{ACCEPT H}_0 \\
T\text{-STATISTIC}(500, 400) &= -0.01815 & \text{ACCEPT H}_0 \\
T\text{-STATISTIC}(500, 450) &= -0.22720 & \text{ACCEPT H}_0 \\
\end{align*}
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T\text{-STATISTIC}(150, 50) &= 1.15367 & \text{ACCEPT H}_0 \\
T\text{-STATISTIC}(200, 50) &= 1.71737 & \text{ACCEPT H}_0 \\
T\text{-STATISTIC}(250, 50) &= 2.06041 & \text{REJECT H}_0 \text{***} \\
T\text{-STATISTIC}(300, 50) &= 2.29879 & \text{REJECT H}_0 \text{***} \\
T\text{-STATISTIC}(350, 50) &= 2.30228 & \text{REJECT H}_0 \text{***} \\
T\text{-STATISTIC}(400, 50) &= 2.44119 & \text{REJECT H}_0 \text{***} \\
T\text{-STATISTIC}(450, 50) &= 2.57489 & \text{REJECT H}_0 \text{***} \\
T\text{-STATISTI}(500, 50) &= 2.47543 & \text{REJECT H}_0 \text{***} \\
T\text{-STATISTIC}(150, 100) &= 1.32652 & \text{ACCEPT H}_0 \\
T\text{-STATISTIC}(200, 100) &= 2.06422 & \text{REJECT H}_0 \text{***} \\
T\text{-STATISTIC}(250, 100) &= 2.53430 & \text{REJECT H}_0 \text{***} \\
T\text{-STATISTIC}(300, 100) &= 2.96268 & \text{REJECT H}_0 \text{***} \\
T\text{-STATISTIC}(350, 100) &= 2.91272 & \text{REJECT H}_0 \text{***} \\
T\text{-STATISTIC}(400, 100) &= 3.11664 & \text{REJECT H}_0 \text{***} \\
\end{align*}
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CALCULATION OF T-STATISTIC:

- T-STATISTIC(100, 50) = 0.13558  ACCEPT H0
- T-STATISTIC(150, 50) = 1.20323  ACCEPT H0
- T-STATISTIC(200, 50) = 1.75152  ACCEPT H0
- T-STATISTIC(250, 50) = 2.12013  REJECT H0
- T-STATISTIC(300, 50) = 2.35278  REJECT H0
- T-STATISTIC(350, 50) = 2.56574  REJECT H0
- T-STATISTIC(400, 50) = 2.50335  REJECT H0
- T-STATISTIC(450, 50) = 2.54650  REJECT H0
- T-STATISTIC(500, 50) = 2.54953  REJECT H0
- T-STATISTIC(150, 100) = 1.33479  ACCEPT H0
- T-STATISTIC(200, 100) = 2.04910  REJECT H0
- T-STATISTIC(250, 100) = 2.55133  REJECT H0
- T-STATISTIC(300, 100) = 2.93142  REJECT H0
- T-STATISTIC(350, 100) = 2.93295  REJECT H0
- T-STATISTIC(400, 100) = 3.13377  REJECT H0
- T-STATISTIC(450, 100) = 3.33520  REJECT H0
- T-STATISTIC(500, 100) = 3.22187  REJECT H0
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- T-STATISTIC(250, 150) = 1.19407  ACCEPT H0
- T-STATISTIC(300, 150) = 1.57172  ACCEPT H0
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**CALCULATION OF T-STATISTIC:**

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WAREHOUSE CAPACITY = 864 ITEMS

COMPARISON OF DIFFERENT MEANS OF TRAVELLED DISTANCE RESULTING FROM DIFFERENT SIMULATION RUN LENGTHS

\( H_0 \) = THE TWO MEANS ARE EQUAL

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CALCULATION OF T-STATISTIC:

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\[ T-\text{STATISTIC}(150, 50) = 0.48544 \text{ ACCEPT } H_0 \]
\[ T-\text{STATISTIC}(200, 50) = 0.64366 \text{ ACCEPT } H_0 \]
\[ T-\text{STATISTIC}(250, 50) = 0.92399 \text{ ACCEPT } H_0 \]
\[ T-\text{STATISTIC}(300, 50) = 0.07038 \text{ ACCEPT } H_0 \]
\[ T-\text{STATISTIC}(350, 50) = -0.17961 \text{ ACCEPT } H_0 \]
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7-STATISTIC(450, 400) = 0.24203 ACCEPT H0
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7-STATISTIC(500, 450) = 0.05475 ACCEPT H0

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CALCULATION OF T-STATISTIC:

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7-STATISTIC(250, 100) = -0.90832 ACCEPT H0
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| T-STATISTIC(500, 100) | -0.49905 | ACCEPT H0 |
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| T-STATISTIC(250, 150) | -0.55191 | ACCEPT H0 |
| T-STATISTIC(300, 150) | -0.27090 | ACCEPT H0 |
| T-STATISTIC(350, 150) | -0.42695 | ACCEPT H0 |
| T-STATISTIC(400, 150) | -0.30235 | ACCEPT H0 |
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| T-STATISTIC(250, 200) | -0.12120 | ACCEPT H0 |
| T-STATISTIC(300, 200) | -0.20492 | ACCEPT H0 |
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| T-STATISTIC(400, 200) | 0.20269 | ACCEPT H0 |
| T-STATISTIC(450, 200) | 0.46648 | ACCEPT H0 |
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| T-STATISTIC(400, 350) | 0.17332 | ACCEPT H0 |
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| T-STATISTIC(500, 350) | 0.55197 | ACCEPT H0 |
| T-STATISTIC(450, 400) | 0.33116 | ACCEPT H0 |
| T-STATISTIC(500, 400) | 0.35711 | ACCEPT H0 |
| T-STATISTIC(500, 450) | 0.04690 | ACCEPT H0 |
ITEMS ARRANGEMENT: ZIG-ZAG

WAREHOUSE CAPACITY = 4368 ITEMS

COMPARISON OF DIFFERENT MEANS OF TRAVELLED DISTANCE RESULTING FROM DIFFERENT SIMULATION RUN LENGTHS

H0 = THE TWO MEANS ARE EQUAL

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T-STATISTIC (306, 50) = 0.59761  ACCEPT H0
T-STATISTIC (356, 50) = 0.54914  ACCEPT H0
T-STATISTIC (406, 50) = 0.48740  ACCEPT H0
T-STATISTIC (456, 50) = 0.60307  ACCEPT H0
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**CALCULATION OF T-STATISTIC:**

- T-STATISTIC(100, 50) = 0.07993, ACCEPT H0
- T-STATISTIC(150, 50) = 1.34346, ACCEPT H0
- T-STATISTIC(200, 50) = 1.32730, ACCEPT H0
- T-STATISTIC(250, 50) = 1.22444, ACCEPT H0
- T-STATISTIC(300, 50) = 0.82967, ACCEPT H0
- T-STATISTIC(350, 50) = 0.63059, ACCEPT H0
- T-STATISTIC(400, 50) = 0.74537, ACCEPT H0
- T-STATISTIC(450, 50) = 0.71113, ACCEPT H0
- T-STATISTIC(500, 50) = 0.75046, ACCEPT H0
- T-STATISTIC(150, 100) = 1.62054, ACCEPT H0
- T-STATISTIC(200, 100) = 1.63819, ACCEPT H0
- T-STATISTIC(250, 100) = 1.52566, ACCEPT H0
- T-STATISTIC(300, 100) = 1.00824, ACCEPT H0
- T-STATISTIC(350, 100) = 0.74641, ACCEPT H0
- T-STATISTIC(400, 100) = 0.90662, ACCEPT H0
- T-STATISTIC(450, 100) = 0.86301, ACCEPT H0
- T-STATISTIC(500, 100) = 0.91933, ACCEPT H0
- T-STATISTIC(200, 150) = -0.05664, ACCEPT H0
- T-STATISTIC(250, 150) = -0.20742, ACCEPT H0
- T-STATISTIC(300, 150) = -0.82674, ACCEPT H0
- T-STATISTIC(350, 150) = -1.14720, ACCEPT H0
- T-STATISTIC(400, 150) = -0.98014, ACCEPT H0
- T-STATISTIC(450, 150) = -1.05557, ACCEPT H0
- T-STATISTIC(500, 150) = -1.00938, ACCEPT H0
T-STATISTIC(500, 350) = 0.20502 ACCEPT H0
T-STATISTIC(450, 400) = -0.04925 ACCEPT H0
T-STATISTIC(550, 400) = -0.03619 ACCEPT H0
T-STATISTIC(500, 450) = 0.01476 ACCEPT H0

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CALCULATION OF T-STATISTIC:

T-STATISTIC(100, 50) = -0.43680 ACCEPT H0
T-STATISTIC(150, 50) = 0.34804 ACCEPT H0
T-STATISTIC(200, 50) = 0.25029 ACCEPT H0
T-STATISTIC(250, 50) = 0.21141 ACCEPT H0
T-STATISTIC(300, 50) = 0.11735 ACCEPT H0
T-STATISTIC(350, 50) = 0.06489 ACCEPT H0
T-STATISTIC(400, 50) = -0.01540 ACCEPT H0
T-STATISTIC(450, 50) = 0.02719 ACCEPT H0
T-STATISTIC(500, 50) = 0.04994 ACCEPT H0
T-STATISTIC(150, 100) = 1.07762 ACCEPT H0
T-STATISTIC(200, 100) = 1.00127 ACCEPT H0
T-STATISTIC(250, 100) = 0.97038 ACCEPT H0
T-STATISTIC(300, 100) = 0.81698 ACCEPT H0
T-STATISTIC(350, 100) = 0.56384 ACCEPT H0
T-STATISTIC(400, 100) = 0.64960 ACCEPT H0
T-STATISTIC(450, 100) = 0.99610 ACCEPT H0
T-STATISTIC(500, 100) = 0.72706 ACCEPT H0