A COMPUTERIZED SIMULATION APPROACH TO THE SOLUTION OF THE CARRIER DISPATCHING PROBLEM

763

by

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TABLE OF CONTENTS

APPENDICES

INTRODUCTION

Background and Purpose

The movement or relocation of consumer products ranging from air-rifle shot to huge machine tools, and covering items from the food and clothing industries to hardware items such as sewer pipe, electric motors and weapons for the Viet Nam war all serve to point up the invaluable usage of transportation to the United States' mobile economy. It is stated that in 1964, over 1½ million railroad freight cars were utilized for the movement of physical facilities (11).

This number of freight cars does not include the additional transportation of passengers. Add to the railroad industries movement the fact that todays' trucks haul over 29 billion intercity ton-miles of goods (one ton-mile being equivalent to one ton being carried one mile) (5). Furthermore, the transportation of school children throughout the United States to and from school buildings requires the carrying of four times the amount of passengers daily, than does the commercial intercity transport system composed of railroads and commercial bus lines (5).

Air lines and water movement of physical facilities and passengers are also to be included when considering the nations' transportation system. Combining the cost of this phenomenal amount of transportation required annually would result in a figure reaching into the hundreds of billions of dollars.

Many areas of the nation's transportation system are available for study to the Industrial Engineer seriously interested in reducing the cost of transportation for an industry, school system, or transportation facility of some type. These areas, such as scheduling frequency, vehicle capacity, routing, terminal facilities, and automatic vehicle control are all fertile areas for study and eventually a reduction of costs (10). However, the study of all these areas would be a magnanimous task in its own right, but the study of any one part of the transportation system could conceivably be conducted by one researcher. A glance at the possible areas of improvement in terms of reducing mileage and inherent costs thereof yielded the choice of the routing or dispatching problem as rather a contral problem area and an excellent basis for reducing costs. It appears that if an optimum routing procedure could be developed, some of the associated problems would be reduced in magnitude, such as scheduling of vehicles, and vehicle capacity.

Routing, for purposes of this study, is defined to be the derivation of a permutation of demand points or stops over which to send carriers of passengers or physical goods. Before the advent of operations research techniques, the typical means of routing carrier vehicles was to pick the best looking array of stops from a map of the area over which routing was to take place and mold it to the utilization of carriers consistent with their capacity. If a shorter route could be determined by manipulating routes and vehicles it was used.

This procedure could be computationally possible for four or five stops, but as distribution points increased the efficiency of "routing" would tend to decrease, the optimum route becoming more and more difficult to locate.

The possibility of performing much the same operation by means of utilizing a computer for the computational labor and simulation for organizing the problem came under full consideration, and was consequently developed as herein stated. This means of searching for a short route as constrained by necessary assumptions in the solution of the problem is compared to methods of solution utilizing operations research analysis, for purposes of determining the best available routing technique currently available.

Problem

The problem is basically one of minimizing the distance through an array of demand points while satisfying certain restrictions, given the original distance between all demand points and a point referred to as the origin, where demand equals zero. In solving the problem the following considerations must be taken into account;

(1) The demand at each demand point must be fulfilled, preferably simultaneously.

(2) Carriers may or may not all be equivalent in capacity.

(3) The demand at any demand point may not be greater than the capacity of any one fleet vehicle.

(4) The determined routes are all either 'pick-up' or 'distribution' routes, and not both.

"Truck dispatching" or "carrier routing" are titles for problems which fall along the lines of the problem as outlined above. A solution to the particular problem as above specified is herein sought, by means of computer simulation.

SURVEY OF THE LITERATURE

Many solutions to the classic traveling salesman problem have been proposed in literature published in the past fifteen years. This problem gained a reputation of being that type of problem which had a simple title, although requiring an extreme amount of labor in seeking out a satisfactory solution (12). However, a solution did exist and in a recent promotional contest, several contestants determined the solution to a 33-city problem (12). The fact that many early attempts to solve the traveling salesman were abortive, lead to the quick exclusion of those articles from the reference list. Since an algorithm was needed which could be programmed for a computer, besides guaranteeing an optimal solution and at the same time remaining applicable to a variable size of problem, the obvious solution was found in the form of a Master's Report in the Industrial Engineering Department at Kansas State University. V. C. Patel, (13) working with a 'branch and bound' algorithm, (12), wrote a computer program for the solution of variable sizes of traveling salesman problems. By changing the form of the program and the values of the dimension statements, Patel's work was completely adaptable to the needs of the proposed study.

Other than literature directly concerned with the traveling salesman problem, Boyer's article (2) made reference to a similar method to the proposed simulation procedure in passing, by noting that years would be required to obtain and test all routes using a method of random generation of stop order. Boyer further goes on to state that an extension of this very program became the basis of his method of solving carrier routing problems.
A number of approaches have been taken in attempting to solve the routing or carrier dispatching problem. These methods, which include Boyer's

'feasible route generation' (2), dynamic programming (16), algorithms by Dantzig & Ranser (8), Clarke and Wright (4), and Cochran (5) are discussed briefly below for purposes of result comparison later in this paper.

Approaches to the Problem

A semi-simulation approach to the carrier dispatching problem was taken by Boyer (2) in that the original feasible route is determined by partitioning the school system (in this case) into individual bus routes. At this point, a computer program written in SPS is used to generate all feasible routes for each partition of the school system. Upon generation of all routes, the computer printout is perused to locate the 'best' route generated for each vehicle or system partition. The cost is then determined and the best route is utilized.

Tillman (16) attacked a small scale school bus scheduling problem (carrier dispatching) by applying the technique of dynamic programming. For the particular problem used, involving five stops, three busses and 40 pupils, an optimum solution was obtained. However, for larger problems, computational difficulty by reason of overwhelming numbers of calculations to be performed outweighs the advantages of this method (5).

An algorithm published in 1958 by Dantzig and Ramser (8) has yielded quite satisfactory, albeit, not optimal results, in carrier dispatching. Basically, the algorithm consists of ordering demand at demand points from least to greatest. These demands are then used in the following manner; the solution is one of stage-wise combination of demands, such that in the first stage pairs of points are joined, pairs of pairs are joined in the second stage, etc. (5). Therefore the demands must be combined initially so that when the first pair of points is joined, the demand does not exceed the capacity of the carrier fleet. If another joining is desired, the original combinations must allow two pairs of points to be joined without exceeding carrier capacity, and so on until the maximum number of joinings desired is satisfied. The remaining variables are interpair distances and therefore to optimize route length, the sum of these interpair distances is minimized at each stage, and the final stage results in the minimum trip length.

A modification to the above algorithm was proposed in 1962 by Clarke and Wright (4). These authors felt that Dantzig and Ramser paid too much heed to vehicle loading and not enough to distance saving. Therefore, their algorithm consisted of ordering the demand points according to distance from the origin, closest first, next closest second, and so on until all points were ordered. Capacity of vehicles was also ordered from smallest to largest to aid in the computation. The distance matrix was then used to determine maximum savings between each two respective stops. These maximum savings were then sought out, largest first until no more savings existed, and the allocated routes were then determined. This algorithm seems to yield quite good, although still not minimal routes.

Cochran (5) proceeded to modify the algorithm set forth by Clarke and Wright by adding additional constraints in an attempt to further reduce total mileage per route. One modification which Cochran made was to utilize 'freed' vehicles, or carriers which had initially been assigned to some demand point and were displaced by a new combination of demand points, by including a reassignment of carriers to loads after each pair of loads was combined (5). Each demand, beginning with the smallest was then allocated to the vehicle of smallest capacity which could take on that demand. This modification was intended to more fully utilize available vehicles, thus reducing total miles travelled. Another modification set forth by Cochran was one of limiting the mileage of any vehicle in the fleet to less than a certain set figure. This modification, more for practical considerations than as an additional means of reducing route mileage is listed here for completeness. Cochran's reassignment modification did aid in further reducing mileage below that of former methods on several example problems, and appears to be the most efficient method available to date in the literature.

Evaluation of the Proposed Simulation Solution

To the present, then, a method of solution of the carrier dispatching problem which can guarantee an optimal route is still not to be found in the literature. Therefore it is proposed herein to seek a simulation solution in which a minimum route can be determined, or to at least be able to make a probability statement as to the "closeness" of the actual determined route to the true minimal route. This, then, is to be conducted as a feasibility study on one simulation approach to the carrier dispatching problem. As a need for a true optimum route becomes more and more acute, it is obvious that a study of this nature may open the way for further research in this area. Such was the case, as to be noted in the section headed "Recommendations."

THEORETICAL CONSIDERATIONS

In deciding how best to program the computer to 'search' for a minimal route, several factors had to be taken into account. These are the following;

(1) It must be assumed that the capacity of at least the largest carrier (assuming here that carriers of varying size are available) exceeds that of the load to be either loaded or distributed at each demand point. In the event that a load does exceed the largest capacity carrier's capability, allocate a carrier of highest capacity to the demand point and include the remainder of the load, which will be less than a vehicle load of the highest capacity. The remainder is then considered to be the demand at that particular demand point and full truck-loads are excluded from consideration in solution of the problem.

(2) It must be assumed that a sufficient number of carriers are available to be able to contain the total demand at all demand points so that if all carriers are dispatched simultaneously on their respective routes, no demand point is slighted.

(3) It must be assumed that as carriers proceed from the origin (for example, a loading dock) they complete the route either distributing the load originally carried from the loading dock without replenishing the supply along the way, or conversely, picking up loads beginning empty at the origin and not unloading any commodities along the route.

(4) A final assumption is that if a carrier does not retain the capacity to assume the full demand at a demand point, no demand at that point is taken on by that vehicle. It is assumed that the

next vehicle will proceed with full potential capacity to this stop, and if assumption (1) holds, pick up all demand at that point.

COMPUTATIONAL PROCEDURE

Step 1.

Proceeding under the assumptions as discussed above, the first step in the computation procedure is one of assigning identification numbers to respective demand points for easy numerical association in computer subscripting operations, and for referability as to final output of routes. These demand points are labeled P_i (i = 1, 2, ..., NS), where NS equals the number of demand points. The arrangement in order of demand points is immaterial for simulation purposes since a matrix of respective distances between every pair of demand points is a prerequisite for solving the traveling salesman problem. This is a definite advantage over most of the operations research approaches to the problem. Adding 1 (one) to the value of NS given above yields the value MM, which is the identification number assigned to the origin or point of departure and return of the carrier facilities. An MM by MM matrix is then assembled, giving the respective distance between each two demand points or a demand point and the origin. Consider the matrix shown in Figure 1 of Plate I. Note that MM is the highest numbered stop in the matrix designation.

Associated with each demand point in the matrix is the demand of passengers seeking to obtain a seat in a bus or train, or a load of merchandise to be discharged or taken on. This is represented pictorially in Figure 2 of Plate I. Note that as formerly specified, there is no demand associated with the origin.

Now that the stops and their respective loads are determined, it is natural to consider the available carriers and their capacities.

EXPLANATION OF PLATE I

Fig. 1. Distance matrix in miles between stops.

Fig. 2. Demand at each respective demand point.

Fig. 3. Carrier capacity in same units as demand.

PLATE I

	1	2	3	4	5	MM
1	0	4	6	3	2	5
2	4	0	5	4	11	7
3	6	5	0	7	6	11
4	3	4	7	0	8	13
5	2	11	6	8	0	10
MM	5	7	11	13	10	0

Fig. 1

STOP	DEMAND
1	10
2	8
3	6
4	9
5	7
MM	0
Total	40

Fig. 2

CARRIER	CAPACITY
1	20
2	20
3	20
Total	60

Fig. 3

It may be seen in Figure 3 of Plate I that the capacity of the available carriers is fixed; that is, the capacity of Carrier 1 equals the capacity of Carrier 2 equals the capacity of Carrier 3. In comparing these capacities with the demands at each stop, it can be seen that the requirement of carrier capacity exceeding demand point loads is met. Also, a sufficient number of carriers is available to simultaneously pick up the demand on each route, and the demand is all positive so that no demand is to be discharged along a route.

Since the capacity of carriers for this example problem is the same, a fixed capacity solution is necessary. But in the event that all carriers were not equal in capacity, it would not do to load or unload them in a fixed capacity format. Therefore, a provision was made in which either fixed or variable capacity vehicles could be utilized through changing a minimal amount of input data as explained in Appendix II. In order to carry out this computation, however, the capacities of vehicles to be utilized must be ordered from least to greatest such that q_i (i = 1, 2, ..., NB), where NB is the total number of carriers available, fulfill the requirement that:

$$q_i \leq q_{i+1} \leq q_{i+2} \leq \cdots \leq q_{NB}$$

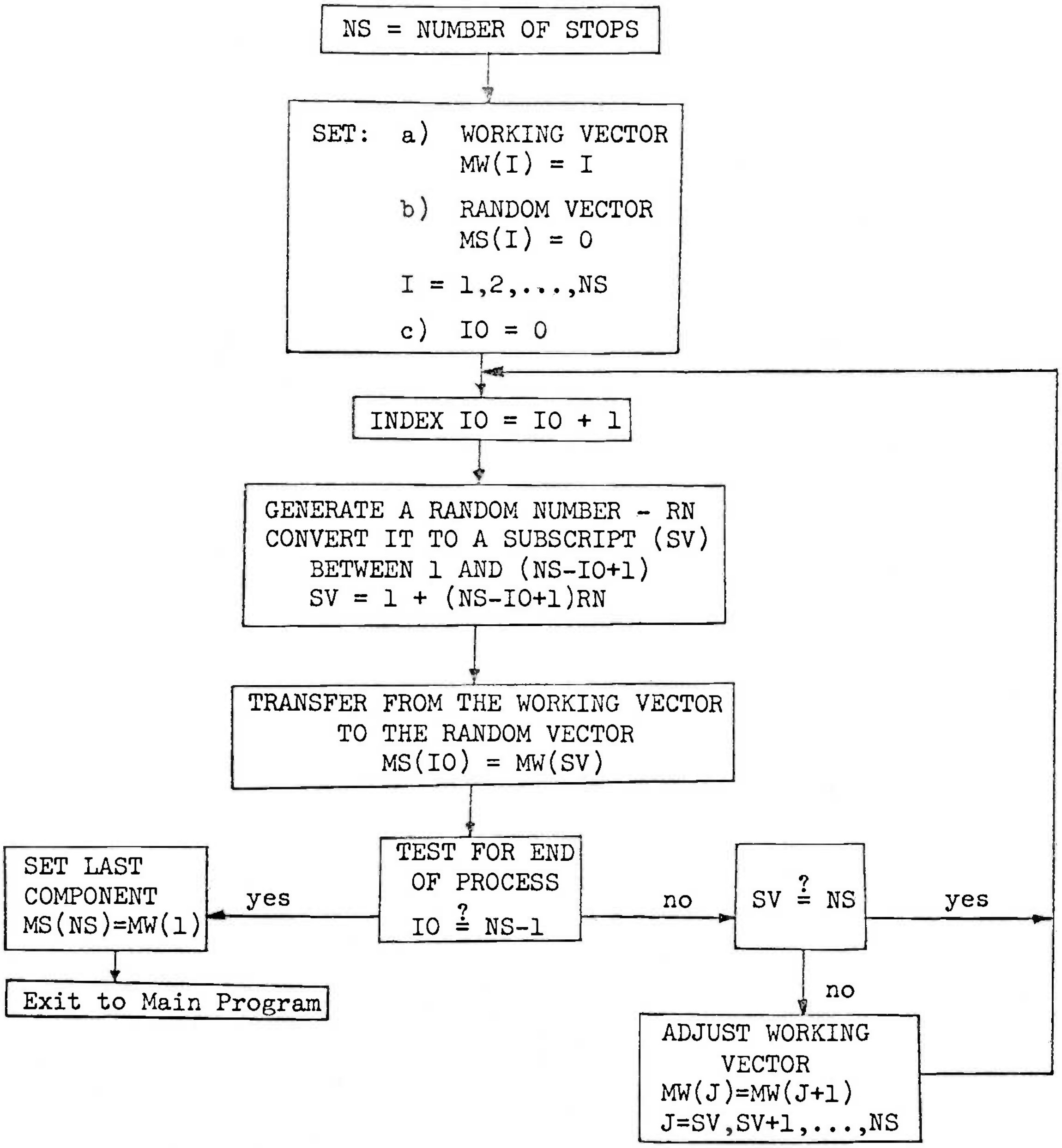
Step 2.

The next item to consider in setting up the problem is the number of total routes to simulate for each run of the simulation program. The program is based upon the assumption that the probability of obtaining a minimal length route is a monotonic nondecreasing function of run length. Computer speed and cost would be a critical factor at this point, as well as the number of demand points over which the routing problem is to take place.

EXPLANATION OF PLATE II

A flow diagram of utilization of random numbers in sequencing the order of stops.

PLATE II


NS = NUMBER OF STOPS
SET: a) WORKING VECTOR MW(I) = I
b) RANDOM VECTOR MS(I) = 0
I = 1,2,...,NS
c) IO = 0
INDEX IO = IO + 1
GENERATE A RANDOM NUMBER - RN CONVERT IT TO A SUBSCRIPT (SV) BETWEEN 1 AND (NS-IO+1) SV = 1 + (NS-IO+1)RN
TRANSFER FROM THE WORKING VECTOR TO THE RANDOM VECTOR MS(IO) = MW(SV)
TEST FOR END OF PROCESS IO ≟ NS-1
yes
SET LAST COMPONENT MS(NS)=MW(1)
Exit to Main Program
no
SV ≟ NS
yes
no
ADJUST WORKING VECTOR MW(J)=MW(J+1) J=SV,SV+1,...,NS

As NS increases, time per pass increases. The IBM 1410 computer is a medium-fast computer capable of turning out one route every two seconds for a small five stop problem, and a route every 11.8 seconds for a problem involving 25 demand points using the simulation program. These times could be decreased markedly by a faster computer or increased considerably by, say, the IBM 1620 computer. However, when the number of total test routes is determined it is labeled MCASE and punched into the control card as described in Appendix II. Therefore, if 2000 test routes are desired, the number 2000 is punched into the input data card for MCASE.

Step 3.

After the number of demand points involved is decided upon, it becomes necessary to determine an ordering of the stops. This is done by the use of a random number generator function which has been converted from IBM's System Library Subroutine to an Autocoder function for the IBM 1410. This generator, capable of producing five thousand random numbers per second, has been tested for randomness by D. J. Wichlan (17) using the Kendall-Babington-Smith chi-square test. Wichlan showed it to result in non-significant variation from a random uniform distribution at an alpha level of .05. An algorithm for converting each random number generated to a permuted stop is used and illustrated in PLATE II. Thus, for a matrix of NS stops, NS random numbers are all that are required to permute all the demand points into a random order. This permutation of stops or demand points occurs routinely, once for every trial route desired. This part of the program is solely responsible for the total number of miles per complete route since a generation of stops located in the same general area to later be allocated to the same vehicle will quite naturally reduce the number of miles per total trip, and conversely, generating stops at alternate ends of the demand point array to be allocated to one vehicular route will produce a non-minimal route.

Step 4.

Now that a permuted order of demand points has been generated, the carriers must be loaded or unloaded in one of the following two ways;

(1) If the fleet of carrier vehicles is composed of carriers which all have equivalent capacity, the fleet is considered to be one of 'fixed capacity'. Therefore to insure vehicles which are filled to maximum capacity without actually exceeding their load capabilities, each respective carrier is dispatched to the first stop in its route as determined by the random number generator. At this point the vehicle's capacity is reduced by the amount of demand at that particular demand point. The capacity remaining (NQ in the program) available for additional loads is tested and determined to be positive (some remaining potential capacity exists), zero (the demand exactly equals the carrier's capacity), or negative (the vehicle is overloaded). The program continues in one of three ways from this point;

(a) If some remaining capacity exists, the vehicle is forwarded to the next stop in its route sequence. Once again the available capacity is reduced by the new demand at the demand point, and again tested for an overloaded condition. If capacity remains at this point, (a) is repeated. If capacity just equals the load, proceed to section (b). If the vehicle has been filled beyond its capacity, proceed to section (c).

(b) If the program arrives at this section, it is assured that the load just exactly fills the carrier to capacity. The program continues by extracting the stops involved in the route for which this capacity is fulfilled and assembling a unique sub-matrix from the original distance matrix as explained below in Step 5.

(c) When the program reaches this point, it is due to the exceeding of a vehicle's capacity. In order to restore conditions to what they were prior to assuming the excess demand at this last demand point, the demand at the final demand point on this route is removed and the index of stop numbers, (JI) is reduced by one. In effect this restores conditions to the satisfactory state prior to overloading and resets the demand point extracted from this route as the first stop on the succeeding vehicle's route.

(2) In the event that the carrier fleet is composed of vehicles which differ in capacity, the fleet is considered to be one of 'variable capacity'. Therefore, the program must know how to choose an appropriate size of vehicle for a given load. There are two ways in which this may be done, both of which will be explained below. The first method was rejected in favor of the second method.

(a) As first programmed, the vehicles were loaded (unloaded) as described under (1), above. The vehicles were filled until such time as the minimal capacity was exceeded, that is the capacity of the smallest carrier in the fleet. At this time, then, the negative load (overload) was converted to the equivalent positive load. For example, if a 4000 pound load had been exceeded at a certain demand point, by 200 pounds, the load was merely assumed to be 4200 pounds and the remaining vehicles of larger capacity were tested in order of size (smallest to largest) until a carrier of sufficient size, possibly 5000 pounds of capacity, was chosen for the given route. This was discarded for two reasons; first, the process used by the program for finding a suitable capacity vehicle tended to emphasize usage of the smallest vehicles in the fleet first. Obviously, this left the larger capacity vehicles idle which without a doubt represent a higher initial investment. Secondly, it may be reasoned that the usage of larger capacity vehicles in hauling loads over a route could quite easily eliminate the need and therefore expense for one or more carriers. This has actually been borne out in previous attempts at solution of the routing problem.

(b) As the program now exists, the carriers are loaded in the following manner to utilize most fully the vehicles of largest capacity. The carriers are filled until the capacity of the largest vehicle in the fleet is exceeded. Then, as explained under Number (1), Part (c) above, conditions are restored to that preceding the demand point causing overload by removing the demand at the last stop on this route and decreasing the stop index by one. At this time the load remaining on the carrier is tested against all vehicle capacities beginning with that of the smallest vehicles and proceeding to the largest. When a sufficiently large carrier is obtained to assume the remaining load, this capacity vehicle is assigned to that route. This feature of the program does tend to utilize the carriers of largest capacity first. Also if all carriers of one capacity are previously assigned to routes within the total trip, a vehicle of the next largest capacity will be assigned to the route requiring a similar sized vehicle. If the maximum vehicle capacity has not been exceeded during successive demand point loadings, the program works under the same decision process as explained under (1) above. Also, as the program tests for overload conditions of vehicles after each demand point, it also checks to determine if all stops have been satisfied. If at any time the demand at the last permuted stop has been loaded without exceeding the capacity of the specified vehicle, the load is tested to determine which capacity of carrier is necessary to haul the load for that series of demand points.

Step 5.

As each carrier is loaded in the manner illustrated in the preceding section, the number of each stop (NSTOP) is retained by the computer method of subscripting a variable. After obtaining vehicles loaded to their maximum through use of the above procedure, it has been stated that overload stops are disregarded on the route for which they cause overload conditions. Thus, each value of NSTOP (saved by subscript notation MR(JI)) is extracted from the original distance matrix read in at the beginning of the program. The value of MM is also included in the sub-matrix, so that the final matrix for each truck might appear as in Figure 1, Plate III.

EXPLANATION OF PLATE III

Fig. 1. Section of original distance matrix.

Fig. 2. New sub-matrix to which traveling salesman is applied.

Fig. 3. Transformation of stop numbers to consecutive integers.

PLATE III

	1	2	...	8	...	16
1	0	3	...	5	....	7
2	3	0	...	6	...	10
⋮	⋮	⋮		⋮		⋮
8	5	6	...	0	...	11
⋮	⋮	⋮		⋮		⋮
16	7	10	..	11	....	0

Fig. 1

	1	2	8	16
1	0	3	5	7
2	3	0	6	10
8	5	6	0	11
16	7	10	11	0

Fig. 2

	1	2	3	4
1	0	3	5	7
2	3	0	6	10
3	5	6	0	11
4	7	10	11	0

Fig. 3

It is further changed for ease of computer programming as indicated in Figure 3, PLATE III, by transforming the stop numbers to consecutive integers. (The stop numbers are retained by subscripting for printout of the final route, if the route is determined to be a low one.) Upon securing this sub-matrix for each carrier, the optimum ordering of the demand points remains to be obtained.

Step 6.

In attempting to find the optimum order of demand points consistent with a minimum route for each carrier, the problem has been reduced to that of the traveling salesman problem.[1] Fortunately for the author, a computerized solution to the traveling salesman problem was available in the form of a Master's Report completed in 1964 by V. C. Patel (13). The computer solution to the traveling salesman problem as determined by Patel needed some modification in order to incorporate it into the current simulation program. This modification included the elimination of four subprograms and their attendant dimension and common statements, by their incorporation into the body of the main program, and also included the incorporation of a series of Fortran statements into the program in order to eliminate blocking of a subtour on the last pass of the traveling salesman algorithm, so that all demand points could be salvaged for the print out of the total route for each vehicle. With these changes applied to Patel's program and tested for validity, the traveling salesman algorithm became an integral part of

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[1] The traveling salesman problem may be stated as follows: Determine the shortest route for a salesman (vehicle) starting from a given city, visiting each of a specified group of cities, (demand points), and then returning to his original point of departure (origin).

the program, and the means of determining a minimum path through a given series of stops. The fact exists that for only two demand points allocated to a route in conjunction with the origin, only one possible path exists and the mileage between the two points, and each point and the origin would yield the total route mileage (which is also symmetrical; that is ORIGIN - Stop 1 - Stop 2 - ORIGIN equals ORIGIN - Stop 2 - Stop 1 - ORIGIN). It is when there are more than two demand points allocated to a route that the traveling salesman solution provides a minimal path of several possible paths. Actually, there exist $\frac{1}{2}$ (N-1) ! routes for the symmetrical problem, where N equals the size of the matrix to which the traveling salesman problem is applied. Therefore, for two demand points plus the origin, N = 3, and there are $\frac{1}{2}$ (3-1) ! = 1 route. For three demand points and the origin, there are $\frac{1}{2}$ (4-1) ! = 3 distinct routes. The traveling salesman algorithm therefore becomes extremely valuable as the number of demand points per carrier route increases.

Step 7.

After obtaining the shortest route through the randomly generated demand points for one carrier, the program returns to Step 3 where each succeeding carrier is loaded, its demand points and its lowest route then being determined. The route mileage for each carrier is retained through subscripts used in programming. Upon the programs determination that all demand points have been satisfied, the mileage for each separate vehicle is accumulated into a total number of miles for all carriers. This total mileage figure is then tested against the shortest preceding value of total mileage (equal to 9999 miles for the initialized lowest route value) and if found to be a new lowest value, the total accumulated route mileage is printed, along with individual mileage for each carrier, the capacity of each carrier, and the exact route for each carrier. If the total mileage figure is not a new minimal value, the program merely records the total length of the route and proceeds to a new pass or case to search for another possible route.

Step 8.

Finally for each total route which is formed, the value MCASE is tested to determine whether another trial route is to be searched for. If so, a new route is sought, but if the last iteration has concluded the search, the total time for all processing of routes on the 1410 is printed and the program halts. The time recorded may be used for calculation of time per iteration by dividing the number of minutes by the total number of passes made. This may prove very useful for predetermining the number of cases to attempt given a specified amount of computer time.

SUMMARIZATION OF THE SIMULATION PROCEDURE

The computational procedure may be stated briefly as follows:

Step 1. Label the demand points from 1 to NS. Add 1 to NS to obtain MM. Form an inter-stop distance matrix. Order the carrier capacities from smallest to largest.

Step 2. Determine the value MCASE to tell the computer how many attempted routes are to be sought.

Step 3. A random permutation of the NS stops is generated.

Step 4. The carriers are loaded by dispatching each vehicle to the first permuted demand point not on the route of a previous vehicle.

Step 5. A sub-matrix of distances is formed for each distinct carrier route.

Step 6. The traveling salesman solution is then applied to each submatrix.

Step 7. The mileage is retained for each distinct carrier route.

Step 8. Sum the mileage saved from each distinct carrier route to obtain a grand total mileage figure. Compare this with the preceding route of shortest length and print the route for each carrier, mileage for each carrier, mileage summed for all carriers, and capacity of each vehicle if it is the shortest route. Otherwise, return to Step 3 unless the number of required iterations has occurred. If the number of passes originally required have been made, the program halts.

DISCUSSION OF SAMPLE PROBLEMS

As discussed previously in the literature survey section of this paper, several attempts have been made to solve the carrier dispatching or routing problem. As a basis of comparison among approaches to the problem, several small to medium sized problems now exist. The computer simulation approach as herein used is applied to four of these problems, which consist of the following:

(1) A 5-stop problem used in the dynamic programming approach to solving routing problems, is referred to as sample problem 1. The distance matrix for this, and all other sample problems may be found in Appendix IV. Note that the number of stops does not include one unit for the origin. Note also that destination identification numbers may vary from those used in this paper to those used in other publications, although the answers may be identical.

(2) A 12 stop problem is one utilizing a variable capacity fleet of vehicles. This problem was used to test the variable capacity portion of the simulation program and is included to demonstrate this feature of the program. This is referred to as sample problem 2.

(3) Sample problem 3 is a 13 stop problem with a fixed capacity fleet of vehicles. This was included as a means of determining the efficiency of the program on an intermediate size of problem. This is an actual problem concerning the routing of a fleet of feed delivery trucks. This problem and sample problem 4 were provided by the 'Grain and Feed Marketing Project of the Agricultural

Experiment Station at Kansas State University' (5).

(4) This problem is an actual 33 stop problem concerning the routing of a fleet of fixed capacity vehicles. Fortunately, 8 demand points could be eliminated by sending full vehicles to each of 8 delivery points and the resulting problem utilizing 25 demand points fell within the limitations of the computer dimension statements.

A comparison of the results as obtained by the approach taken by the author and those methods used by other authors is best illustrated by the grid included in the section headed "Results".

RESULTS

The results of several methods of attack on the routing problem are shown pictorially in Plate IV. Note that the simulation approach at best was able to tie the minimum route determined for the smallest problem. As may be noted, the simulation approach used by the author continues to worsen as problem size increases. This is quite naturally explained as follows:

For the five stop problem, a total of fifteen distinctly different routes existed. This is determined through combinatorial analysis by using the number of demand points picked up by each vehicle, the number of vehicles, and symmetry. Therefore, if it can be known that of the five stops available, two must be assigned to one vehicle, the situation of five items taken two at a time occurs, or C_2^5. Similarly for the three remaining stops, if it is known that two appear in the next vehicle, the combination C_2^3 occurs. Lastly, the last demand point is picked up by one truck, or C_1^1 is the result. Multiplying;

$$C_2^5 \cdot C_2^3 \cdot C_1^1 = \left(\frac{5 \cdot 4}{2 \cdot 1}\right)\left(\frac{3 \cdot 2}{2 \cdot 1}\right)\left(\frac{1}{1}\right)$$

$$= 10 \cdot 3$$

$$= 30$$

The factor of symmetry occurs in this problem, since the route 'ORIGIN - A - B - ORIGIN' equals the route 'ORIGIN - B - A - ORIGIN'. Therefore, the number of routes (30) is divided by two, and equal to 15. Therefore it would seem quite natural that one of every fifteen generated routes would be the minimum route, (assuming that only one minimum exists).

EXPLANATION OF PLATE IV

Minimal computer simulation results and their relationship to other approaches to the routing problem.

PLATE IV

PROBLEM SIZE	METHOD (Number of miles/Number of vehicles)				
(Number of Stops)	DYNAMIC PROGRAMMING	DANTZIG and RAMSER	FEED * COMPANY	MODIFIED CLARKE and WRIGHT	COMPUTER SIMULATION
5	44/3	-	-	44/3	44/3
12	-	294/4	-	290/4	296/4
13	-	-	1474/5	1433/4	1510/4†
33	-	1587/16	1587/16	1468/14	1870/14†

* Feed Company listed here is the supplier of the 13 and 33 stop problem, as discussed earlier.

† See Appendix I for minimum routes obtained with other numbers of vehicles for this number of stops.

Such is precisely the case. Of 520 generated routes for the 5 stop problem, 32 were the minimum route. But since 32 is not exactly equal to one fifteenth of 520 (nearer to 35), a non-parametric Kolmogrov-Smirnov and a χ^2 one sample test were applied, and it was determined that the observed distribution was equivalent to the expected theoretical distribution (see Appendix VI). This method of calculation of all possible routes, then, works quite well for small, simple problems.

If the above calculation could be further extended to larger problems, all would be quite simple. It could merely be stated that the probability of a minimum route's appearance would be equivalent to the number of passes made times one over the number of total possible distinct routes. Then by generating this total number of routes one would expect to obtain the minimum route length at least once.

However, it was determined in all example problems except the 5 stop problem that the number of demand points per vehicle varied between trial routes. Therefore the above calculation may not be precisely carried out to yield a certain total number of possible routes for larger and more practical problems. At best, a rough approximation could be made to the total number of possible distinct routes, and repetition could occur (i. e., the same route might appear more than once). Curves of total route mileage were plotted versus frequency of occurence in a class interval. Some of the resultant curves (see Appendix V for examples) were bimodal, others were unimodal, and all were skewed to the left. Part of the skewness could be attributed to the traveling salesman's reduction of all truck routes to their minimal value, so the simulation program was re-written without the traveling salesman feature. The resulting program merely figured mileage for each route in the random manner in which the stops were selected. Curves plotted from this 'no-traveling salesman' program appeared still markedly skewed to the left. Therefore, it was decided that in order to attempt to make a statement regarding whether or not a true minimum had been determined, a distribution free approach had to be taken. An approximation to the standard form of Tchebycheff's inequality was chosen for these statements, and a specific confidence coefficient had to be calculated for each distinct problem, broken down further by total number of vehicles per total route. A calculation of the confidence interval for the 13 stop problem utilizing 4 vehicles follows:

Tchebycheff's inequality = $P(|y - \bar{z}| \geq ks) \leq 1/k^2$

where, y = minimum observed value = 1510
$\bar{z}$ = mean of observed values = 1959.46
s = standard deviation of observed values = 149.8
k = confidence factor = unknown.

Then, setting $|y - \bar{z}| = ks$, assuming the worst possible event,

$$|1510 - 1959.46| = k\,(148.9)$$

and $k = (449.46)/(148.9)$
$= 3.02$

Then $1/k^2$ becomes $1/(3.02)^2 = 1/9.07 = .110$

Therefore, it may be stated that no more than 11.0 per cent of all possible routes lie outside the Tchebycheff limits. Recall that this confidence coefficient applies to one specific problem for a given number of vehicles. Similar confidence coefficients may be located in Appendix I for all other example problems.

CONCLUSIONS

Surprisingly, the routing or carrier dispatching problem has been relatively untouched considering the fruitful results potentially available in an optimal solution. A few dedicated men have carried on the research in this area, mostly from an operation's research or optimization approach. However, even though the results of the approach as used by the author were somewhat disappointing in that improvement on existing solutions did not occur, the research did result in some possible ways of obtaining a better solution. This will be discussed further at the end of this section.

At present then, it appears that Cochran's modified Clarke and Wright algorithmic approach yields the 'best' results in every example problem, where best indicates lowest mileage and fewest vehicles. The simulation approach did tie the modified Clarke and Wright approach in number of vehicles to be assigned to a route. A major difference, however, lies in the fact that the algorithmic approach tends to produce more nearly optimal routes as the number of demand points increases, whereas the simulation approach results in poorer approximations to the minimum as the problem size increases. Although the feature of finding the fewest available vehicles needed for a route is fine, a difference of 1870 - 1468 = 402 miles can hardly be dispelled as a drop in the bucket when speaking of route mileage and expense (in the 33 stop problem). But this discrepancy lies in the fact that the simulation method as used by the author falls in the category of 'incomplete' search. If therefore, it were possible to convert the approach to 'complete' search, the minimal existing route could be guaranteed, a property of which no algorithm to date can boast. A means of doing this on a high speed computer has been hypothesized in the section labeled

"Recommendations". Another method which could reduce computer time considerably would be an approach utilizing a program with the traveling salesman as a subroutine, to be applied strictly to routes which have a route length shorter than a given value when mileage is first figured in the random ordering of stops sequence. It was determined that as problem size increased and especially as the number of demand points loaded onto a vehicle increased, this approach could produce roughly five to six times as many routes in the same period of time as the program utilizing the traveling salesman algorithm for every route. However, this method would still fall into the area labeled 'incomplete' search. Further pursuing of an optimal route, therefore, could prove quite valuable.

Obviously, a need for more research and minimal distance routes exists at present. With the aid of a high speed computer, such as IBM's 360, and the programming of the hypothesized method, an optimal solution should not be out of reason for the size of problems used as examples in this thesis.

RECOMMENDATIONS

In determining the feasibility of computer simulation as an approach to solving carrier dispatching problems, a statement cannot truly be made that it is either good or bad. The reason for this is that simulation may be applied to the same problem from many differing approaches. Hence, although the research as conducted herein by the author failed to attain a prominence all its own in the sense that no new optimum route was determined over other methods, and the simulation could at best only tie the optimum distance in a small available problem, this does not rule out the fact that simulation may be utilized most effectively in carrier dispatching. On the contrary, a new approach to the problem was discovered as a result of the research conducted on this problem. It is included here as a suggested proposal for exploration as a thesis, report, or problems topic in future research. The suggested new approach is stated as follows;

Step 1.

Determine a distance matrix between all respective demand points as explained in the "Computational Procedure" section herein. Order all the stops from one (1) to the maximum number of stops (NS).

Step 2.

For a given number and capacity of carriers, load the vehicles by including as many stops as possible in ascending order on the vehicles in their order as determined by capacity when setting up the problem.

Step 3.

Proceed at this point in one of two ways;[1]

(1) Apply the traveling salesman solution as included in the program found in the Appendix of this thesis to the stops' demand loaded on each vehicle to determine a minimum route for each vehicle.

(2) Permute and calculate the cost of each possible ordering of stops within vehicles; that is, calculate the distance for each vehicle in the order the demand points were originally picked up. Then within each vehicle's route, permute the stops and determine the new cost, until the minimum cost for this loading is obtained.

Step 4.

Now permute stops between vehicles. This is to say, replace a stop in the first (second, third, etc.) carrier with one found in the second (third, fourth, etc.) carrier. Then return to Step 3, saving only the shortest route as the program progresses. Repeat this step until all ordering and routes are determined and the minimum route determined should be the true minimal route.

A true solution is still being sought for optimizing carrier routing problems. The advocation of continued research in this area has been mentioned by many authors. Without doubt, a true minimum route solution for all vehicles dispatched through a series of demand points remains to be determined.

---

[1] A third approach at this point is one of utilizing a method of finding a short path through a series of demand points as discovered by Shen Lin of Bell Telephone Laboratories. A write-up of this method may be located in the Bell advertisement in the October 1966 issue of Scientific American, page 19.

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APPENDICES

APPENDIX I

CONFIDENCE COEFFICIENTS

NO. OF STOPS	NO. OF VEHICLES	MINIMUM ROUTE	NO. OF OBSERVED ROUTES	CONFIDENCE COEFFICIENT
5	3	44*	520	.154
12	4	296	1517	.113
13	4	1510	663	.110
	5	1553	360	.099
26	13	2124	29	Insufficient Data
	14	1870	402	.0806
	15	1996	823	.1064
	16	1959	317	.0990
	17	2294	17	Insufficient Data

*Actual Minimum

APPENDIX II

Discussion of Computer Program

Attempting to manually determine a minimum route for a carrier routing problem of even small size by the process of trial and error becomes exceptionally tedious, laborious, and very lengthy with respect to time, what with modern high speed computers which thrive on this particular situation; that is, one of carrying out repeated sequences of calculation. Therefore, a manual solution to the problem of minimizing a route through a series of stops was never questioned as to its practicality and an immediate attempt was made to compile a Fortran II computer program for the IBM 1620 to carry out the iterative computations. This was eventaully converted to PR-155 for the IBM 1410 computer. This program is limited in the number of demand points only by the size of dimension statements and the capacity of core storage available to the user of the program. In particular, for the IBM 1401-1410 system, the program is maximally dimensioned for a problem of 28 demand points (including the origin), occupying 39,741 core storage positions. The number of carrier vehicles and their capacities are not limited except by practical considerations of the problem itself. A discussion of the computer program has unlimited usefulness to the potential user of the program as well as clarifying the steps in the program necessary to its successful running. This discussion will be broken into two categories as follows:

(1) Input data

(2) Output data and ways to modify it

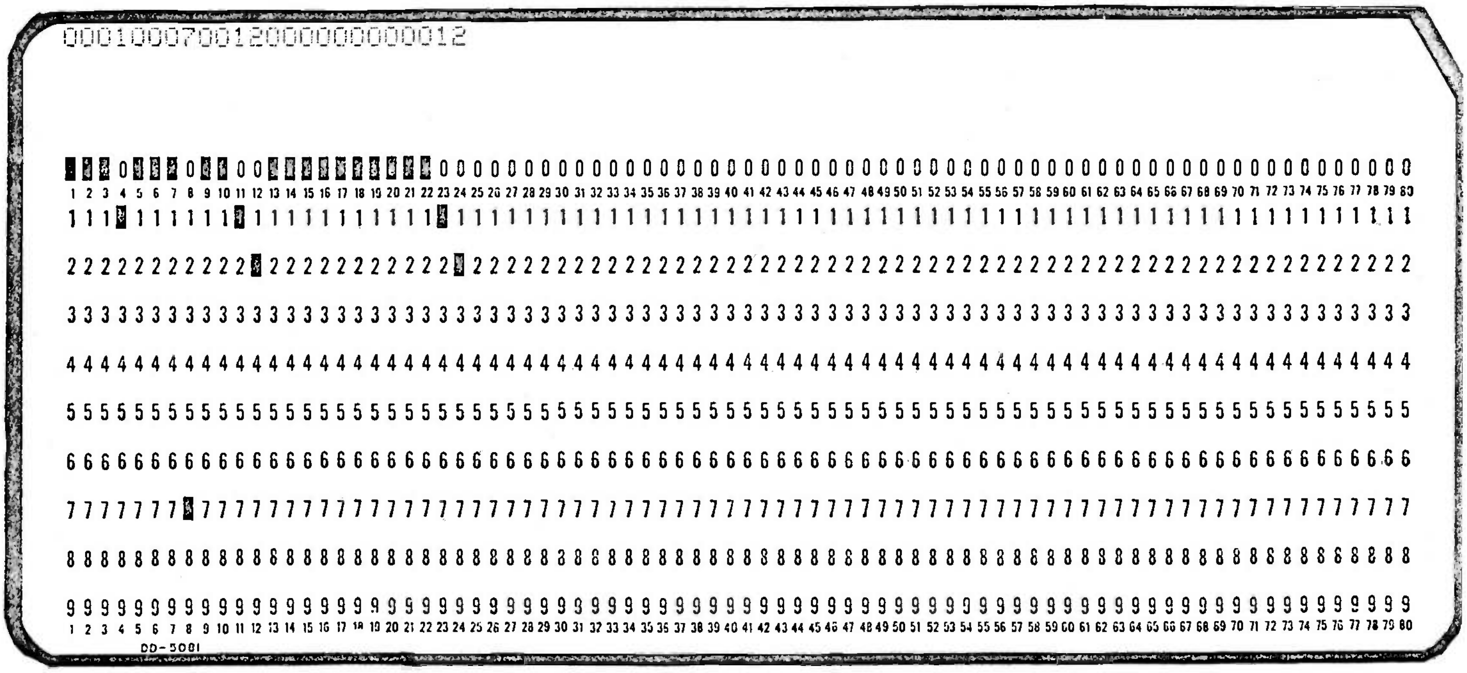
(1) Data Cards

Three control cards, followed by three sets of data cards are necessary for the successful running of the computer program. These cards will be discussed in the order in which they are processed by the 1401 and they must therefore be ordered accordingly.

The first card, referred to here as control card number one (1) contains three items in the I4 format. This merely means that the first item (MM), which is the number of stops or points (including one for the origin), must be right justified in columns 1 - 4. Similarly, the second item, (NS), the number of stops (excluding the origin and therefore equal to MM minus 1) is right justified in columns 5 - 9. Thirdly, the number of carrier vehicles, (NB), is right justified in columns 9 - 12. This completes the first card of the data deck.

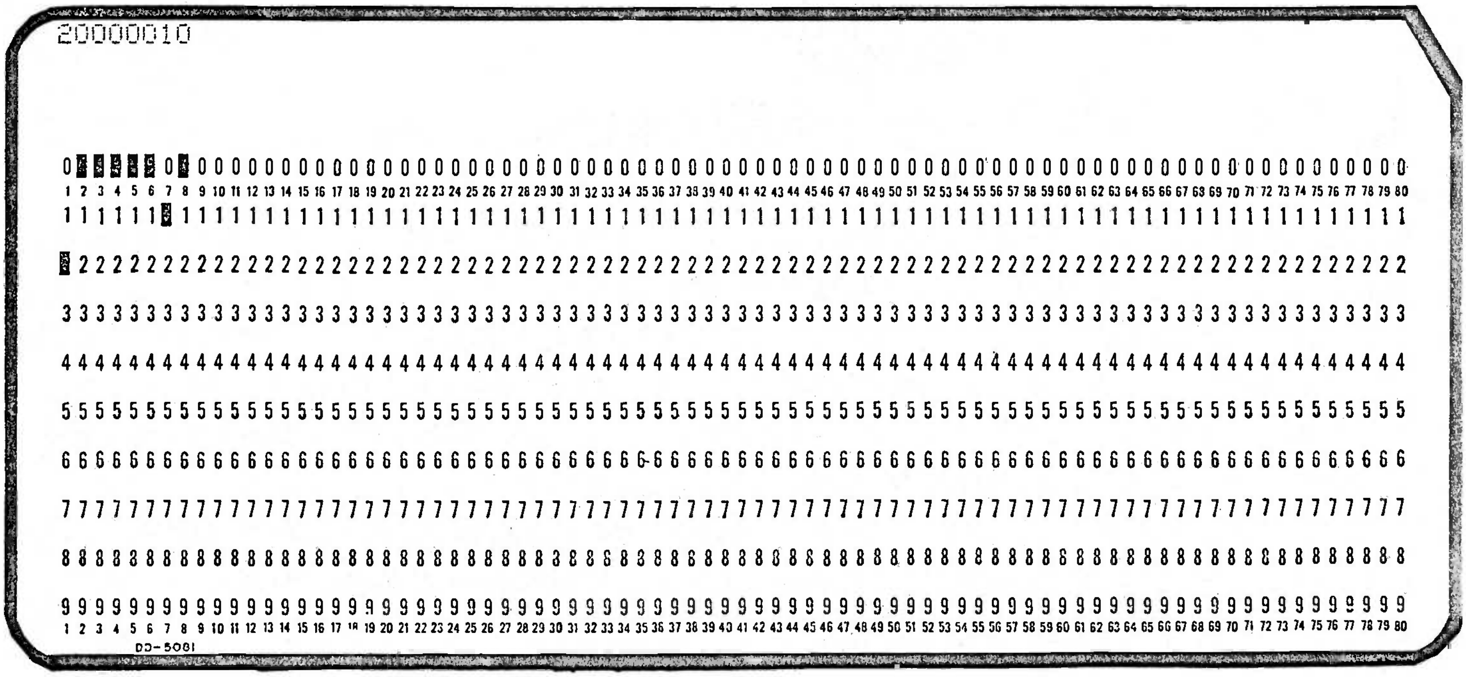
The second control card, called control card number two (2) is for specifying whether or not the carrier fleet is composed of vehicles of equivalent or non-equivalent capacity (a fixed or variable capacity fleet). If all vehicles are of the same capacity, the digits 0000 are punched into columns 1 - 4 of this control card to indicate that MVAR, the variable fleet capacity option of the program is not to be used. On the other hand, if the variable capacity option is desired, insert a number 1 in column 4 of this card, with three leading zeros preceding it. The variable names MM1, MM2, MM3, and MM4 refer to the number of vehicles of each capacity including all vehicles of a given capacity and all those whose capacity is less than the given capacity. This is used for calculation in the variable capacity problem to determine appropriate vehicle size to dispatch over a series of stops. Therefore if three vehicles of 4000 pound capacity are available and four vehicles of 4500 pound capacity are available, MM1 would be equivalent to seven (7). MM1 is therefore seen to be used for vehicles of the second largest category, and not the smallest category. This was done for ease of programming. MM1 through MM4 therefore allow the possibility of using vehicles of 5 different capacities. The last item on this control card, still utilizing the I4 format is LASCP, equal to either MM1, MM2, MM3, or MM4, depending on which is the largest and last to be punched with a number other than zero. Extending the example given below, if five carriers of a third and last vehicle capacity of 5000 pounds were available for use, MM2 and LASCP would both be punched with a 0012, and MM3 and MM4 would be 0000. A sample punched card for control card two for a variable capacity fleet composed of the following vehicles is shown below:

NUMBER	CAPACITY
3	4000
4	4500
5	5000



000100070012000000000012

The third control card, control card number three (3) is used for specifying the number of complete computer runs through the program, MCASE, and a factor used as a multiplier of the vehicle capacity for final output, NFACT. This factor, NFACT, is for purposes of deleting low order (units, tens) digits when reading in data to conserve core and reduce labor. Therefore a truck of capacity 45000 may be read in as 4500 and at the time of the resulting print out, 4500 X NFACT = 4500 X 10 = 45000 capacity. MCASE is punched right justified in columns 1 - 4, NFACT similarly in 5 - 8. For 2000 cases and a factor of 10, this control card would appear as;



20000010

Following the control cards is the first set of input data cards required by the program. This set of cards is composed of the distance matrix punched one number per card in the I4 format in the following manner. Beginning with row one and column one of the distance matrix, assumed to be symmetrical and square, either punching the distance matrix values from top to bottom in a column and moving to the right column-wise or punching values from left to right and moving down row-wise is equally acceptable. Since infinity is unknown in the language of computers, 9999 is assumed to be far larger than any actual distances encountered and is therefore used to represent infinity. This value is the first to be encountered in the distance matrix since it represents the distance from the first stop to itself, actually a distance of zero, but infinity at all such positions is a prerequisite for the utilization of the available 1620 Fortran II traveling salesman program. Thus, the correct distance matrix card set for the given sample matrix with MM = 4 and NS = 3 below is as shown.

Distance to Origin

		1	2	3	Origin
Distance From Origin	1	0	5	10	13
	2	5	0	17	22
	3	10	17	0	24
Origin		13	22	24	0

Actual Distances

Distance to Origin

		1	2	3	Origin
Distance From Origin	1	9999	5	10	13
	2	5	9999	17	22
	3	10	17	9999	24
Origin		13	22	24	9999

0 Replaced by 9999

Punched distance matrix cards (Format I4)

```
9999
   5
  10
  13
   5
9999
  17
  22
  10
  17
9999
  24
  13
  22
  24
9999
```

It may be noted in the above example that there are 16 punched values, equal to four squared (4^2) and also that MM = 4 is the location of the origin in the matrix. This completes the card set immediately following the control cards.

Next in order is a set of cards assigning the respective demand to each of the demand points. This group of cards will number exactly NS, since no demand is assigned to the origin. These cards are punched in the I4 format and are ordered in ascending order according to stop number.

In other words, the demand for the stop labelled 1 is punched right justified into columns 1 - 4 in the first card, at stop 2 is punched in the second card, and so on. When NS cards have been punched, the demand at each demand point will be satisfied.

The third set of input data cards is used to assign capacity to the carrier vehicles. If NB is set equal to 20, then 20 cards must be punched to satisfy the data read-in requirement. Normally it is assumed that carriers will be relatively equal in capacity, except when the variable capacity portion of the program is used. Therefore the values to be read in at this point would usually be equivalent, say, 5 busses of capacity 35.

If the variable capacity portion of the program is utilized, the vehicles must be ordered in capacity from smallest to largest. Therefore, if there were three vehicles of smallest capacity, possibly 10 tons, three vehicles of 12 tons, and 2 vehicles of 14 tons, the capacity data would be read in as follows, in the I4 format.

```
10
10
10
12
12
12
14
14
```

This ordering is very important to the proper operation of the variable capacity program option.

Arrangement of the data input cards is critical and must be in the same order as the read statements, which is the following:

(1) Three control cards as specified above
(2) Set of distance cards
(3) Set of demand cards
(4) Set of carrier capacity cards arranged as described above.

(2) Output

The simulation program compiled for the IBM 1410 utilizes printed output for three reasons. In compiling and debugging the program on the 1410, it was necessary to leave the program at the 1410 center for an operator to run until such time as the program was debugged and the author became competent at running this particular computer himself. Card output, besides being more cumbersome than printed output, allowed the possibility of disorganizing the results through card dropping, operator neglect, or shuffling the cards at the time of printing out of the results. Reason two for the use of printed output is one of speed. The 1401 systems print unit provides a rate of 600 lines per minute as compared to 250 cards per minute on the card punch. Thirdly, volume of output alone necessitated the use of printed output, since a run of 2000 complete passes would use well over 2000 cards, but could easily be contained on 50 pages of output form paper. However, it should be interjected here that a change may be made to eliminate this factor of extensive output. This will be discussed after the form of output currently utilized is discussed.

The output as presently printed includes the following:

(1) A printout of total mileage for all vehicular routes versus a given pass, or iteration number is first printed. This value of total mileage is then checked against the previous lowest route retained by the program and if found to be greater in mileage than the minimum route encountered previously, a new pass is undertaken. If, however, the new mileage value is less than any previous route encountered, the following printout results.

(a) The total route is broken down into individual carriers, and their particular mileage and their individual routes are given. At this time, the capacity of each vehicle is also stated. An example of fixed capacity output is given below:

```
DISTANCE COVERED BY TRUCK NUMBER 1 =  23
SEND TRUCK OF CAPACITY    20 ON ROUTE AS FOLLOWS,
   6
   4
   3
   6
DISTANCE COVERED BY TRUCK NUMBER 2 =  17

                          . . .

                          . . .
DISTANCE COVERED BY TRUCK NUMBER 3 =   4
SEND TRUCK OF CAPACITY    20 ON ROUTE AS FOLLOWS,
   1
   6
TOTAL ROUTE FOR ALL TRUCKS =  44 ON PASS  22
```

Now, as suggested earlier, a very small change can substantially reduce the voluminous output which was necessary originally for purposes of statistical analysis and checking of the program. By merely eliminating the printout of total mileage versus pass number (see above) for all routes which are greater than a previous minimum route, which are really useless anyway, the output can be reduced by roughly 95%. And previously, after collecting the prodigious output for X number of passes through the maze of stops, it was necessary to search through the output until the last minimized route could be found. Now with the elimination of the unnecessary large routes, the lowest value of mileage and the required breakdown of routes will be the last complete route to appear in the printed output. It must be realized that due to the nature of the problem, programming efficiency, and the limited amount of core storage available, some unnecessary previous minimum routes will appear in the output, since saving the previous values calls for some extensive dimension statements to reserve core for minimum values. Another factor also enters the picture at this point and this is one of retrieving the necessary values from core storage of the 1410 in the event of earlier than anticipated termination of the simulation program. These extra routes actually do no harm, taken a minimum of time and output forms and reduce considerably the above problems. One item which should be mentioned in this regard, is the fact that the first route is always compared with infinity, or 9999 in computer language and therefore will always be printed for future reference by the program.

Since it has now been determined how to substantially reduce output volume, punched cards once again become feasible as a form of output. To convert the program from printed output to punched output, substitute the first digit within the parentheses of each write statement (currently a 3), with the digit 2. This will cause punching to replace printing, if this is desired. If, however, both output media are desired, include an additional write statement directly beneath each write statement currently existing in the program and identical to the print statement, except for the substitution of a 2 for the 3 in the print statement.

One other feature of the program which should be mentioned is this; for a truck route which includes only one stop and the origin, the route output would appear as follows:

```
XX
MM,
```

Where XX is any stop other than stop MM, and MM is the origin number. More specifically, for a 25 stop problem including the origin, the output might look like this:

13
25

This should be interpreted as "send a carrier from the origin to demand point 13, and after either loading or unloading the payload, return to the origin, stop number 25.

However, if more than one stop other than the origin is included in a route for one carrier, a route is printed with one stop number appearing twice; once in the first position and once in the last position in the order of the route. This is merely to indicate that a complete route has been determined. A route with two stops other than the origin might appear as follows:

XX		MM
YY	or	XX
MM		YY
XX		MM

Substituting possible values for a 25 stop problem (including the origin) in the above would yield the following theoretical routes;

22		25
13	or	22
25		13
22		25

It is assumed that the origin is the starting point for each route and also the end point, and therefore the above representations of a route indicate starting at the origin (stop number 25), proceeding to demand point 22, proceeding further to demand point 13, and returning to the origin. This results in a given number of miles. It is to be noted that exactly reversing the order of the stops would yield the same number of total miles, and therefore not affect the outcome of the solution, although it might be more convenient when actual use is made as to timing truck stops at certain points along a delivery or pickup route. However, scrambling of the demand point order as obtained in the output will serve to undo all the value of finding the shortest distance between each subset of demand points.

In summarizing the output, then, it would appear wise to remove the printing (punching) out of all routes which are not smaller than the smallest retained in the computer program, thus substantially reducing the output. Other changes may be made as noted to manipulate the output to the desires of the prospective user of the program.

APPENDIX III

COMPUTER PROGRAM

```
**********************
*                    *
*  COMPUTER PROGRAM  *
*                    *
**********************
```

```
    MON$$     JOB  BRAUN, TS PROBLEM
    MON$$     COMT 30 MINUTES,10 PAGES
    MON$$     ASGN MJB,12
    MON$$     ASGN MGO,16
    MON$$     MODE GO,TEST
    MON$$     EXEQ FORTRAN,,,11,06,,,BRAUN
C
C         MONITOR CARDS NECESSARY FOR PR-155 PROCESSOR
C
      DIMENSION MCAP(26),NCB(20),KS(26),MW(26),N(26,26),NSUM(26)
      DIMENSION MA(26,26),ICHEK(26),JCHEK(26),NRET(26),MR(26),MS(26)
C
C                   INPUT FORMAT STATEMENTS
C
    1 FORMAT(3I4)
  103 FORMAT(I4)
  112 FORMAT(I4)
  113 FORMAT(6I4)
  600 FORMAT(2I4)
C
C                   OUTPUT FORMAT STATEMENTS
C
  946 FORMAT(1HT,27HTOTAL ROUTE FOR ALL TRUCKS=I4,9H ON PASS I4)
  303 FORMAT(1X,32HDISTANCE COVERED BY TRUCK NUMBER I4,1H=I4)
  323 FORMAT(1X,I3)
  329 FORMAT(23H SEND TRUCK OF CAPACITYI5,21H ON ROUTE AS FOLLOWS,)
  322 FORMAT(21H ROUTE IS AS FOLLOWS,)
   12 FORMAT(26H TOTAL TIME FOR THIS RUN =F6.1,8H MINUTES)
      ITIME=ICLOCK(ITIME)
C
C         ITIME AND OTHER VARIABLE NAMES INCLUDING THE WORD TIME ARE
C         USED IN DETERMINING THE TOTAL TIME FOR ALL ITERATIONS
C
      ATIME=ITIME
C
C                   READ IN INFORMATION WHICH IS KNOWN
C
      READ (1,1)MM,NS,NB
C
C         MM=THE NUMBER OF STOPS INCLUDING 1 FOR THE ORIGIN
C         NS=THE NUMBER OF STOPS NOT INCLUDING THE ORIGIN
C         NB=THE NUMBER OF TRUCKS (BUSSES, ETC.) AVAILABLE FOR USE
C
    2 READ (1,103)((MA(I,J),I=1,MM),J=1,MM)
```

```
C
C         MA(I,J) = THE ORIGINAL DISTANCE MATRIX
C
      READ (1,112)(KS(I),I=1,NS)
C
C         KS=THE NUMBER OF ITEMS (IN POUNDS, TONS, BUNDLES, PEOPLE, ETC)
C         TO BE LOADED AT A STOP
C
      READ (1,103)(NCB(I),I=1,NB)
C
C         NCB= THE CAPACITY OF TRUCKS (BUSSES, ETC) TO BE ROUTED
C
      READ(1,113)MVAR,MM1,MM2,MM3,MM4,LASCP
C
C         MVAR = ZERO IF THE VARIABLE CAPACITY PORTION OF THE PROGRAM IS
C         NOT DESIRED, ONE IF IT IS DESIRED
C
C
C         MM1 TO MM4 ARE THE HIGHEST NUMBER (IN ASCENDING ORDER) OF
C         CARRIERS IN ALL CAPACITIES EXCEPT THE SMALLEST
C
C
C         LASCP = THE HIGHEST NUMBER OF THE CARRIERS OF LARGEST CAPACITY,
C         EQUIVALENT TO EITHER MM1, MM2, MM3, OR MM4.  FOR FIXED CAPACITY
C         VEHICLES, LASCP = THE HIGHEST NUMBER OF THE NUMBER OF CARRIERS
C         AVAILABLE.
C
      READ(1,600)MCASE,NFACT
C
C         MCASE = THE NUMBER OF DESIRED TRIAL ROUTES
C
C
C     TEST FOR NUMBER OF TRIAL TOTAL ROUTES DESIRED
C
      NCASE=0
C
C         NCASE = THE RUNNING INDEX FOR COUNTING ITERATIONS OR PASSES
C
      NMIN=9999
C
C         NMIN = THE INITIAL VALUE  WITH WHICH TO COMPARE TOTAL MILEAGE
C
  937 ICK=0
C
C         ICK= AN INITIAL VALUE OF A VARIABLE USED IN PRINTING OUT
C         FINAL ROUTES
C
      IF(NCASE-0)948,948,947
C                   SUMMATION OF TOTAL TRUCK MILES
  947 NTSUM=0
C
C         NTSUM = TOTAL MILEAGE VARIABLE INITIALIZED TO ZERO
C
```

```
      DO 945 I=1,JK
  945 NTSUM=NTSUM+NSUM(I)
      WRITE(3,946)NTSUM,NCASE
      IF(NTSUM-NMIN)632,948,948
  632 NMIN=NTSUM
      IJI=0
C
C        IJI = AN INITIALIZING VALUE OF A VARIABLE NEEDED TO TRANSMIT
C        A SUBMATRIX FROM THE ORIGINAL DISTANCE MATRIX
C
      NORIT=1
C
C        NORIT = A VARIABLE USED TO DETERMINE WHETHER OR NOT TO PRINT
C        A ROUTE
C
      GO TO 633
  948 NCASE=NCASE+1
      NORIT=0
      IF(NCASE-MCASE)32,32,938
C        THE PRECEDING STATEMENT DETERMINES WHETHER OR NOT THIS IS THE
C        FINAL ITERATION FOR THIS DATA SET
  938 ITIME=ICLOCK(ITIME)
      BTIME=ITIME
      CTIME=(BTIME-ATIME)*.06
      WRITE(3,12)CTIME
C
C        PRINT TOTAL TIME FOR ALL ITERATIONS
C
      STOP
C
C        AFTER SUCCESFUL RUNNING OF THE PROGRAM, THE PROGRAM ENDS AT THE
C        ABOVE STATEMENT
C
   32 CONTINUE
      IJI=0
C
C                       GENERATE RANDOM ARRAY OF STOPS
C
  105 NA=NS
      DO 106 JO=1,NS
      MW(JO)=JO
  106 MS(JO)=0
C
C        MW(JO) AND MS(JO) ARE USED IN FINDING A RANDOM STOP SEQUENCE
C
      NBB=NS-1
      DO 109 IO=1,NBB
      B=NA
      NXNX=325
C
C        NXNX=A STARTING VALUE FOR THE RANDOM NUMBER GENERATOR
C
      NA1=IRANDM(NXNX)
```

```
C
C         IRANDM=A RANDOM NUMBER GENERATOR FUNCTION WRITTEN IN AUTOCODER
C         LANGUAGE FOR USE WITH FORTRAN PROGRAMS ON THE IBM 1410 SYSTEM
C
      GEN=NA1
      A1=GEN*(.000001)
      JO=A1*B+1.
      MS(IO)=MW(JO)
      NC=NA-1
      IF(JO-NA)108,109,109
  108 DO 410 KO=JO,NC
  410 MW(KO)=MW(KO+1)
  109 NA=NA-1
      MS(NS)=MW(1)
C
C                     LOAD TRUCK JK AND CHECK CAPACITY
C
  633 JK=1
C
C         JK = RUNNING INDEX NUMBERING TRUCKS
C
      M1=MM1
      M2=MM2
      M3=MM3
      M4=MM4
      JI=1
C
C         JI = A RUNNING INDEX OF STOP NUMBERS
C
   19 NSTOP=MS(JI)
      MR(JI)=MS(JI)
      NEED=JI
      NEE=NEED
      NET=NEE-1
      MCAP(NSTOP)=NCB(LASCP)-KS(NSTOP)
      NQ=MCAP(NSTOP)
      IF(JI-NS)118,117,99
  118 IF(NQ)114,115,116
  116 JI=JI+1
      NSTOP=MS(JI)
      MR(JI)=MS(JI)
      MCAP(NSTOP)=NQ-KS(NSTOP)
      NQ=MCAP(NSTOP)
      IF(JI-NS)118,117,99
  117 IF(NQ)114,120,119
  119 NQ=NCB(LASCP)-NQ
      IF(NQ-NCB(1))121,122,122
  121 JCAPY=NCB(1)
      GO TO 115
  122 NQ=NQ-NCB(1)
      GO TO 123
  120 JCAPY=NCB(LASCP)
      GO TO 115
  114 IF(MVAR-1)230,235,235
```

```
 230 NQ=KS(NSTOP)+NQ
     JI=JI-1
     JCAPY=NCB(LASCP)
C
C        JCAPY = A VALUE OF CAPACITY OF A CARRIER TO BE SAVED FOR THE
C        PRINTOUT OF RESULTS
C
     GO TO 115
C
C         **OPTIONAL VARIABLE CAPACITY FEATURE OF THIS PROGRAM**
C
 235 NQ=NCB(LASCP)-NCB(1)-(KS(NSTOP)+NQ)
     JI=JI-1
C
C        CHECK CARRIERS OF INCREASING CAPACITY UNTIL LOAD REQUIREMENTS
C        ARE MET
C
 123 IF(NCB(M1)-NCB(1))938,202,205
C
C        CHECK TO DETERMINE IF ANY CARRIERS OF THIS CAPACITY ARE STILL
C        AVAILABLE
C
 205 NEX=NCB(M1)-NCB(1)
     M1=M1-1
     IF(NQ-NEX)201,201,202
 201 JCAPY=NCB(M1+1)
     GO TO 115
 202 M1=M1+1
     IF(M2-0)938,215,232
 232 IF(NCB(M2)-NCB(M1))938,204,220
C
C        CHECK TO DETERMINE IF ANY CARRIERS OF THIS CAPACITY ARE STILL
C        AVAILABLE
C
 220 NEX=NCB(M2)-NCB(1)
     M2=M2-1
     IF(NQ-NEX)203,203,204
 203 JCAPY=NCB(M2+1)
     GO TO 115
 204 M2=M2+1
     IF(M3-0)938,215,234
 234 IF(NCB(M3)-NCB(M2))938,206,221
C
C        CHECK TO DETERMINE IF ANY CARRIERS OF THIS CAPACITY ARE STILL
C        AVAILABLE
C
 221 NEX=NCB(M3)-NCB(1)
     M3=M3-1
     IF(NQ-NEX)208,208,206
 208 JCAPY=NCB(M3+1)
     GO TO 115
 206 M3=M3+1
     IF(M4-0)938,215,236
 236 IF(NCB(M4)-NCB(M3))938,215,209
```

```
C
C         CHECK TO DETERMINE IF ANY CARRIERS OF THIS CAPACITY ARE STILL
C         AVAILABLE
C
  209 NEX=NCB(M4)-NCB(1)
      M4=M4-1
      IF(NQ-NEX)211,211,215
  211 JCAPY=NCB(M4+1)
      GO TO 115
  215 NQ=KS(NSTOP)-NQ
      JI=JI-1
      JCAPY=NCB(1)
      GO TO 115
  115 NJI=JI+1
C
C                        TRANSMIT ROUTE SUBMATRIX FROM TOTAL MATRIX
C
      NJO=NJI
      IF(IJI-0)127,127,128
  128 DO 129 II=1,IJI
      NEED=NEED-NRET(II)
  129 NJI=NJI-NRET(II)
  127 MR(NJO)=MM
      IZ=NEE-1
      DO 126 I=NEED,NJI
      IZ=IZ+1
      JZ=NEE-1
      DO 125 J=NEED,NJI
      JZ=JZ+1
      IO=MR(IZ)
      JO=MR(JZ)
  125 N(I,J)=MA(IO,JO)
  126 CONTINUE
      NRET(JK)=NJI-1
      GO TO 501
C
C                          CHECK FOR REMAINING STOPS
C
  502 IF(JI-NS)25,937,937
C
C                     INDEX NUMBER OF TRUCK AND STOP NUMBER SUBSCRIPT
C
   25 JK=JK+1
      JI=JI+1
      GO TO 19
C
C         *** TRAVELING SALESMAN FINDS DISTANCE TRUCK JK MUST COVER ***
C
C                      DEFINED STATEMENTS DIRECTLY BELOW
C
  501 MMA=NJI-NEED
      M=MMA+1
      LL=0
```

```
C
C        LL = AN INITIAL VALUE FOR MILEAGE SUMMATION IN DISTANCE
C        SUBMATRIX
C
      IPRCT=0
C
C        IPRCT IS A VALUE OF A VARIABLE USED TO SET A NODE IN THE
C        SUBMATRIX TO INFINITY
C
      KKK=0
C
C        KKK = A VARIABLE USED TO ELIMINATE SUBTOUR BLOCKING OF LAST
C        ITERATION OF TRAVELING SALESMAN
C
C
C                    FIND ROW MINIMUM VALUES IN SUBMATRIX
C
    3 DO 70 I=1,M
      MINR=N(I,1)
C
C        MINR IS EQUAL TO THE MINIMUM VALUE IN A ROW
C
      DO 100 JB=2,M
      IF(N(I,JB)-MINR)90,100,100
   90 MINR=N(I,JB)
  100 CONTINUE
      L=MINR
      IF (L-9999)4,70,4
C
C                         SUM DISTANCE IN MILES
C
    4 LL=LL+L
C
C                    SUBTRACT OUT MINIMAL ROW VALUES
C
      DO 6 JC=1,M
      IF(N(I,JC)-9999)5,6,5
    5 N(I,JC)=N(I,JC)-L
    6 CONTINUE
C
C                    FIND COLUMN MINIMUM VALUES IN SUBMATRIX
C
   70 CONTINUE
      DO 80 J=1,M
      MINC=N(1,J)
C
C        MINC IS EQUAL TO THE MINIMUM VALUE IN A COLUMN
C
      DO 200 IB=2,M
      IF(N(IB,J)-MINC)190,200,200
  190 MINC=N(IB,J)
  200 CONTINUE
      L=MINC
```

```
      IF(L-9999)30,80,30
C
C                       SUM DISTANCE IN MILES
C
   30 LL=LL+L
C
C                   SUBTRACT OUT MINIMAL COLUMN VALUE
C
      DO 7 IC=1,M
      IF(N(IC,J)-9999)31,7,31
   31 N(IC,J)=N(IC,J)-L
    7 CONTINUE
   80 CONTINUE
C
C                  EVALUATES MATRIX FOR DETERMINATION OF PIVOTAL NODE
C
      X1=-1
      X2=-1
      DO 8I=1,M
      DO 8 J=1,M
      IF (N(I,J))99,9,8
   99 STOP
    9 K=J
      MINER=9999
      DO 10 JA=1,M
      IF(JA-K)14,10,14
   14 IF(MINER-N(I,JA))10,10,88
   88 MINER=N(I,JA)
   10 CONTINUE
      L1=MINER
      MINEC=9999
      DO 20 IA=1,M
      IF(IA-K)15,20,15
   15 IF(MINEC-N(IA,J))20,20,18
   18 MINEC=N(IA,J)
   20 CONTINUE
      L2=MINEC
      X1=L1+L2
      IF(X1-X2)8,990,11
  990 IF(J-I)8,8,11
   11 X2=X1
      I1=I
      J1=J
    8 CONTINUE
C
C                  SETS CHOSEN NODE TO INFINITY
C
      IPRCT=IPRCT+1
      ICHEK(IPRCT)=I1
      JCHEK(IPRCT)=J1
      N(J1,I1)=9999
C
C                  SETS SELECTED ROW AND COLUMN TO INFINITY
C
```

```
      DO110 K=1,M
      N(I1,K)=9999
  110 N(K,J1)=9999
C
C                     ELIMINATES BLOCKING SUBTOUR FOR LAST ITERATION
C
      KKK=KKK+1
      IF(KKK-MMA)304,305,306
  304 KKK=KKK-1
C
C                             BLOCKS ITERATION SUBTOURS
C
      DO 300 I=1,IPRCT
      DO 290 J=1,IPRCT
      IF(ICHEK(I)-JCHEK(J))290,280,290
  280 IROW=JCHEK(I)
      JCOL=ICHEK(J)
      N(IROW,JCOL)=9999
  281 DO 285 K=1,IPRCT
      IF(ICHEK(K)-IROW)285,282,285
  282 IROW=JCHEK(K)
      N(IROW,JCOL)=9999
      GO TO 281
  285 CONTINUE
      GO TO 300
  290 CONTINUE
  300 CONTINUE
      GO TO 306
  305 KKK=KKK-1
  306 I4=X2
      KKK=KKK+1
      IF(KKK-M)3,555,555
C
C                     PRINT DISTANCE TO BE COVERED BY EACH TRUCK
C
  555 IX=1
      IJI=IJI+1
      NSUM(IJI)=LL
      IF(NORIT-0)99,502,631
  631 WRITE(3,303)IJI,LL
C
C                     DETERMINE ROUTE OF TRUCK
      WRITE(3,329)JCAPY
C
      WRITE(3,322)
      IS=ICHEK(IX)+NET
      IT=JCHEK(IX)+NET
      WRITE(3,323)MR(IS)
      NEW=NJI-NEED
      IF(NEW-1)99,503,324
  503 WRITE(3,323)MR(IT)
      GO TO 502
  324 WRITE(3,323)MR(IT)
  326 JX=1
```

```
   327 ICK=ICHEK(JX)+NET
       IF(IT-ICK)328,321,328
   328 JX=JX+1
       GO TO 327
   321 IT=JCHEK(JX)+NET
       WRITE(3,323)MR(IT)
       IX=IX+1
       IF(IX-MMA)326,504,99
   504 WRITE(3,323)MR(IS)
       GO TO 502
       END
0001AMON$$      EXEQ AUTOCODER,,,NOPCH
0002A           HEADR*****RANDOM NUMBER GENERATOR SUBROUTINE*****
0003A           TITLEIRANDM
0004A           SBR  X13
0005A           MLNA 4+X13,*+6
0006A           MLNB 0,RECEIVE=3
0007A           C    RECEIVE,STORE=3
0008A           BE   CALC
0009A           MLNA RECEIVE,STORE
0010A           MLNA -0000001-,RNUM=21-11
0011A           MLNA STORE,RNUM-18
0012ACALC       M    -1977326743-,RNUM
0013A           MLCWARNUM-4,299
0014A           SW   294
0015A           MLNB RNUM,RNUM-11
0016A           B    5+X13
0017A           LTORG*
0018A           DCW  -)-
0019A           END
     MON$$      EXEQ AUTOCODER,,,NOPCH
                TITLEICLOCK
                SBR  X13
                MLCWABLANKS,299
                STC  299
                BCE  *-18,295,9
                B    5+X13
     BLANKS     DCW  =5
                END
     MON$$      EXEQ LINKLOAD
                CALL BRAUN
     MON$$      EXEQ BRAUN,MJB
```

APPENDIX IV

EXAMPLE PROBLEMS

FIVE STOP PROBLEM

	1	2	3	4	5	6
1	9999	11	9	12	13	10
2	11	9999	10	11	4	8
3	9	10	9999	8	9	4
4	12	11	8	9999	7	2
5	13	4	9	7	9999	5
6	10	8	4	2	5	9999

INTER-STOP DISTANCE MATRIX

STOP NUMBER	DEMAND
1	10
2	8
3	6
4	9
5	7

DEMAND AT RESPECTIVE STOPS

VEHICLE NUMBER	CAPACITY
1	20
2	20
3	20

CAPACITY OF AVAILABLE VEHICLES

TWELVE STOP PROBLEM

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	9999	5	12	22	21	24	31	35	37	41	49	51	9
2	5	9999	7	17	16	23	26	30	36	36	44	46	14
3	12	7	9999	10	21	30	27	37	43	31	37	39	21
4	22	17	10	9999	19	28	25	35	41	29	31	29	23
5	21	16	21	19	9999	9	10	16	22	20	28	30	22
6	24	23	30	21	9	9999	7	11	13	17	25	27	25
7	31	26	27	25	10	7	9999	10	16	10	18	20	32
8	35	30	37	35	16	11	10	9999	6	6	14	16	36
9	37	36	43	41	22	13	16	6	9999	12	12	20	38
10	41	36	31	29	20	17	10	6	12	9999	8	10	42
11	49	44	37	31	28	25	18	14	12	8	9999	10	50
12	51	46	39	29	30	27	20	16	20	10	10	9999	52
13	9	14	21	23	22	25	32	36	38	42	50	52	9999

INTER-STOP DISTANCE MATRIX

TWELVE STOP PROBLEM (contd.)

STOP NUMBER	DEMAND
1	1200
2	1700
3	1500
4	1400
5	1700
6	1400
7	1200
8	1900
9	1800
10	1600
11	1700
12	1100

DEMAND AT RESPECTIVE STOPS

VEHICLE NUMBER	CAPACITY
1	4000
2	4000
3	4000
4	4000
5	4000
6	5000
7	5000
8	5000
9	6000
10	6000
11	6000
12	6000

CAPACITY OF AVAILABLE VEHICLES

THIRTEEN STOP PROBLEM

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	9999	8	31	77	87	59	85	88	155	193	190	215	234	25
2	8	9999	32	84	94	53	79	101	162	200	197	223	228	32
3	31	32	9999	78	10	105	123	149	113	118	188	214	223	48
4	77	84	78	9999	88	25	43	121	158	196	206	222	118	51
5	87	94	10	88	9999	111	137	156	98	94	98	185	232	63
6	59	53	105	25	111	9999	26	128	173	211	211	237	173	65
7	85	79	123	43	137	26	9999	154	199	237	237	263	164	92
8	88	101	149	121	156	128	154	9999	223	250	289	315	301	100
9	155	162	113	158	98	173	199	223	9999	38	85	111	166	133
10	193	200	118	196	94	211	237	250	38	9999	94	120	192	161
11	190	197	188	206	98	211	237	289	85	94	9999	26	145	186
12	215	223	214	222	185	237	263	315	111	120	26	9999	159	212
13	234	228	223	188	232	173	164	301	166	192	145	159	9999	222
14	25	32	48	51	63	65	92	100	133	161	186	212	222	9999

INTER-STOP DISTANCE MATRIX

THIRTEEN STOP PROBLEM (contd.)

STOP NUMBER	DEMAND
1	1000
2	8700
3	19500
4	8580
5	6400
6	12220
7	12120
8	7800
9	4550
10	4000
11	10500
12	12000
13	37260

DEMAND AT RESPECTIVE STOPS

VEHICLE NUMBER	CAPACITY
1	45000
2	45000
3	45000
4	45000
5	45000
6	45000
7	45000
8	45000
9	45000
10	45000

CAPACITY OF AVAILABLE VEHICLES

TWENTY SIX STOP PROBLEM

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	∞	8	11	13	18	129	151	133	138	164	155	159	161	65	176	176	176	155	150	141	153	221	213	146	143	141
2	8	∞	3	8	10	121	143	125	130	156	147	151	153	57	168	168	168	174	142	133	145	213	205	138	135	133
3	11	3	∞	6	9	121	143	125	130	156	147	151	153	57	168	168	168	174	142	133	145	213	205	138	135	133
4	13	8	6	∞	3	123	145	127	132	158	149	153	155	59	170	170	170	176	141	132	144	215	207	140	137	135
5	18	10	9	3	∞	126	148	130	135	161	152	156	158	162	173	173	173	179	144	135	147	218	210	143	140	138
6	129	121	121	123	126	∞	22	36	30	31	26	30	32	36	47	47	47	53	105	103	109	92	84	17	14	12
7	151	143	143	145	148	22	∞	46	40	37	36	40	42	46	57	57	57	63	115	113	119	102	94	27	24	22
8	133	125	125	127	130	36	46	∞	5	51	38	28	44	34	45	45	38	46	98	96	102	104	78	29	26	24
9	138	130	130	132	135	30	40	5	∞	45	32	23	38	29	40	40	33	41	93	91	97	98	73	23	20	18
10	164	156	156	158	161	31	37	51	45	∞	41	45	47	51	62	62	62	68	120	118	124	107	99	32	29	27
11	155	147	147	149	152	26	36	38	32	41	∞	32	6	31	36	36	42	45	102	102	108	81	73	19	14	14
12	159	151	151	153	156	30	40	28	23	45	32	∞	38	14	25	25	17	23	75	73	79	70	55	23	18	18
13	161	153	153	155	158	32	42	44	38	47	6	38	∞	31	42	42	48	56	108	106	114	87	79	25	20	20
14	165	157	157	159	162	36	46	34	29	51	31	14	31	∞	23	23	17	20	89	87	93	68	48	29	24	24
15	176	168	168	170	173	47	57	45	40	62	36	25	42	23	∞	0	42	26	100	98	104	48	48	40	35	35
16	176	168	168	170	173	47	57	45	40	62	36	25	42	23	0	∞	42	26	100	98	104	48	48	40	35	35
17	176	168	168	170	173	47	57	38	33	62	42	17	48	17	42	42	∞	11	57	55	61	60	45	40	35	35
18	155	174	174	176	179	53	63	46	41	68	45	23	56	20	26	26	11	∞	52	50	56	49	34	46	41	41
19	150	142	142	141	144	105	115	98	93	120	102	75	108	89	100	100	57	52	∞	8	14	101	80	98	93	93
20	141	133	133	132	135	103	113	96	91	118	102	73	106	87	98	98	55	50	8	∞	12	99	78	96	91	91
21	153	145	145	144	147	109	119	102	97	124	108	79	114	93	104	104	61	56	14	12	∞	105	84	102	97	97
22	221	213	213	215	218	92	102	104	98	107	81	70	87	68	48	48	60	49	101	99	105	∞	33	85	80	80
23	213	205	205	207	210	84	94	78	73	99	73	55	79	48	48	48	45	34	80	78	84	33	∞	77	72	72
24	146	138	138	140	143	17	27	29	23	32	19	23	25	29	40	40	40	46	98	96	102	85	77	∞	5	5
25	143	135	135	137	140	14	24	26	20	29	14	28	20	24	35	35	35	41	93	91	97	80	72	5	∞	2
26	141	133	133	135	138	12	22	24	18	27	14	18	20	24	35	35	35	41	93	91	97	80	72	5	2	∞

INTER-STOP DISTANCE MATRIX

TWENTY SIX STOP PROBLEM (contd.)

VEHICLE NUMBER	CAPACITY
1	120
2	120
3	120
4	120
5	120
6	120
7	120
8	120
9	120
10	120
11	120
12	120
13	120
14	120
15	120
16	120
17	120
18	120
19	120
20	120

CAPACITY OF AVAILABLE VEHICLES

STOP NUMBER	DEMAND
1	30
2	60
3	30
4	90
5	30
6	50
7	60
8	60
9	20
10	90
11	90
12	60
13	100
14	30
15	60
16	80
17	60
18	40
19	30
20	30
21	50
22	60
23	60
24	80
25	60

DEMAND AT RESPECTIVE STOPS

APPENDIX V

COMPUTER OUTPUT

The volume of computer output included herein has been reduced as much as possible without sacrificing completeness. The output included is as follows:

PROBLEM 1

The complete 1410 output is included for 520 passes of the 5 stop problem. Immediately following the computer output is a relative frequency distribution of the total route mileage.

PROBLEM 2

Two pages of 1410 output including the minimum obtained route are included for the 12 stop problem. A relative frequency distribution of total route mileage is included to illustrate the form of the output.

PROBLEM 3

Output for the 13 stop problem is similar to Problem 2 with the inclusion of all routes which are lower than previous low routes and also frequency distributions for both 4 and 5 vehicle routes.

PROBLEM 4

Output for the 33 stop problem is similar to that of Problem 2 with the inclusion of frequency distributions for 14, 15, and 16 vehicle routes.

PROBLEM 1

```
 1505
TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS     1


DISTANCE COVERED BY TRUCK NUMBER    1=   14
ROUTE IS AS FOLLOWS,
   5
   6
   4
   5
DISTANCE COVERED BY TRUCK NUMBER    2=   23
ROUTE IS AS FOLLOWS,
   1
   3
   6
   1
DISTANCE COVERED BY TRUCK NUMBER    3=   16
ROUTE IS AS FOLLOWS,
   2
   6
TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS     1


TOTAL ROUTE FOR ALL TRUCKS=   49 ON PASS     2


DISTANCE COVERED BY TRUCK NUMBER    1=   24
ROUTE IS AS FOLLOWS,
   1
   6
   4
   1
DISTANCE COVERED BY TRUCK NUMBER    2=   17
ROUTE IS AS FOLLOWS,
   2
   5
   6
   2
DISTANCE COVERED BY TRUCK NUMBER    3=    8
ROUTE IS AS FOLLOWS,
   3
   6
TOTAL ROUTE FOR ALL TRUCKS=   49 ON PASS     2


TOTAL ROUTE FOR ALL TRUCKS=   54 ON PASS     3


TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS     4


TOTAL ROUTE FOR ALL TRUCKS=   57 ON PASS     5


TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS     6


TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS     7


TOTAL ROUTE FOR ALL TRUCKS=   59 ON PASS     8


TOTAL ROUTE FOR ALL TRUCKS=   57 ON PASS     9


TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS    10


TOTAL ROUTE FOR ALL TRUCKS=   58 ON PASS    11


TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS    12


TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS    13
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 TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS   14

 TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS   15

 TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS   16

 TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS   17

 TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS   18

 TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS   19

 DISTANCE COVERED BY TRUCK NUMBER    1=   17
 ROUTE IS AS FOLLOWS,
    2
    5
    6
    2
 DISTANCE COVERED BY TRUCK NUMBER    2=   23
 ROUTE IS AS FOLLOWS,
    1
    3
    6
    1
 DISTANCE COVERED BY TRUCK NUMBER    3=    4
 ROUTE IS AS FOLLOWS,
    4
    6
 TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS   19

 TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS   20

 TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS   21

 TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS   22

 TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS   23

 TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS   24

 TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS   25

 TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS   26

 TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS   27

 TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS   28

 TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS   29

 TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS   30

 TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS   31

 TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS   32

 TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS   33
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TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS   34

TOTAL ROUTE FOR ALL TRUCKS=   44 ON PASS   35

TOTAL ROUTE FOR ALL TRUCKS=   44 ON PASS   36

TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS   37

TOTAL ROUTE FOR ALL TRUCKS=   59 ON PASS   38

TOTAL ROUTE FOR ALL TRUCKS=   54 ON PASS   39

TOTAL ROUTE FOR ALL TRUCKS=   44 ON PASS   40

TOTAL ROUTE FOR ALL TRUCKS=   56 ON PASS   41

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS   42

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS   43

TOTAL ROUTE FOR ALL TRUCKS=   56 ON PASS   44

TOTAL ROUTE FOR ALL TRUCKS=   59 ON PASS   45

TOTAL ROUTE FOR ALL TRUCKS=   59 ON PASS   46

TOTAL ROUTE FOR ALL TRUCKS=   49 ON PASS   47

TOTAL ROUTE FOR ALL TRUCKS=   44 ON PASS   48

TOTAL ROUTE FOR ALL TRUCKS=   59 ON PASS   49

TOTAL ROUTE FOR ALL TRUCKS=   49 ON PASS   50

TOTAL ROUTE FOR ALL TRUCKS=   58 ON PASS   51

TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS   52

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS   53

TOTAL ROUTE FOR ALL TRUCKS=   56 ON PASS   54

TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS   55

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS   56

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS   57

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS   58

TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS   59
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TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS    60

TOTAL ROUTE FOR ALL TRUCKS=   56 ON PASS    61

TOTAL ROUTE FOR ALL TRUCKS=   49 ON PASS    62

TOTAL ROUTE FOR ALL TRUCKS=   54 ON PASS    63

TOTAL ROUTE FOR ALL TRUCKS=   54 ON PASS    64

TOTAL ROUTE FOR ALL TRUCKS=   54 ON PASS    65

TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS    66

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS    67

TOTAL ROUTE FOR ALL TRUCKS=   54 ON PASS    68

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS    69

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS    70

TOTAL ROUTE FOR ALL TRUCKS=   49 ON PASS    71

TOTAL ROUTE FOR ALL TRUCKS=   58 ON PASS    72

TOTAL ROUTE FOR ALL TRUCKS=   59 ON PASS    73

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS    74

TOTAL ROUTE FOR ALL TRUCKS=   54 ON PASS    75

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS    76

TOTAL ROUTE FOR ALL TRUCKS=   58 ON PASS    77

TOTAL ROUTE FOR ALL TRUCKS=   53 ON PASS    78

TOTAL ROUTE FOR ALL TRUCKS=   59 ON PASS    79

TOTAL ROUTE FOR ALL TRUCKS=   51 ON PASS    80

TOTAL ROUTE FOR ALL TRUCKS=   57 ON PASS    81

TOTAL ROUTE FOR ALL TRUCKS=   54 ON PASS    82

TOTAL ROUTE FOR ALL TRUCKS=   54 ON PASS    83

TOTAL ROUTE FOR ALL TRUCKS=   57 ON PASS    84

TOTAL ROUTE FOR ALL TRUCKS=   54 ON PASS    85
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TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS   86

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS   87

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS   88

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS   89

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS   90

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS   91

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS   92

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS   93

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS   94

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS   95

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS   96

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS   97

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS   98

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS   99

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  100

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  101

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  102

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  103

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  104

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  105

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  106

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  107

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  108

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  109

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  110

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  111
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TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  112

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  113

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  114

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  115

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  116

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  117

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  118

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  119

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  120

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  121

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  122

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  123

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  124

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  125

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  126

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  127

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  128

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  129

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  130

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  131

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  132

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  133

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  134

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  135

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  136

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  137
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TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  138
TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  139
TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  140
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  141
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  142
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  143
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  144
TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  145
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  146
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  147
TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  148
TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  149
TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  150
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  151
TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  152
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  153
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  154
TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  155
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  156
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  157
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  158
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  159
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  160
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  161
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  162
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  163
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TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  164

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  165

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  166

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  167

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  168

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  169

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  170

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  171

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  172

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  173

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  174

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  175

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  176

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  177

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  178

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  179

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  180

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  181

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  182

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  183

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  184

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  185

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  186

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  187

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  188

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  189
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TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  190

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  191

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  192

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  193

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  194

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  195

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  196

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  197

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  198

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  199

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  200

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  201

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  202

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  203

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  204

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  205

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  206

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  207

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  208

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  209

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  210

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  211

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  212

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  213

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  214

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  215
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TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  216

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  217

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  218

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  219

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  220

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  221

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  222

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  223

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  224

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  225

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  226

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  227

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  228

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  229

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  230

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  231

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  232

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  233

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  234

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  235

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  236

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  237

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  238

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  239

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  240

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  241
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TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  242

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  243

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  244

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  245

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  246

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  247

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  248

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  249

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  250

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  251

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  252

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  253

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  254

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  255

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  256

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  257

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  258

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  259

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  260

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  261

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  262

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  263

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  264

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  265

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  266

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  267
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TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  268

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  269

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  270

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  271

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  272

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  273

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  274

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  275

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  276

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  277

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  278

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  279

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  280

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  281

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  282

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  283

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  284

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  285

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  286

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  287

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  288

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  289

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  290

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  291

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  292

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  293
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TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  294
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  295
TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  296
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  297
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  298
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  299
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  300
TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  301
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  302
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  303
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  304
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  305
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  306
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TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  309
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  310
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  311
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TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  318
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  319
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TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  320
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  321
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  322
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  323
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TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  326
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  327
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TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  329
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  330
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  331
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  332
TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  333
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  334
TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  335
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  336
TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  337
TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  338
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  339
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  340
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  341
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  342
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  343
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  344
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  345
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TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  346

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  347

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  348

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  349

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  350

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  351

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  352

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  353

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  354

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  355

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  356

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  357

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  358

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  359

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  360

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  361

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  362

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  363

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  364

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  365

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  366

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  367

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  368

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  369

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  370

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  371
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TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  372

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  373

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  374

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  375

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  376

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  377

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  378

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  379

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  380

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  381

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  382

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  383

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  384

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  385

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  386

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  387

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  388

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  389

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  390

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  391

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  392

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  393

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  394

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  395

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  396

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  397
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TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  398
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  399
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  400
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  401
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  402
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  403
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  404
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  405
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  406
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  407
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  408
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  409
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  410
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  411
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  412
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  413
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  414
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  415
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  416
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  417
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  418
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  419
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  420
TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  421
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  422
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  423
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TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  424
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  425
TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  426
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  427
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  428
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  429
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  430
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  431
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  432
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  433
TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  434
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  435
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  436
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  437
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  438
TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  439
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  440
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  441
TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  442
TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  443
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  444
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  445
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  446
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  447
TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  448
TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  449
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TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  450
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  451
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  452
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  453
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  454
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  455
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  456
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  457
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  458
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  459
TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  460
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  461
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  462
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  463
TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  464
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  465
TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  466
TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  467
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  468
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  469
TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  470
TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  471
TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  472
TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  473
TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  474
TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  475
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TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  476

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  477

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  478

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  479

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  480

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  481

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  482

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  483

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  484

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  485

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  486

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  487

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  488

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  489

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  490

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  491

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  492

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  493

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  494

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  495

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  496

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  497

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  498

TOTAL ROUTE FOR ALL TRUCKS=  59 ON PASS  499

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  500

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  501
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TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  502

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  503

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  504

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  505

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  506

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  507

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  508

TOTAL ROUTE FOR ALL TRUCKS=  54 ON PASS  509

TOTAL ROUTE FOR ALL TRUCKS=  56 ON PASS  510

TOTAL ROUTE FOR ALL TRUCKS=  44 ON PASS  511

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  512

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  513

TOTAL ROUTE FOR ALL TRUCKS=  53 ON PASS  514

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  515

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  516

TOTAL ROUTE FOR ALL TRUCKS=  51 ON PASS  517

TOTAL ROUTE FOR ALL TRUCKS=  49 ON PASS  518

TOTAL ROUTE FOR ALL TRUCKS=  58 ON PASS  519

TOTAL ROUTE FOR ALL TRUCKS=  57 ON PASS  520

 1535
TOTAL TIME FOR THIS RUN =  18.0 MINUTES
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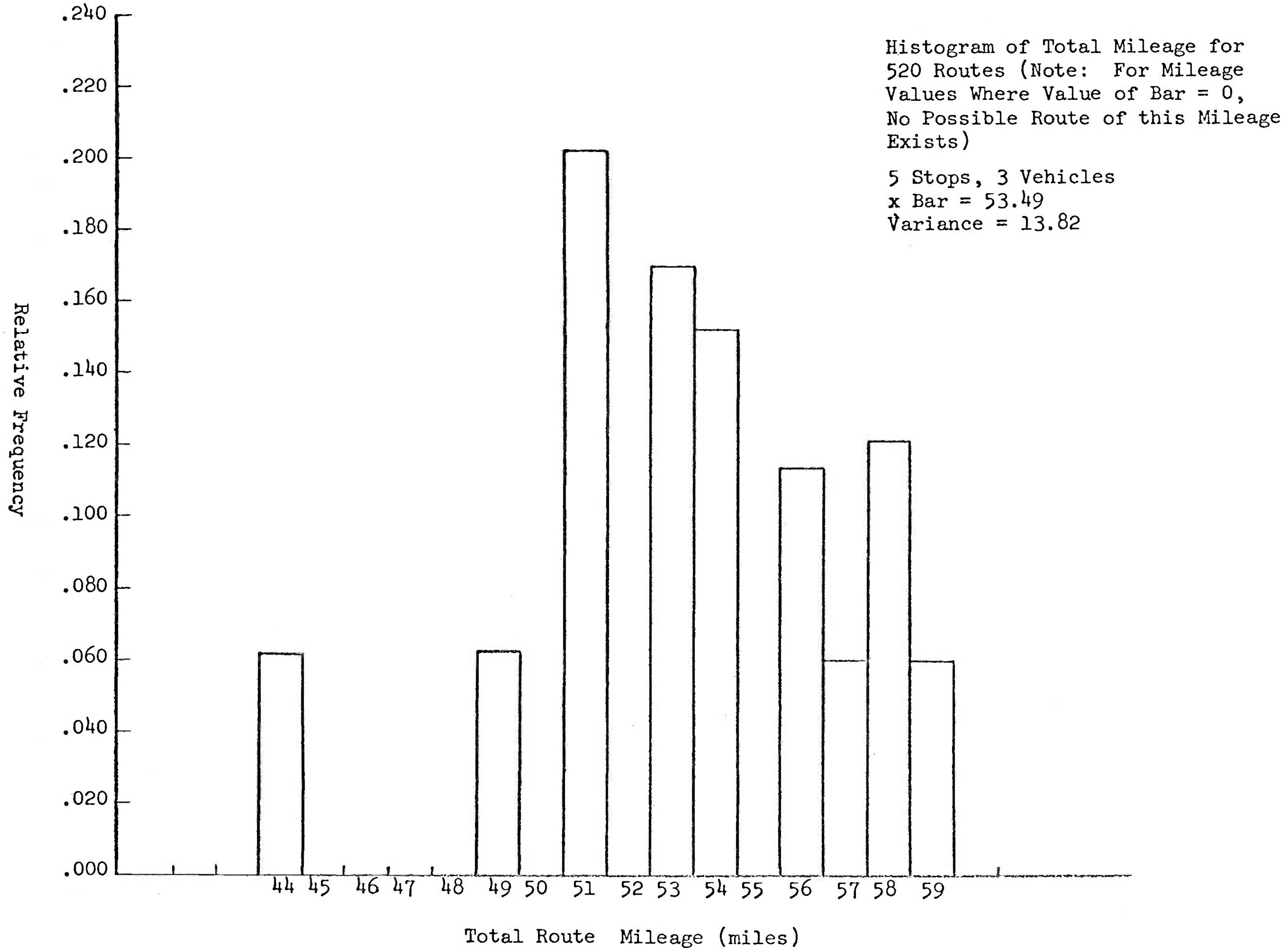

Histogram of Total Mileage for 520 Routes (Note: For Mileage Values Where Value of Bar = 0, No Possible Route of this Mileage Exists)

5 Stops, 3 Vehicles
x Bar = 53.49
Variance = 13.82

PROBLEM 2

```
TOTAL ROUTE FOR ALL TRUCKS=   342 ON PASS     263      4
TOTAL ROUTE FOR ALL TRUCKS=   388 ON PASS     264      4
TOTAL ROUTE FOR ALL TRUCKS=   390 ON PASS     265      4
TOTAL ROUTE FOR ALL TRUCKS=   370 ON PASS     266      4
TOTAL ROUTE FOR ALL TRUCKS=   398 ON PASS     267      4
TOTAL ROUTE FOR ALL TRUCKS=   326 ON PASS     268      4
TOTAL ROUTE FOR ALL TRUCKS=   398 ON PASS     269      4
TOTAL ROUTE FOR ALL TRUCKS=   380 ON PASS     270      4
TOTAL ROUTE FOR ALL TRUCKS=   388 ON PASS     271      4
TOTAL ROUTE FOR ALL TRUCKS=   346 ON PASS     272      4
TOTAL ROUTE FOR ALL TRUCKS=   356 ON PASS     273      4
TOTAL ROUTE FOR ALL TRUCKS=   394 ON PASS     274      4
TOTAL ROUTE FOR ALL TRUCKS=   368 ON PASS     275      4
TOTAL ROUTE FOR ALL TRUCKS=   386 ON PASS     276      4
TOTAL ROUTE FOR ALL TRUCKS=   392 ON PASS     277      4
TOTAL ROUTE FOR ALL TRUCKS=   352 ON PASS     278      4
TOTAL ROUTE FOR ALL TRUCKS=   362 ON PASS     279      4
TOTAL ROUTE FOR ALL TRUCKS=   404 ON PASS     280      4
TOTAL ROUTE FOR ALL TRUCKS=   392 ON PASS     281      4
TOTAL ROUTE FOR ALL TRUCKS=   382 ON PASS     282      4
TOTAL ROUTE FOR ALL TRUCKS=   360 ON PASS     283      4
TOTAL ROUTE FOR ALL TRUCKS=   376 ON PASS     284      4
TOTAL ROUTE FOR ALL TRUCKS=   386 ON PASS     285      4
TOTAL ROUTE FOR ALL TRUCKS=   336 ON PASS     286      4
TOTAL ROUTE FOR ALL TRUCKS=   376 ON PASS     287      4
TOTAL ROUTE FOR ALL TRUCKS=   358 ON PASS     288      4
TOTAL ROUTE FOR ALL TRUCKS=   372 ON PASS     289      4
TOTAL ROUTE FOR ALL TRUCKS=   368 ON PASS     290      4
TOTAL ROUTE FOR ALL TRUCKS=   396 ON PASS     291      4
TOTAL ROUTE FOR ALL TRUCKS=   342 ON PASS     292      4
TOTAL ROUTE FOR ALL TRUCKS=   398 ON PASS     293      4
TOTAL ROUTE FOR ALL TRUCKS=   386 ON PASS     294      4
TOTAL ROUTE FOR ALL TRUCKS=   394 ON PASS     295      4
TOTAL ROUTE FOR ALL TRUCKS=   392 ON PASS     296      4
TOTAL ROUTE FOR ALL TRUCKS=   372 ON PASS     297      4
TOTAL ROUTE FOR ALL TRUCKS=   348 ON PASS     298      4
TOTAL ROUTE FOR ALL TRUCKS=   416 ON PASS     299      4
TOTAL ROUTE FOR ALL TRUCKS=   396 ON PASS     300      4
TOTAL ROUTE FOR ALL TRUCKS=   362 ON PASS     301      4
TOTAL ROUTE FOR ALL TRUCKS=   364 ON PASS     302      4
TOTAL ROUTE FOR ALL TRUCKS=   378 ON PASS     303      4
TOTAL ROUTE FOR ALL TRUCKS=   408 ON PASS     304      4
TOTAL ROUTE FOR ALL TRUCKS=   358 ON PASS     305      4
TOTAL ROUTE FOR ALL TRUCKS=   396 ON PASS     306      4
TOTAL ROUTE FOR ALL TRUCKS=   358 ON PASS     307      4
TOTAL ROUTE FOR ALL TRUCKS=   382 ON PASS     308      4
TOTAL ROUTE FOR ALL TRUCKS=   408 ON PASS     309      4
TOTAL ROUTE FOR ALL TRUCKS=   342 ON PASS     310      4
TOTAL ROUTE FOR ALL TRUCKS=   376 ON PASS     311      4
TOTAL ROUTE FOR ALL TRUCKS=   380 ON PASS     312      4
TOTAL ROUTE FOR ALL TRUCKS=   356 ON PASS     313      4
TOTAL ROUTE FOR ALL TRUCKS=   352 ON PASS     314      4
TOTAL ROUTE FOR ALL TRUCKS=   340 ON PASS     315      4
TOTAL ROUTE FOR ALL TRUCKS=   296 ON PASS     316      4
DISTANCE COVERED BY TRUCK NUMBER    1=  112
SEND TRUCK OF CAPACITY 4000 ON ROUTE AS FOLLOWS,
ROUTE IS AS FOLLOWS,
 13
  4
 12
 11
  9
 13
DISTANCE COVERED BY TRUCK NUMBER    2=   94
SEND TRUCK OF CAPACITY 5000 ON ROUTE AS FOLLOWS,
ROUTE IS AS FOLLOWS,
  8
 10
  3
 13
  8
DISTANCE COVERED BY TRUCK NUMBER    3=   72
SEND TRUCK OF CAPACITY 5000 ON ROUTE AS FOLLOWS,
ROUTE IS AS FOLLOWS,
 13
  2
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```
   5
   7
   6
  13
DISTANCE COVERED BY TRUCK NUMBER    4=   18
SEND TRUCK OF CAPACITY 4000 ON ROUTE AS FOLLOWS,
ROUTE IS AS FOLLOWS,
   1
  13
TOTAL ROUTE FOR ALL TRUCKS=     296 ON PASS      316      4
TOTAL ROUTE FOR ALL TRUCKS=     382 ON PASS      317      4
TOTAL ROUTE FOR ALL TRUCKS=     398 ON PASS      318      4
TOTAL ROUTE FOR ALL TRUCKS=     402 ON PASS      319      4
TOTAL ROUTE FOR ALL TRUCKS=     326 ON PASS      320      4
TOTAL ROUTE FOR ALL TRUCKS=     312 ON PASS      321      4
TOTAL ROUTE FOR ALL TRUCKS=     384 ON PASS      322      4
TOTAL ROUTE FOR ALL TRUCKS=     368 ON PASS      323      4
TOTAL ROUTE FOR ALL TRUCKS=     388 ON PASS      324      4
TOTAL ROUTE FOR ALL TRUCKS=     390 ON PASS      325      4
TOTAL ROUTE FOR ALL TRUCKS=     408 ON PASS      326      4
TOTAL ROUTE FOR ALL TRUCKS=     382 ON PASS      327      4
TOTAL ROUTE FOR ALL TRUCKS=     390 ON PASS      328      4
TOTAL ROUTE FOR ALL TRUCKS=     336 ON PASS      329      4
TOTAL ROUTE FOR ALL TRUCKS=     390 ON PASS      330      4
TOTAL ROUTE FOR ALL TRUCKS=     398 ON PASS      331      4
TOTAL ROUTE FOR ALL TRUCKS=     386 ON PASS      332      4
TOTAL ROUTE FOR ALL TRUCKS=     360 ON PASS      333      4
TOTAL ROUTE FOR ALL TRUCKS=     322 ON PASS      334      4
TOTAL ROUTE FOR ALL TRUCKS=     386 ON PASS      335      4
TOTAL ROUTE FOR ALL TRUCKS=     344 ON PASS      336      4
TOTAL ROUTE FOR ALL TRUCKS=     368 ON PASS      337      4
TOTAL ROUTE FOR ALL TRUCKS=     362 ON PASS      338      4
TOTAL ROUTE FOR ALL TRUCKS=     362 ON PASS      339      4
TOTAL ROUTE FOR ALL TRUCKS=     342 ON PASS      340      4
TOTAL ROUTE FOR ALL TRUCKS=     400 ON PASS      341      4
TOTAL ROUTE FOR ALL TRUCKS=     392 ON PASS      342      4
TOTAL ROUTE FOR ALL TRUCKS=     352 ON PASS      343      4
TOTAL ROUTE FOR ALL TRUCKS=     360 ON PASS      344      4
TOTAL ROUTE FOR ALL TRUCKS=     360 ON PASS      345      4
TOTAL ROUTE FOR ALL TRUCKS=     390 ON PASS      346      4
TOTAL ROUTE FOR ALL TRUCKS=     372 ON PASS      347      4
TOTAL ROUTE FOR ALL TRUCKS=     356 ON PASS      348      4
TOTAL ROUTE FOR ALL TRUCKS=     408 ON PASS      349      4
TOTAL ROUTE FOR ALL TRUCKS=     386 ON PASS      350      4
TOTAL ROUTE FOR ALL TRUCKS=     388 ON PASS      351      4
TOTAL ROUTE FOR ALL TRUCKS=     396 ON PASS      352      4
TOTAL ROUTE FOR ALL TRUCKS=     380 ON PASS      353      4
TOTAL ROUTE FOR ALL TRUCKS=     388 ON PASS      354      4
TOTAL ROUTE FOR ALL TRUCKS=     390 ON PASS      355      4
TOTAL ROUTE FOR ALL TRUCKS=     340 ON PASS      356      4
TOTAL ROUTE FOR ALL TRUCKS=     366 ON PASS      357      4
TOTAL ROUTE FOR ALL TRUCKS=     342 ON PASS      358      4
TOTAL ROUTE FOR ALL TRUCKS=     414 ON PASS      359      4
TOTAL ROUTE FOR ALL TRUCKS=     392 ON PASS      360      4
TOTAL ROUTE FOR ALL TRUCKS=     386 ON PASS      361      4
TOTAL ROUTE FOR ALL TRUCKS=     378 ON PASS      362      4
TOTAL ROUTE FOR ALL TRUCKS=     400 ON PASS      363      4
TOTAL ROUTE FOR ALL TRUCKS=     352 ON PASS      364      4
TOTAL ROUTE FOR ALL TRUCKS=     354 ON PASS      365      4
TOTAL ROUTE FOR ALL TRUCKS=     352 ON PASS      366      4
TOTAL ROUTE FOR ALL TRUCKS=     370 ON PASS      367      4
TOTAL ROUTE FOR ALL TRUCKS=     334 ON PASS      368      4
TOTAL ROUTE FOR ALL TRUCKS=     344 ON PASS      369      4
TOTAL ROUTE FOR ALL TRUCKS=     348 ON PASS      370      4
TOTAL ROUTE FOR ALL TRUCKS=     368 ON PASS      371      4
TOTAL ROUTE FOR ALL TRUCKS=     392 ON PASS      372      4
TOTAL ROUTE FOR ALL TRUCKS=     386 ON PASS      373      4
TOTAL ROUTE FOR ALL TRUCKS=     390 ON PASS      374      4
TOTAL ROUTE FOR ALL TRUCKS=     390 ON PASS      375      4
TOTAL ROUTE FOR ALL TRUCKS=     382 ON PASS      376      4
TOTAL ROUTE FOR ALL TRUCKS=     368 ON PASS      377      4
TOTAL ROUTE FOR ALL TRUCKS=     406 ON PASS      378      4
TOTAL ROUTE FOR ALL TRUCKS=     362 ON PASS      379      4
TOTAL ROUTE FOR ALL TRUCKS=     318 ON PASS      380      4
TOTAL ROUTE FOR ALL TRUCKS=     326 ON PASS      381      4
TOTAL ROUTE FOR ALL TRUCKS=     388 ON PASS      382      4
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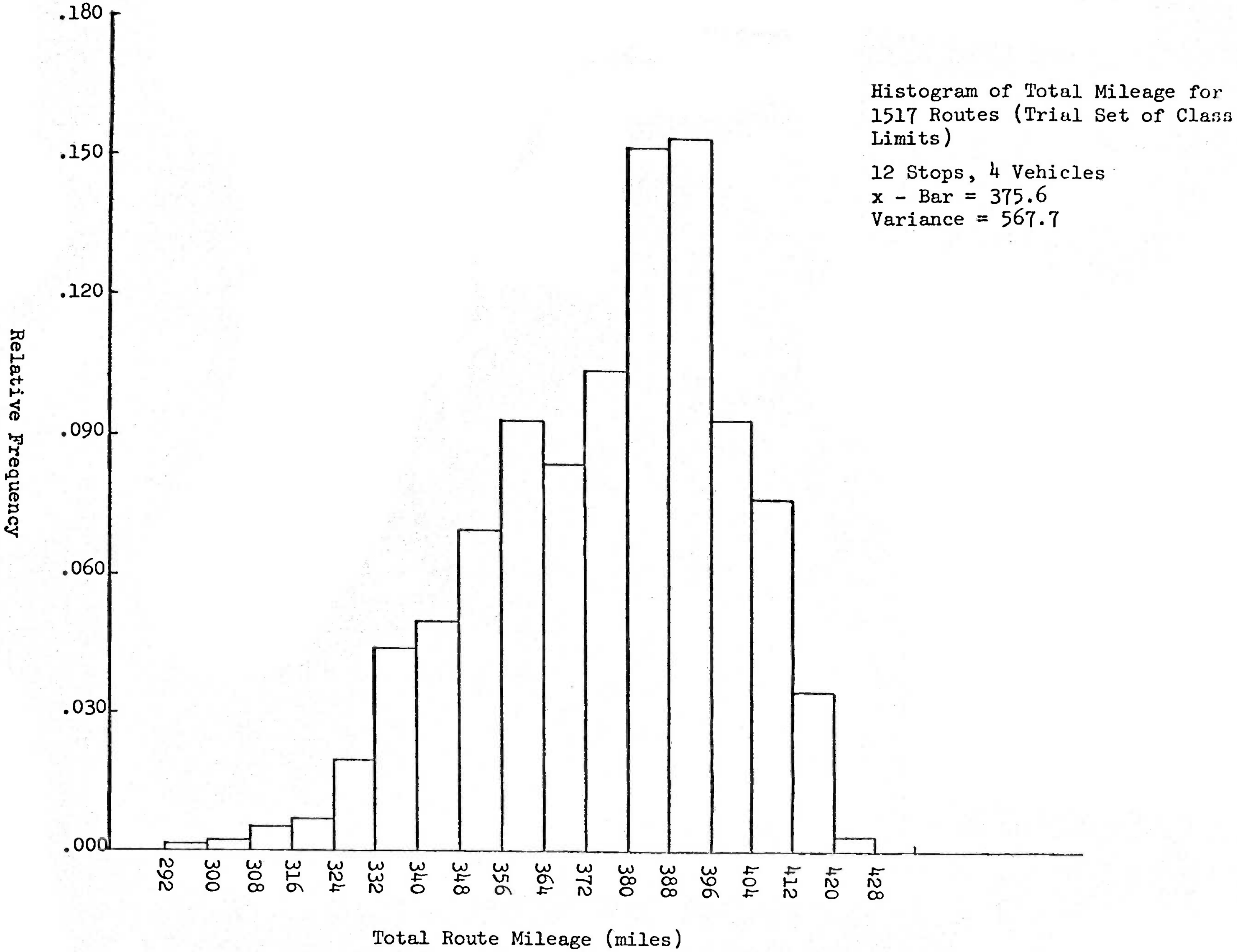
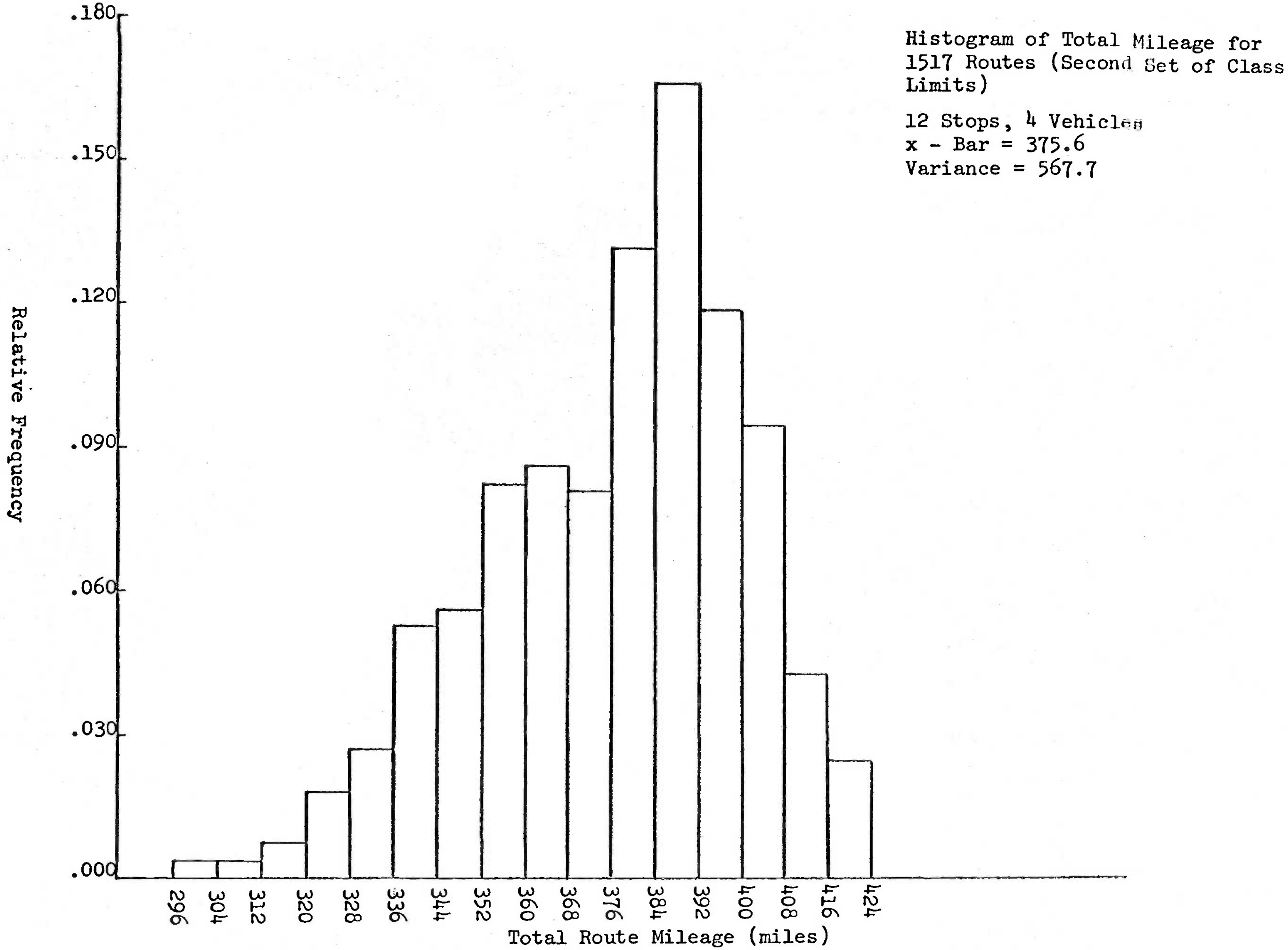


Histogram of Total Mileage for 1517 Routes (Trial Set of Class Limits)

12 Stops, 4 Vehicles
x - Bar = 375.6
Variance = 567.7



Histogram of Total Mileage for 1517 Routes (Second Set of Class Limits)

12 Stops, 4 Vehicles
x - Bar = 375.6
Variance = 567.7

PROBLEM 3

```
 232
 TOTAL ROUTE FOR ALL TRUCKS=1994 ON PASS     1


 DISTANCE COVERED BY TRUCK NUMBER    1= 633
 ROUTE IS AS FOLLOWS,
   11
    9
    3
    8
   14
   11
 DISTANCE COVERED BY TRUCK NUMBER    2= 626
 ROUTE IS AS FOLLOWS,
   12
   10
    2
    1
   14
    4
   12
 DISTANCE COVERED BY TRUCK NUMBER    3= 291
 ROUTE IS AS FOLLOWS,
    7
    6
   14
    5
    7
 DISTANCE COVERED BY TRUCK NUMBER    4= 444
 ROUTE IS AS FOLLOWS,
   13
   14
 TOTAL ROUTE FOR ALL TRUCKS=1994 ON PASS     1


 TOTAL ROUTE FOR ALL TRUCKS=1683 ON PASS     2


 DISTANCE COVERED BY TRUCK NUMBER    1= 575
 ROUTE IS AS FOLLOWS,
   13
   10
   14
   13
 DISTANCE COVERED BY TRUCK NUMBER    2= 281
 ROUTE IS AS FOLLOWS,
    3
    2
    8
   14
    3
 DISTANCE COVERED BY TRUCK NUMBER    3= 517
 ROUTE IS AS FOLLOWS,
    4
   14
    9
   11
   12
    4
 DISTANCE COVERED BY TRUCK NUMBER    4= 310
 ROUTE IS AS FOLLOWS,
    7
    6
    5
   14
    1
    7
 TOTAL ROUTE FOR ALL TRUCKS=1683 ON PASS     2


 TOTAL ROUTE FOR ALL TRUCKS=2210 ON PASS     3


 TOTAL ROUTE FOR ALL TRUCKS=2000 ON PASS     4


 TOTAL ROUTE FOR ALL TRUCKS=2222 ON PASS     5
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TOTAL ROUTE FOR ALL TRUCKS=1972 ON PASS  110

TOTAL ROUTE FOR ALL TRUCKS=2139 ON PASS  111

TOTAL ROUTE FOR ALL TRUCKS=2217 ON PASS  112

TOTAL ROUTE FOR ALL TRUCKS=1817 ON PASS  113

TOTAL ROUTE FOR ALL TRUCKS=2081 ON PASS  114

TOTAL ROUTE FOR ALL TRUCKS=1941 ON PASS  115

TOTAL ROUTE FOR ALL TRUCKS=1887 ON PASS  116

TOTAL ROUTE FOR ALL TRUCKS=1669 ON PASS  117

DISTANCE COVERED BY TRUCK NUMBER   1= 481
ROUTE IS AS FOLLOWS,
  1
 14
 13
  1
DISTANCE COVERED BY TRUCK NUMBER   2= 365
ROUTE IS AS FOLLOWS,
  7
  6
  2
 14
  8
  7
DISTANCE COVERED BY TRUCK NUMBER   3= 399
ROUTE IS AS FOLLOWS,
  9
 10
  5
  3
 14
  4
  9
DISTANCE COVERED BY TRUCK NUMBER   4= 424
ROUTE IS AS FOLLOWS,
 12
 11
 14
 12
TOTAL ROUTE FOR ALL TRUCKS=1669 ON PASS  117

TOTAL ROUTE FOR ALL TRUCKS=2091 ON PASS  118

TOTAL ROUTE FOR ALL TRUCKS=1721 ON PASS  119

TOTAL ROUTE FOR ALL TRUCKS=2263 ON PASS  120

TOTAL ROUTE FOR ALL TRUCKS=1960 ON PASS  121

TOTAL ROUTE FOR ALL TRUCKS=2161 ON PASS  122

TOTAL ROUTE FOR ALL TRUCKS=1833 ON PASS  123

TOTAL ROUTE FOR ALL TRUCKS=2006 ON PASS  124

TOTAL ROUTE FOR ALL TRUCKS=1865 ON PASS  125
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TOTAL ROUTE FOR ALL TRUCKS=1955 ON PASS  178

TOTAL ROUTE FOR ALL TRUCKS=1924 ON PASS  179

TOTAL ROUTE FOR ALL TRUCKS=2071 ON PASS  180

TOTAL ROUTE FOR ALL TRUCKS=1952 ON PASS  181

TOTAL ROUTE FOR ALL TRUCKS=2159 ON PASS  182

TOTAL ROUTE FOR ALL TRUCKS=1931 ON PASS  183

TOTAL ROUTE FOR ALL TRUCKS=1730 ON PASS  184

TOTAL ROUTE FOR ALL TRUCKS=1941 ON PASS  185

TOTAL ROUTE FOR ALL TRUCKS=1797 ON PASS  186

TOTAL ROUTE FOR ALL TRUCKS=1892 ON PASS  187

TOTAL ROUTE FOR ALL TRUCKS=2075 ON PASS  188

TOTAL ROUTE FOR ALL TRUCKS=1942 ON PASS  189

TOTAL ROUTE FOR ALL TRUCKS=1897 ON PASS  190

TOTAL ROUTE FOR ALL TRUCKS=1982 ON PASS  191

TOTAL ROUTE FOR ALL TRUCKS=1972 ON PASS  192

TOTAL ROUTE FOR ALL TRUCKS=1830 ON PASS  193

TOTAL ROUTE FOR ALL TRUCKS=1968 ON PASS  194

TOTAL ROUTE FOR ALL TRUCKS=2121 ON PASS  195

TOTAL ROUTE FOR ALL TRUCKS=1571 ON PASS  196

DISTANCE COVERED BY TRUCK NUMBER    1= 575
ROUTE IS AS FOLLOWS,
 13
 10
 14
 13
DISTANCE COVERED BY TRUCK NUMBER    2= 400
ROUTE IS AS FOLLOWS,
  4
  6
 14
  1
  8
  7
  4
DISTANCE COVERED BY TRUCK NUMBER    3= 484
ROUTE IS AS FOLLOWS,
 12
 11
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   9
   4
  14
  12
DISTANCE COVERED BY TRUCK NUMBER    4= 112
ROUTE IS AS FOLLOWS,
   3
   2
  14
   3
TOTAL ROUTE FOR ALL TRUCKS=1571 ON PASS  196

TOTAL ROUTE FOR ALL TRUCKS=2273 ON PASS  197

TOTAL ROUTE FOR ALL TRUCKS=2213 ON PASS  198

TOTAL ROUTE FOR ALL TRUCKS=2160 ON PASS  199

TOTAL ROUTE FOR ALL TRUCKS=2379 ON PASS  200

TOTAL ROUTE FOR ALL TRUCKS=2028 ON PASS  201

TOTAL ROUTE FOR ALL TRUCKS=2349 ON PASS  202

TOTAL ROUTE FOR ALL TRUCKS=2158 ON PASS  203

TOTAL ROUTE FOR ALL TRUCKS=1874 ON PASS  204

TOTAL ROUTE FOR ALL TRUCKS=1955 ON PASS  205

TOTAL ROUTE FOR ALL TRUCKS=2172 ON PASS  206

TOTAL ROUTE FOR ALL TRUCKS=2190 ON PASS  207

TOTAL ROUTE FOR ALL TRUCKS=1680 ON PASS  208

TOTAL ROUTE FOR ALL TRUCKS=1797 ON PASS  209

TOTAL ROUTE FOR ALL TRUCKS=2053 ON PASS  210

TOTAL ROUTE FOR ALL TRUCKS=1970 ON PASS  211

TOTAL ROUTE FOR ALL TRUCKS=1838 ON PASS  212

TOTAL ROUTE FOR ALL TRUCKS=2107 ON PASS  213

TOTAL ROUTE FOR ALL TRUCKS=2395 ON PASS  214

TOTAL ROUTE FOR ALL TRUCKS=2133 ON PASS  215

TOTAL ROUTE FOR ALL TRUCKS=1939 ON PASS  216

TOTAL ROUTE FOR ALL TRUCKS=1788 ON PASS  217

TOTAL ROUTE FOR ALL TRUCKS=1965 ON PASS  218
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TOTAL ROUTE FOR ALL TRUCKS=2010 ON PASS  531

TOTAL ROUTE FOR ALL TRUCKS=2001 ON PASS  532

TOTAL ROUTE FOR ALL TRUCKS=1729 ON PASS  533

TOTAL ROUTE FOR ALL TRUCKS=1851 ON PASS  534

TOTAL ROUTE FOR ALL TRUCKS=1990 ON PASS  535

TOTAL ROUTE FOR ALL TRUCKS=2058 ON PASS  536

TOTAL ROUTE FOR ALL TRUCKS=2083 ON PASS  537

TOTAL ROUTE FOR ALL TRUCKS=1967 ON PASS  538

TOTAL ROUTE FOR ALL TRUCKS=1992 ON PASS  539

TOTAL ROUTE FOR ALL TRUCKS=2047 ON PASS  540

TOTAL ROUTE FOR ALL TRUCKS=1857 ON PASS  541

TOTAL ROUTE FOR ALL TRUCKS=2076 ON PASS  542

TOTAL ROUTE FOR ALL TRUCKS=2005 ON PASS  543

TOTAL ROUTE FOR ALL TRUCKS=2253 ON PASS  544

TOTAL ROUTE FOR ALL TRUCKS=1547 ON PASS  545

DISTANCE COVERED BY TRUCK NUMBER   1= 661
ROUTE IS AS FOLLOWS,
   7
  14
  12
  11
  10
   9
   7
DISTANCE COVERED BY TRUCK NUMBER   2= 141
ROUTE IS AS FOLLOWS,
   6
   4
  14
   6
DISTANCE COVERED BY TRUCK NUMBER   3= 444
ROUTE IS AS FOLLOWS,
  13
  14
DISTANCE COVERED BY TRUCK NUMBER   4= 301
ROUTE IS AS FOLLOWS,
   5
   3
   2
   1
   8
  14
   5
TOTAL ROUTE FOR ALL TRUCKS=1547 ON PASS  545

TOTAL ROUTE FOR ALL TRUCKS=1956 ON PASS  546
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TOTAL ROUTE FOR ALL TRUCKS=2437 ON PASS  599

TOTAL ROUTE FOR ALL TRUCKS=2197 ON PASS  600

TOTAL ROUTE FOR ALL TRUCKS=2049 ON PASS  601

TOTAL ROUTE FOR ALL TRUCKS=1975 ON PASS  602

TOTAL ROUTE FOR ALL TRUCKS=2029 ON PASS  603

TOTAL ROUTE FOR ALL TRUCKS=1828 ON PASS  604

TOTAL ROUTE FOR ALL TRUCKS=2310 ON PASS  605

TOTAL ROUTE FOR ALL TRUCKS=1911 ON PASS  606

TOTAL ROUTE FOR ALL TRUCKS=2272 ON PASS  607

TOTAL ROUTE FOR ALL TRUCKS=2047 ON PASS  608

TOTAL ROUTE FOR ALL TRUCKS=1981 ON PASS  609

TOTAL ROUTE FOR ALL TRUCKS=2004 ON PASS  610

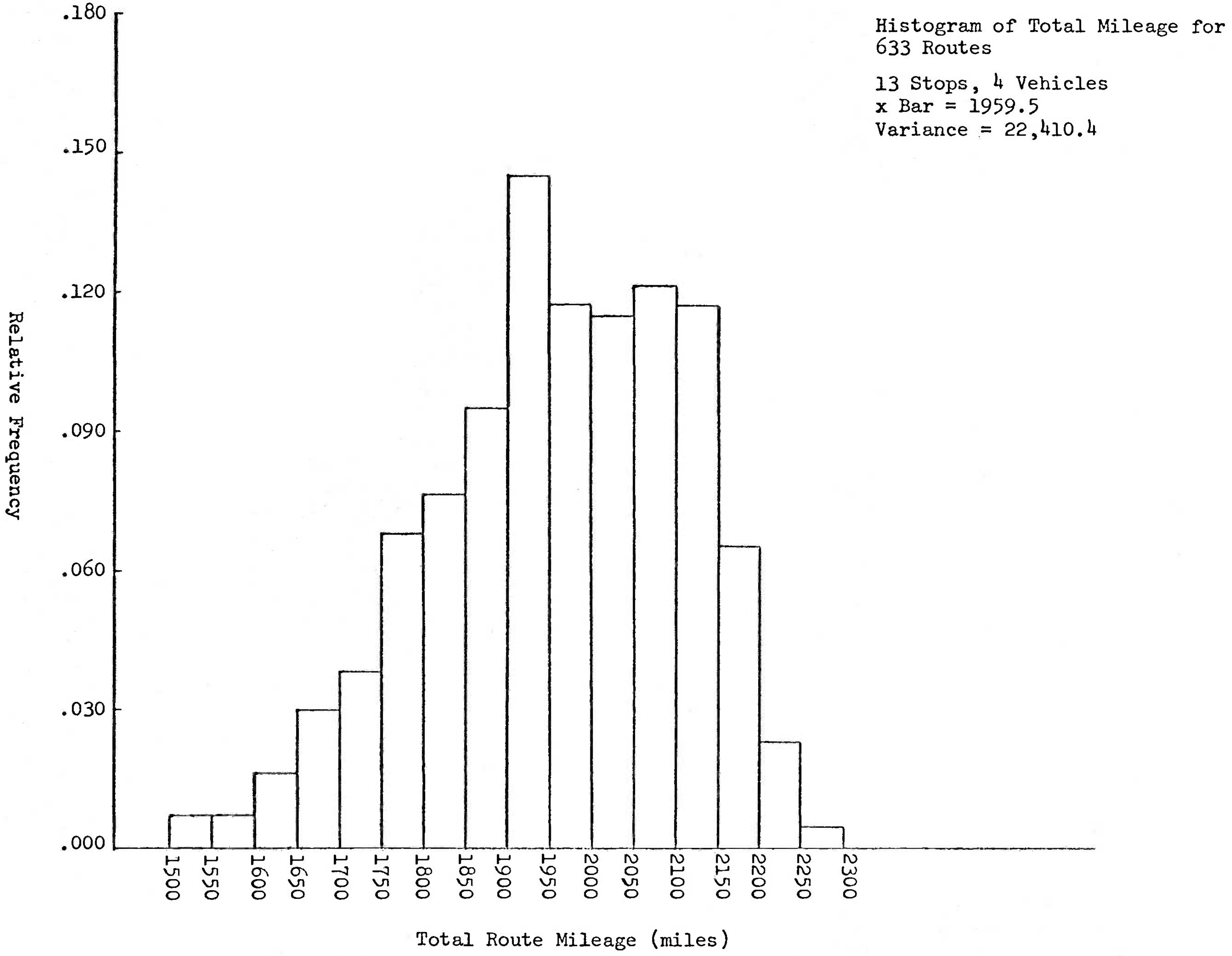
TOTAL ROUTE FOR ALL TRUCKS=1510 ON PASS  611

DISTANCE COVERED BY TRUCK NUMBER    1= 213
ROUTE IS AS FOLLOWS,
  2
 14
  4
  6
  7
  2
DISTANCE COVERED BY TRUCK NUMBER    2=  96
ROUTE IS AS FOLLOWS,
  3
 14
DISTANCE COVERED BY TRUCK NUMBER    3= 521
ROUTE IS AS FOLLOWS,
 13
  9
 14
 13
DISTANCE COVERED BY TRUCK NUMBER    4= 680
ROUTE IS AS FOLLOWS,
 12
 11
 10
  5
 14
  8
  1
 12
TOTAL ROUTE FOR ALL TRUCKS=1510 ON PASS  611

TOTAL ROUTE FOR ALL TRUCKS=2234 ON PASS  612

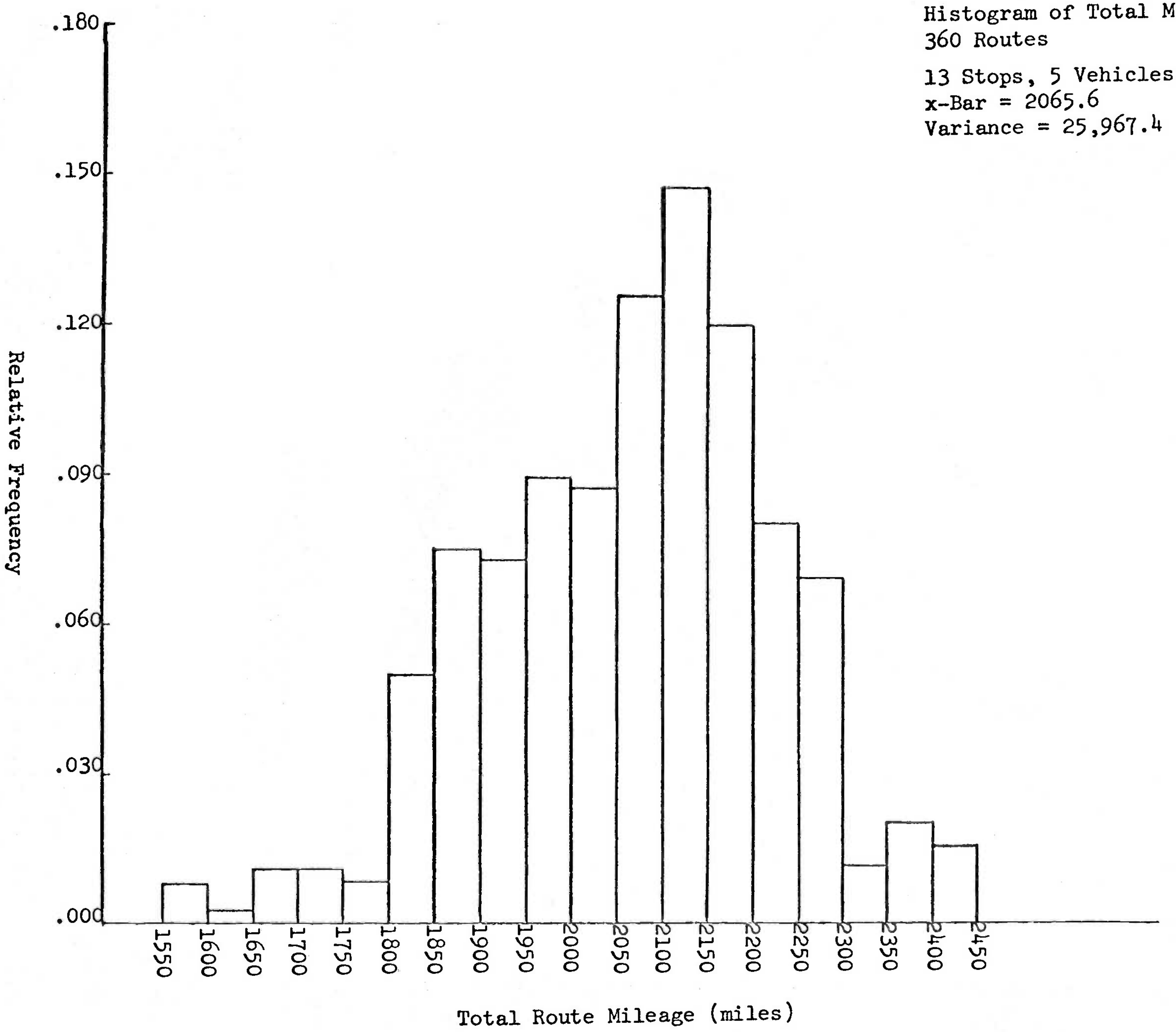
TOTAL ROUTE FOR ALL TRUCKS=2110 ON PASS  613

TOTAL ROUTE FOR ALL TRUCKS=1604 ON PASS  614
```


Histogram of Total Mileage for 633 Routes
13 Stops, 4 Vehicles
x Bar = 1959.5
Variance = 22,410.4
Relative Frequency
.180
.150
.120
.090
.060
.030
.000
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000
2050
2100
2150
2200
2250
2300
Total Route Mileage (miles)

Histogram of Total Mileage for
360 Routes

13 Stops, 5 Vehicles
x-Bar = 2065.6
Variance = 25,967.4



PROBLEM 4

```
 TOTAL ROUTE FOR ALL TRUCKS=2380 ON PASS  144

 TOTAL ROUTE FOR ALL TRUCKS=2396 ON PASS  145

 TOTAL ROUTE FOR ALL TRUCKS=2616 ON PASS  146

 TOTAL ROUTE FOR ALL TRUCKS=2425 ON PASS  147

 TOTAL ROUTE FOR ALL TRUCKS=2580 ON PASS  148

 TOTAL ROUTE FOR ALL TRUCKS=2718 ON PASS  149

 TOTAL ROUTE FOR ALL TRUCKS=2448 ON PASS  150

 TOTAL ROUTE FOR ALL TRUCKS=2307 ON PASS  151

 TOTAL ROUTE FOR ALL TRUCKS=2528 ON PASS  152

 TOTAL ROUTE FOR ALL TRUCKS=2253 ON PASS  153

 TOTAL ROUTE FOR ALL TRUCKS=2418 ON PASS  154

 TOTAL ROUTE FOR ALL TRUCKS=2539 ON PASS  155

 TOTAL ROUTE FOR ALL TRUCKS=2429 ON PASS  156

 TOTAL ROUTE FOR ALL TRUCKS=2609 ON PASS  157

 TOTAL ROUTE FOR ALL TRUCKS=2542 ON PASS  158

 TOTAL ROUTE FOR ALL TRUCKS=1870 ON PASS  159

DISTANCE COVERED BY TRUCK NUMBER    1=  46
ROUTE IS AS FOLLOWS,
   9
  26
  24
   9
DISTANCE COVERED BY TRUCK NUMBER    2= 253
ROUTE IS AS FOLLOWS,
  21
  23
  26
  21
DISTANCE COVERED BY TRUCK NUMBER    3= 191
ROUTE IS AS FOLLOWS,
  26
  17
  19
  20
  26
DISTANCE COVERED BY TRUCK NUMBER    4=   4
ROUTE IS AS FOLLOWS,
  25
  26
DISTANCE COVERED BY TRUCK NUMBER    5=  40
ROUTE IS AS FOLLOWS,
  13
  26
DISTANCE COVERED BY TRUCK NUMBER    6= 102
```

```
 ROUTE IS AS FOLLOWS,
  18
  16
  26
  18
DISTANCE COVERED BY TRUCK NUMBER   7= 283
ROUTE IS AS FOLLOWS,
   2
   3
   5
  26
   2
DISTANCE COVERED BY TRUCK NUMBER   8= 332
ROUTE IS AS FOLLOWS,
  14
  26
   1
   8
  14
DISTANCE COVERED BY TRUCK NUMBER   9=  80
ROUTE IS AS FOLLOWS,
   7
  26
  12
   7
DISTANCE COVERED BY TRUCK NUMBER  10=  54
ROUTE IS AS FOLLOWS,
  10
  26
DISTANCE COVERED BY TRUCK NUMBER  11= 163
ROUTE IS AS FOLLOWS,
  22
  15
  26
  22
DISTANCE COVERED BY TRUCK NUMBER  12=  24
 OUTE IS AS FOLLOWS,
   6
  26
DISTANCE COVERED BY TRUCK NUMBER  13=  28
ROUTE IS AS FOLLOWS,
  11
  26
DISTANCE COVERED BY TRUCK NUMBER  14= 270
ROUTE IS AS FOLLOWS,
   4
  26
TOTAL ROUTE FOR ALL TRUCKS=1870 ON PASS  159

TOTAL ROUTE FOR ALL TRUCKS=2699 ON PASS  160

TOTAL ROUTE FOR ALL TRUCKS=2332 ON PASS  161

TOTAL ROUTE FOR ALL TRUCKS=2057 ON PASS  162

TOTAL ROUTE FOR ALL TRUCKS=2136 ON PASS  163

TOTAL ROUTE FOR ALL TRUCKS=2432 ON PASS  164

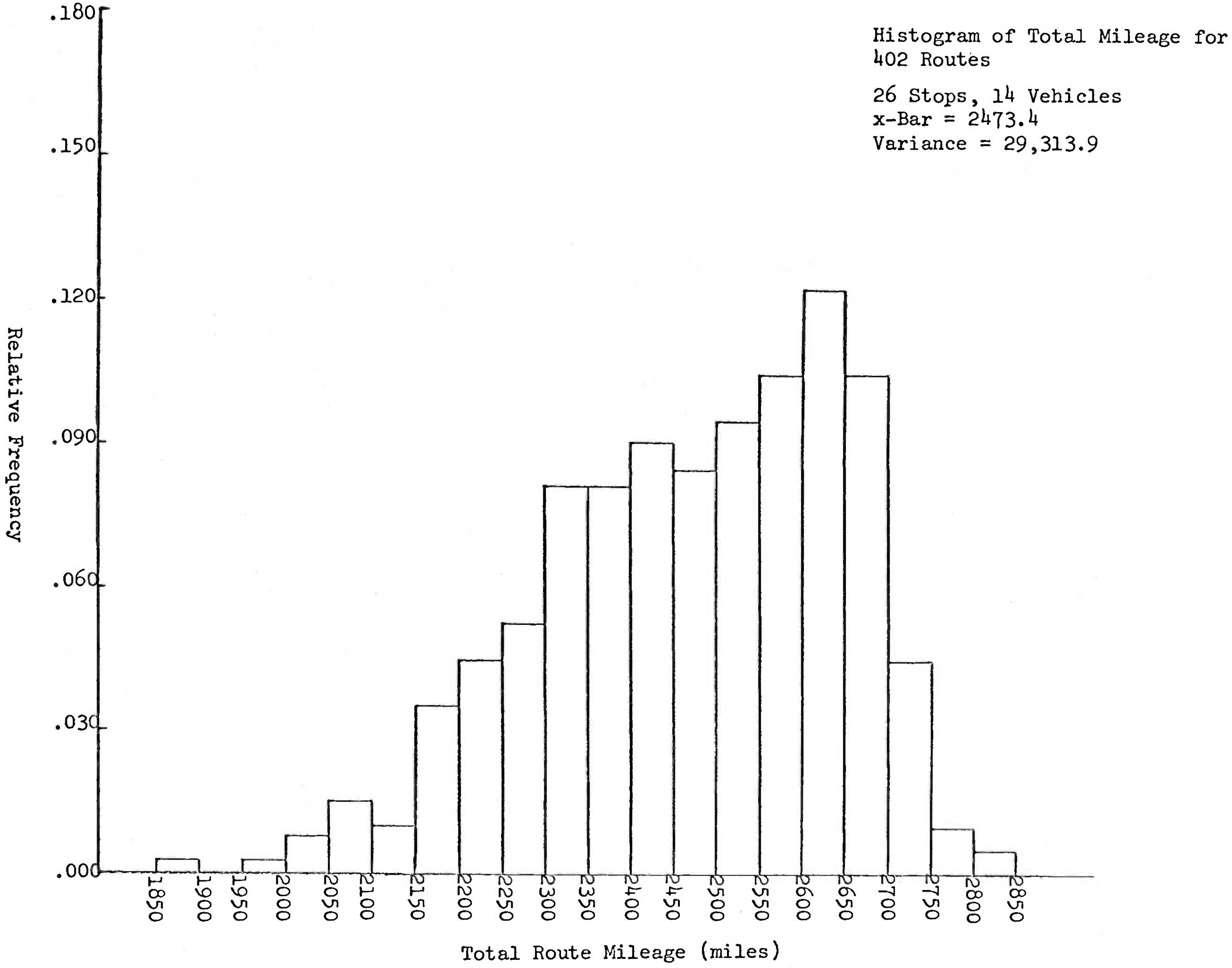
TOTAL ROUTE FOR ALL TRUCKS=2301 ON PASS  165

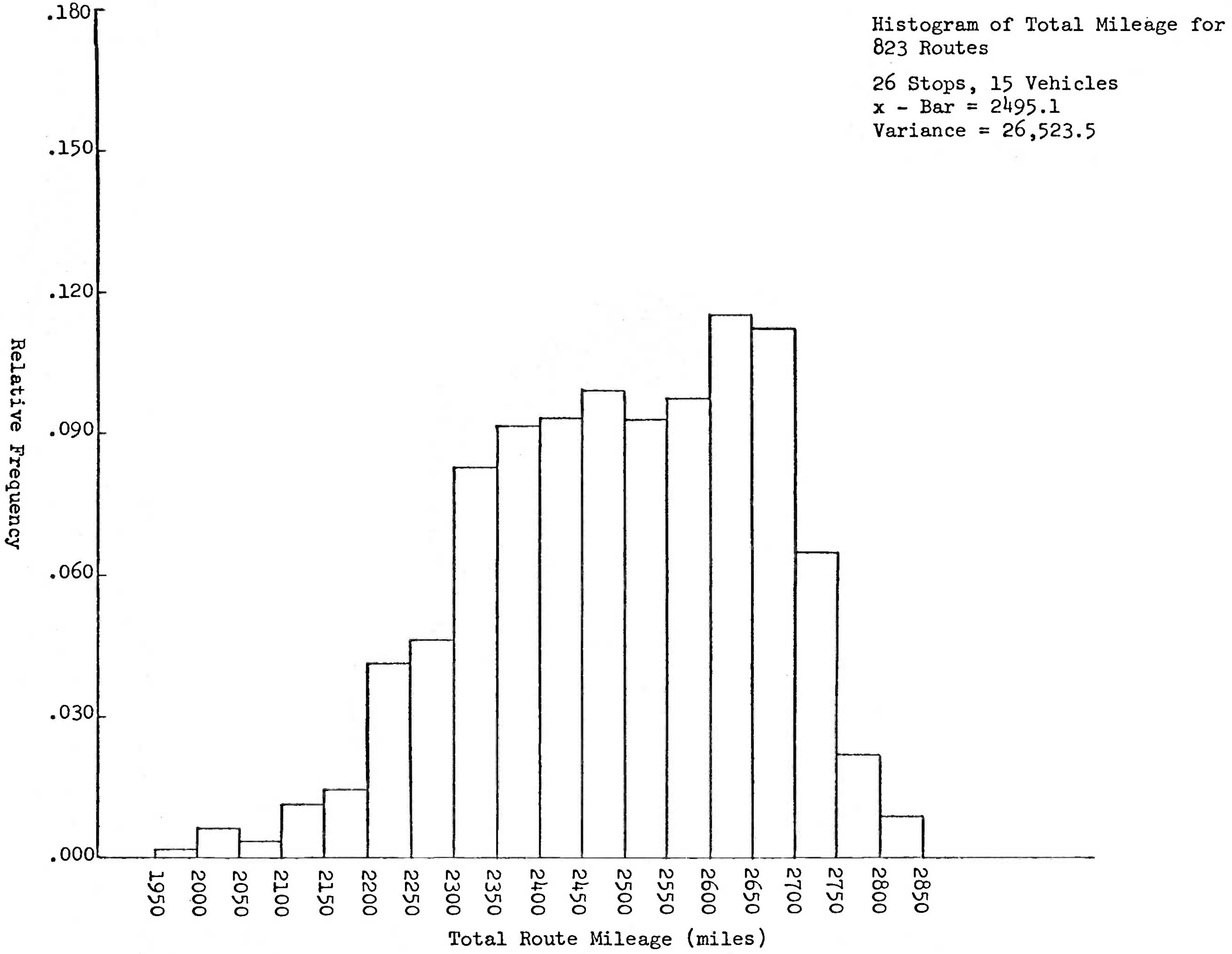
TOTAL ROUTE FOR ALL TRUCKS=2247 ON PASS  166

TOTAL ROUTE FOR ALL TRUCKS=2717 ON PASS  167

TOTAL ROUTE FOR ALL TRUCKS=2556 ON PASS  168

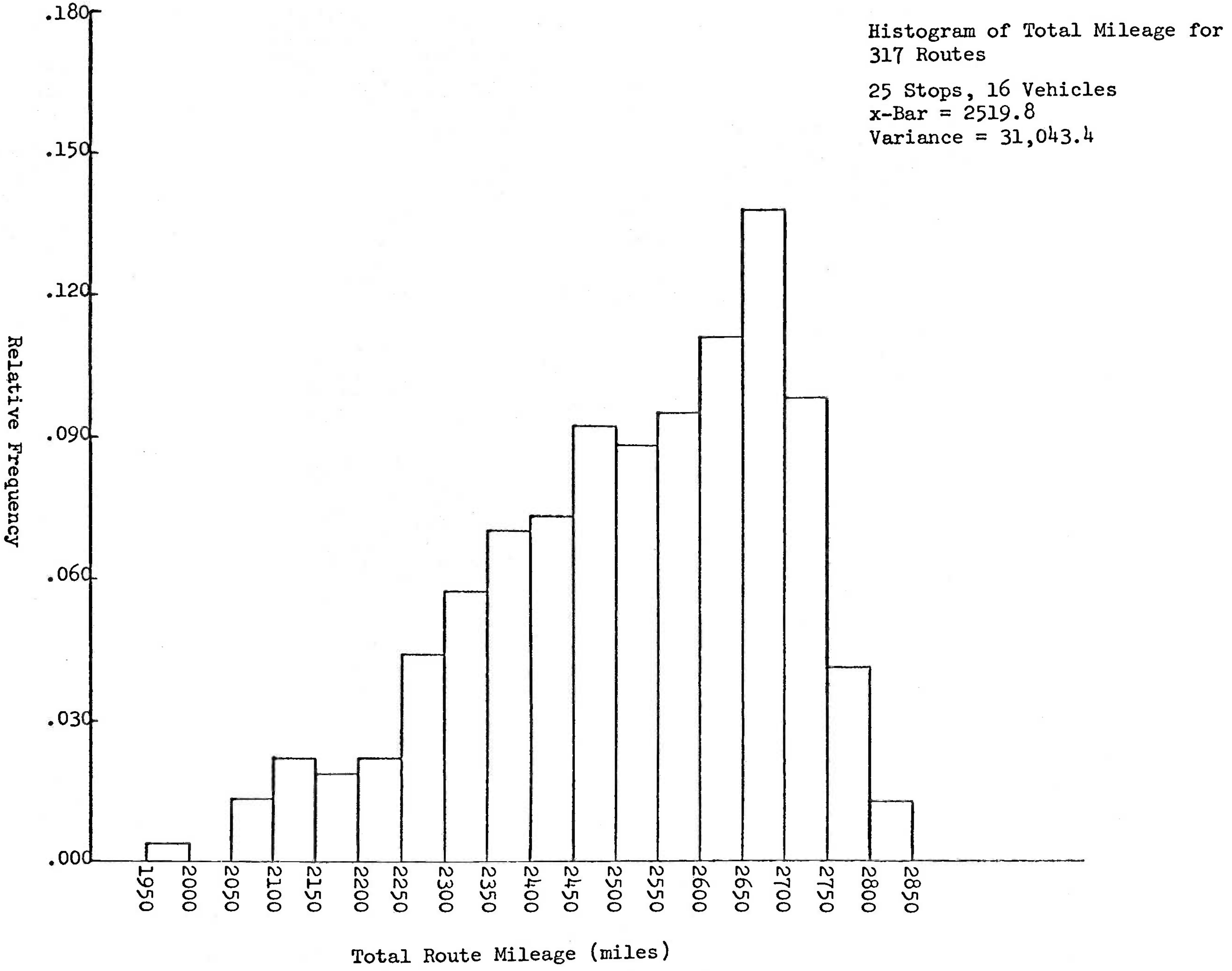
TOTAL ROUTE FOR ALL TRUCKS=2507 ON PASS  169
```


Histogram of Total Mileage for 402 Routes
26 Stops, 14 Vehicles
x-Bar = 2473.4
Variance = 29,313.9
Relative Frequency
.180
.150
.120
.090
.060
.030
.000
1850
1900
1950
2000
2050
2100
2150
2200
2250
2300
2350
2400
2450
2500
2550
2600
2650
2700
2750
2800
2850
Total Route Mileage (miles)



Histogram of Total Mileage for
823 Routes

26 Stops, 15 Vehicles
x - Bar = 2495.1
Variance = 26,523.5



Histogram of Total Mileage for
317 Routes

25 Stops, 16 Vehicles
x-Bar = 2519.8
Variance = 31,043.4

APPENDIX VI

STATISTICAL TESTS

STATISTICAL TEST ONE

Kolmogrov-Smirnov One-Sample Test

(see page 122)

H_o: There is no difference in the theoretical and observed distribution of mileage values obtained for the 5 stop problem

MAXIMUM DEVIATION = D = maximum $|F_o(X) - S_N(X)|$

Let $\alpha = .01$, and N = 520 observed routes

$$D_{observed} = \left|\frac{312}{520} - \frac{335}{520}\right|$$

$$= \frac{23}{520}$$

$$= .0442$$

Going to the K-S one-sample table of critical values (14),

$$D_{tabular,.01} = 1.63 \;/\; \sqrt{520}$$

$$= 1.63 \;/\; 22.8$$

$$= .0715$$

At $\alpha = .01$, $D_{observed} < D_{tabular}$

$\therefore$ ACCEPT H_o: EQUAL POPULATIONS

STATISTICAL TEST TWO

The χ^2 One-Sample Test

(see page 122)

H_o: There is no difference in the theoretical and observed distribution of mileage values obtained for the five stop problem.

Let $\alpha = .01$, and N = 520 observed routes

$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$, where k = number of categories.

	Mileage Value									
	44	49	51	53	54	56	57	58	59	Total
Number Observed	32	32	105	88	80	58	31	63	31	
Number Expected	35	35	104	69	69	69	35	69	35	520
Difference	-3	-3	1	19	11	-11	-4	-6	-4	

$$\chi^2 = \frac{(32 - 35)^2}{35} + \frac{(32 - 35)^2}{35} + \ldots + \frac{(31 - 35)^2}{35}$$

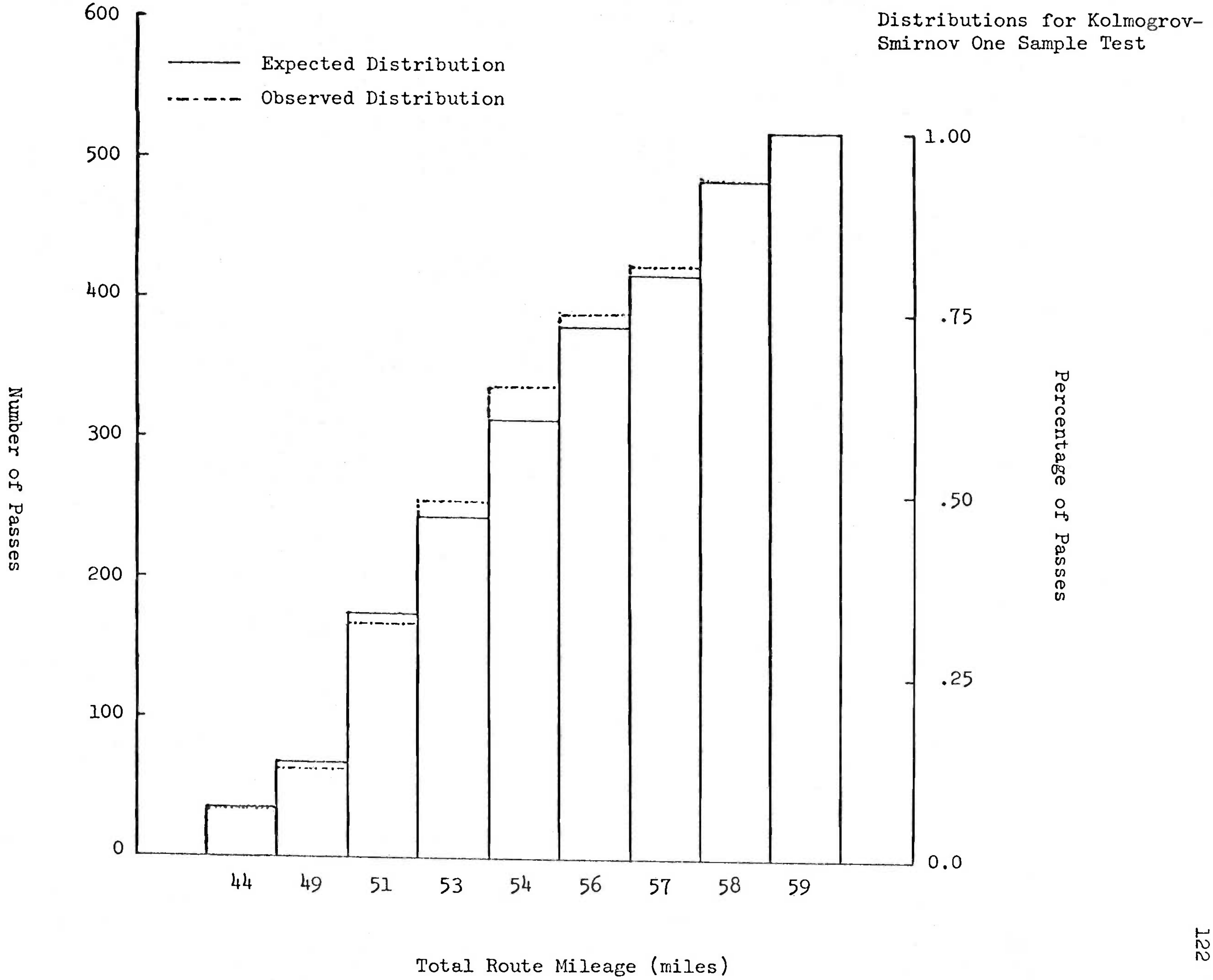
= 10.69 for k-1 df, where k = 9.

Going to the Chi-square one-sample table of critical values (14), for 8 degrees of freedom.

$\text{Chi-square}_{.01,\ 8\ df} = 20.09$

At $\alpha = .01$, $\chi^2 <$ Chi-square

$\therefore$ Accept H_o: EQUAL POPULATIONS



Distributions for Kolmogrov-
Smirnov One Sample Test
Expected Distribution
Observed Distribution
Number of Passes
600
500
400
300
200
100
0
Percentage of Passes
1.00
.75
.50
.25
0.0
44
49
51
53
54
56
57
58
59
Total Route Mileage (miles)

A COMPUTERIZED SIMULATION APPROACH TO THE SOLUTION OF THE CARRIER DISPATCHING PROBLEM

by

WILLIAM CHRISTIAN ELVIN BRAUN

B. S., Kansas State University, 1966

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

ABSTRACT

The purpose of this research is to study the feasibility of determining a solution to the large scale carrier dispatching problem utilizing the tool of computerized simulation and to develop statistical confidence intervals for the shortest resulting route.

A Fortran program was compiled, utilizing a computerized algorithm for solving the now famous 'Traveling Salesman' problem, in conjunction with a random ordering of a series of 'demand points'. The computer program, assembled for an IBM 1410 computer was used in solving several problems with low routes previously suggested to be optimum by various algorithms.

Experience with the sample problems indicates a decrease in efficiency over time of finding a near optimal route with an increasing number of demand points. Although an optimal solution is not apt to be determined, a route is always determined, which is an advantage over some of the algorithms which require an approximation after the solution is obtained.