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Evaluation of IBM Vehicle Scheduling Program for Air Force Base Refuse-Collection Scheduling

New Mexico Univ Albuquerque

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EVALUATION OF IBM VEHICLE SCHEDULING PROGRAM FOR AIR FORCE BASE REFUSE-COLLECTION SCHEDULING

APRIL 1976

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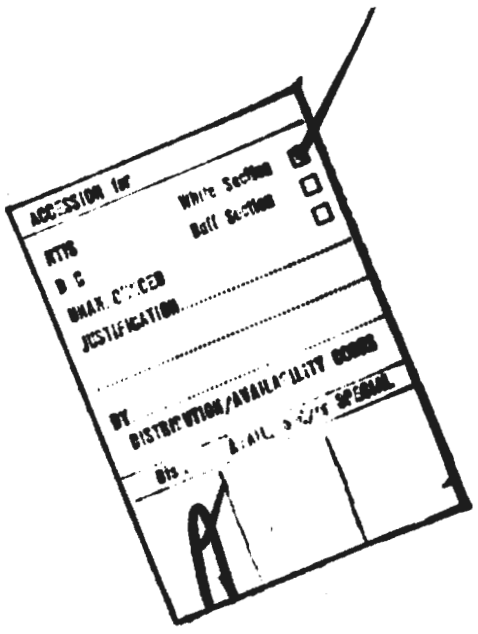

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The IBM Vehicle Scheduling Program (VSP) was used to schedule refuse collection at five Air Force bases. The application procedure and the results are presented for two of these bases. The results indicate that computer scheduling of refuse collection can reduce manpower, distance traveled, and the number of vehicles required by up to 20 percent. Difficulties involved in using the IBM program and in producing the final route maps and schedule indicate that a computer program that would determine the traversal path and draw the route should be written (or obtained if one exists).

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PREFACE

This report was prepared by the Eric H. Wang Civil Engineering Research Facility, University of New Mexico, for the Air Force Civil Engineering Center, Tyndall Air Force Base, Florida. It summarizes work accomplished during the period February 1973 through December 1975 under Job Order 21036W14. Mr Harold J. Iuzzolino was principal investigator. Captain Dennis E. Lundquist was project engineer.

This report has been reviewed by the Information Officer (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I
INTRODUCTION

BACKGROUND

Computer-generated, refuse-collection vehicle scheduling offers possible reductions in fuel consumption, maintenance costs, and manpower cost by more complete use of truck capacity and more efficient selection of collection routes. Although the IBM Vehicle Scheduling Program (VSP) was written to generate efficient delivery schedules, it can be modified to schedule refuse collection by redefining some of the input data.

OBJECTIVE

To evaluate the usefulness of the VSP, two Air Force bases were selected for refuse-collection scheduling: scrap paper collection at Carswell Air Force Base, Texas, and refuse collection in residential areas at Kirtland Air Force Base (East), New Mexico.

SCOPE

The scheduling processes for Carswell and Kirtland are presented in this report. Carswell Air Force Base represented the smallest collection problem in terms of trips and refuse locations (1 or 2 trips to service about 70 refuse locations). Kirtland Air Force Base (East) provided a medium-sized test case with about 1600 collection points serviced in 8 trips.

SECTION II
PROGRAM DESCRIPTION

The IBM VSP is supplied as a series of programs in object-code (binary) form on magnetic tape. The object programs must be copied to disk for execution on an IBM/360 computer. Since the VSP is in object form, it cannot be reprogrammed to extend or modify its abilities. Any functional adaptation must be accomplished by redefining the input data.

The intended function of the program is the scheduling of specified quantities of materials to discrete points by one or more delivery vehicles of specified capacities. All the vehicles must leave from a single depot. The region involved in the deliveries can be specified either in a simple, low-precision manner by coordinates of barriers and delivery points (coordinate method) or in a high-precision manner by street lengths and connections to delivery points (true-distance method). The delivery schedule produced by the program lists the delivery points serviced by each vehicle and a range of permissible delivery times. However, the VSP does not indicate the path to be taken from one delivery point to the next; if such route maps are desired, delivery paths must be determined and the maps drawn by hand.

The VSP is actually a series of programs which perform various phases of the scheduling. Two network-analysis programs (DEY10 and DEY20) are provided. The first applies the true-distance method and the second applies the coordinate method to information from a map of the collection area to produce a savings file. The savings file indicates the distance saved by scheduling two deliveries consecutively rather than by returning to the depot between the deliveries. A program (DEYD) is provided to list a table of input distances. Another program (DEYSORT) sorts the savings file so that the pair of delivery points which produces the greatest savings will be used first. Programs (DEYSP and DEYSX) are provided to print all or selected parts of the savings file. The scheduler programs (DEY30 and DEY40) input information about the fleet of delivery vehicles and the sorted savings file and produce the delivery schedule. Another program (DEY50) prints one or more copies of the schedule. Two additional programs were written by the author. One uses a more compact form of

street length and speed limit data to generate the proper form of input for the network-analysis program; the other expands a compact form of delivery-point data into the proper input for the scheduler program.

A thorough description of the various IBM programs is provided in the IBM manual (ref. 1). However, a brief description of some of the primary data required to perform delivery scheduling is given here. A complete description of the modifications required to perform refuse-collection scheduling is given in section III.

A node is a numbered point on a street at an intersection, an end of a dead end, or a place where some property (e.g., direction or speed limit) changes significantly. A zone is a numbered point representing one or more delivery points. A link is the street segment connecting two nodes, two zones, or a node and a zone. A link is not numbered but can be specified by the node or zone numbers of its endpoints.

The network-analysis program, which uses the true-distance method, requires the following data cards: a title card, an options card, a links header card, and link cards. The only data on the first three cards which might affect the final schedule are the speed by individual link option on the options card and the average speed on the links header card. Each link card defines one link by specifying the node or zone number of each endpoint, the link length, and the speed limit on the link. The speed by individual link option indicates whether one speed limit is to be used for the entire network or whether speed limits will be specified for each link. If a speed limit is omitted from a link card, the average speed on the links header card is used. The default on the links header card is 30 distance units per hour and the maximum is 150.

The savings-sort program is run after the network-analysis program. It requires no data cards; the savings file written on disk by the network-analysis program is used as input and the sorted savings file is written on disk.

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1. *IBM Vehicle Scheduling Program - Extended (OS and DOS) Program Description Manual*, IBM form SH19-2304.

The schedule-production program is run after the savings-sort program. It requires as input the sorted savings file and cards describing delivery vehicles, delivery points, and time restrictions. There are seven types of data cards: a title card, an options card, a parameter card, vehicle cards, trailer cards, delivery cards, and an output options card.

The options selected for refuse-collection scheduling are calling time (limited by delivery point), specific stop time at some delivery points, and multiple trips per truck during a day. Of the 17 parameters which may be specified, the 5 which could affect the scheduling are stop time at the depot, working time per day, maximum route duration, stop time per delivery, and a speed adjustment factor. The vehicle cards describe the number and capacities of the vehicles available. The trailer cards describe the number and capacities of trailers available and which vehicles they may be attached to.

The majority of the data cards for the schedule-production program is delivery cards. One card is required for each delivery point. The data on these cards which affect the final schedule are schedule restrictions (i.e., first delivery or last delivery), quantity of load delivered, additional time for the delivery, earliest calling time, and latest calling time. Other data on each delivery card are the zone in which delivery occurs and a customer identification.

The final data card, the output options card, specifies the number of copies of the route list and fleet utilization summary to be printed. The information on this card is passed to the schedule-output program (DEY50), which does the printing. The route list gives in the order of delivery the zone number, the customer identification, the delivery quantity, the stop time duration, and the range of permissible delivery times. A route summary is printed at the end of this list; it gives the vehicle type and maximum capacity, the actual capacity used, the number of stops, mileage, travel time, total time, and loading time. The fleet utilization summary lists the numbers and capacities of vehicles available and the route summaries for all the routes.

SECTION III
APPLICATION PROCEDURE FOR AIR FORCE BASES

The VSP can be used to schedule refuse collection, since collection is equivalent to the delivery of space. The primary differences between delivery and collection are in the treatments of locations and the depot. Delivery locations usually are more appropriately described by spatially distinct points, whereas collection locations are more efficiently treated as line segments. The single depot in delivery problems corresponds to two locations, the garage and the sanitary landfill, in refuse-collection problems.

The information required for refuse-collection scheduling with the VSP can be grouped into two categories: map data and other data. Map data include those items which normally occur on a suitable map (e.g., map scale, collection locations, landfill and garage locations, and streets connecting the landfill and garage to the collection locations). Other data include the refuse quantity at each collection location, speed limits on each street, average vehicle speed during collection, stop time at collection locations, unloading time, vehicle capacity, number of vehicles available, and working time per day. The map data and speed limits are used in the network-analysis phase of the program; the remaining data are used in the scheduling phase.

The VSP requires that delivery points be grouped into zones, with at least one delivery point per zone. The most appropriate procedure for refuse collection is to group all collection locations on a street segment between two intersections into one zone. The point representing the zone is placed at the center of the street, unless the delivery points are clustered around one point on the street or the street is a dead end. The zone is located at the middle of the street so that the travel distance is equal to the length of the street when the zone is serviced. If the street is a dead end, the point representing the zone is placed at the collection location nearest the dead end so that the street is traversed twice, from the intersection to the last collection location and then back to the intersection.

Most of the zoning for Kirtland Air Force Base was performed as described above. The zone maps are shown in appendix A. However, there were exceptions: some

street segments were broken into two zones, and sometimes a zone included street segments spanning one or two intersections. The portions of Perimeter Drive spanned by zones 240 and 1360 and zone 320, which cover three street segments, are examples of the first and second types of exception, respectively. Both introduce U-turns in the VSP route and should be avoided.

The zoning for Carswell Air Force Base was typical of that for delivery scheduling. Collection locations were usually separated by several blocks; therefore, the zones were placed at the collection locations rather than at the street midpoints. There were one to four scrap paper containers at each collection location (72 zones for the 88 containers). Maps of Carswell Air Force Base with numbered zone locations are given in appendix B.

Zones must be given numbers less than 10000. Zone number 1 is reserved for the depot. The depot corresponds to both the garage and landfill in refuse-collection scheduling; but only one can be zone 1, if they are not at the same location. If the collection vehicles depart from the garage and landfill once per day, either can be zone 1; if the vehicles unload more than once per day, the landfill should be zone 1. This was the case for both Kirtland and Carswell. If the landfill is zone 1, the garage can be indicated on a delivery card as the first stop of the day. The trip from the landfill to the garage can be moved to the end of the day to put the schedule in correct time order. If the garage is zone 1, a trip from the last collection point to the landfill and back to the garage must be added by hand to the schedule. For one trip, this can be done by the VSP by indicating on a delivery card that the landfill is the last stop of the day.

Once the zones are designated, the nodes are indicated by numbers greater than 10000. For residential refuse collection, the intersections become the nodes and, wherever there are houses, the midpoints of street segments usually become the zones. For Carswell, some of the zones occur at the ends of the streets; therefore, these intersections received zone numbers rather than node numbers.

The network-analysis phase of the VSP was performed with the true-distance method so that the times and distances in the final schedule would be as accurate as possible. The first three data cards to the network-analysis program are the title card, the options card, and the links header card. For more

accurate scheduling, the speed by individual link option should be selected on the options card; this allows the speed limit to be specified on every street segment. The speed limit which occurs most often may be specified as the default value on the links header card so that it will be used whenever the speed limit is omitted from a link card. Each link card contains the node or zone numbers of the link endpoints, the length of the link, and the speed limit on the link. There were 264 links for the initial zoning of Kirtland (East) and 309 links for Carswell. Rather than punch these cards individually, link information was concatenated so that up to seven links could be punched in a card. A Fortran program was written to expand these concatenated cards into one card image per link on disk. A listing of the link writing program is given in appendix C.

The format used for the link cards differed slightly from that required by the program manual. The length of each link was in hundredths of a mile instead of tenths; therefore, the lengths appeared to the program to be increased by a factor of 10. Thus, 1.5 miles would be punched 15 (tenths) for regular VSP use but 150 (hundredths) for refuse-collection scheduling. To give correct time measurements, the travel speed on the links should be multiplied by 10 to compensate for the apparent increase. Compensation cannot be accomplished on the link cards, however, because speeds may not exceed 150 mph during the network-analysis phase. Instead the vehicle speed should be adjusted during the scheduling phase by modifying the *fleet speed* parameter. A factor of 10 will not fit in the space assigned for this item, but 9.99 will; this should not cause any significant error.

The link writing program works in the following way. The program copies the first three data cards (title, options, and links header cards) to a disk file (&&LINKS) which is used later as input for the network-analysis program. The fourth data card gives the number of map length measurement units per hundredth of a mile. The remaining cards, the compact form of link cards, each consists of eight node or zone numbers with the link length in map length measurement units between each pair of node or zone numbers. The speed limit on the seven links terminates the card. A listing of the data cards for Kirtland (East) is given in appendix D. The four ones on the options card select options which allow speed limits to be specified on each link, print links, print zones, and

print an ordered link list. The five on the links header card is the default speed limit (5 mph), which is used whenever the speed limit is not specified on the link cards. The control cards used to execute the network-analysis program and the savings-sort program are given in appendix E.

The delivery data, used in the scheduling phase of the VSP, consist of a title card, an options card, two parameters cards, a vehicle card, and delivery cards (one per delivery point). The earliest VSP runs treated each of the 1513 houses on Kirtland (East) as a delivery point. A Fortran program was written to reduce card punching (appendix F). The program used cards, each of which specified the zone numbers and number of houses per zone for 10 zones. These cards were expanded to one card image per delivery point on a disk file, which was used later as delivery input to the scheduler. The schedule produced by using one delivery card per house was inconveniently long (70 pages) and contained time errors (about 100 minutes per trip). The time errors resulted from the inability of the VSP to accept a stop time of 30 seconds per house; the VSP requires that stop time be a multiple of 1 minute. In a second approach, one delivery card per zone was generated, with refuse quantity and stop time (to the nearest minute) based on the number of houses in the zone. This approach produced a 10-page schedule that was more accurate in time.

Since routes already in use indicated that one vehicle could service about 210 houses, 1.3 cubic feet was chosen for the refuse quantity per house. However, the VSP does not allow decimal points in the quantity-of-load entry on the delivery cards; therefore, the number was expressed as 13 and the vehicle capacity was also multiplied by 10. Later scheduling work with other Air Force bases indicated that a more convenient approach was to express vehicle capacity as the maximum number of houses that could be serviced and use 1 for the quantity-of-load per house. In the schedule produced for Kirtland (appendix G) refuse quantity is expressed in 0.1 cubic-foot units.

SECTION IV
RESULTS

The schedule produced by the VSP for Kirtland Air Force Base (East) indicated that 9 trips by 4 trucks of 10-cubic-yard capacity were sufficient to collect refuse; the previous schedule required 10 trips. The previous route covered about 85 miles; the computer-generated route covers about 77 miles. (These distances were measured from maps of the routes.) The distance given in the VSP printed output may contain three types of error: (1) the initial trip starts from the landfill rather than from the refuse vehicle garage, (2) the final trip excludes the return to the garage, and (3) the zones are represented by single points. The first two errors will cancel out if the initial route passes the garage before it reaches the first house on the schedule; otherwise, the mileage may be increased by up to 2.1 miles. The third type of error may cause an additional 0.9 mile per trip. Note that the VSP printed output labels the distances *miles*, although they are actually *tenths of miles*.

The schedule produced by the VSP for Kirtland (East) is given in appendix G; the route maps are shown in appendix H. Note that the trips by one truck are made to different areas. This balances the total time per truck reasonably well (4 hours, 54 minutes; 4 hours, 35 minutes; 4 hours, 13 minutes; and 4 hours, 37 minutes). These times were obtained by removing the effects of the three types of errors mentioned above from the VSP printed output route times. The computer-generated schedule can be adjusted by hand so that each truck makes two trips. The new times would be 4 hours, 56 minutes; 4 hours, 51 minutes; 5 hours, 15 minutes; and 4 hours, 59 minutes. The total distance is about 68 miles. Maps of these final routes are given in appendix I.

The VSP was run twice for Carswell Air Force Base. In the first run, a truck capacity of 60 containers of paper was assumed. Two trips were generated. The total distance was 43.0 miles, and the total route time was 4 hours, 53 minutes. The two-trip route presently in use is 45.5 miles long (measured from the map) and requires 5 hours, 8 minutes (computed with the speed limits provided with the map) to complete. In the second VSP run, it was assumed that the collection

vehicle could carry 88 containers. The single-trip computer solution was 28.0 miles in 4 hours, 12 minutes; the single-trip route presently in use is 30.7 miles in 4 hours, 28 minutes.

Since the decision to make one trip instead of two probably is made during the actual collection, the two-trip route generated by the VSP should always be used if the present route is changed. If the two-trip VSP route is used as a single trip, the mileage is 28.9 miles, and the time required is 4 hours, 17 minutes. The improvements in the routes are shown below.

	Original Route		VSP Two-Trip Route		Savings	
Total Trips	Distance, miles	Time, hours:minutes	Distance, miles	Time, hours:minutes	Distance, miles	Time, min
1	30.7	4:28	28.9	4:17	1.8	11
2	45.5	5:08	43.0	4:53	2.5	15

The percentage of savings in mileage, 5.5 to 5.9 percent, and the actual mileage saved, 1.8 to 2.5 miles, are both small. Part of the reason for this is that round trips to the landfill account for 14 miles of the 28.9-mile, single-trip route or 27 miles of the 43-mile, two-trip route. These round trips to the landfill cannot be shortened. Maps of the final single-trip route are given in appendix B. The single-trip route is changed to the two-trip route by inserting a trip to the landfill after zone 360.

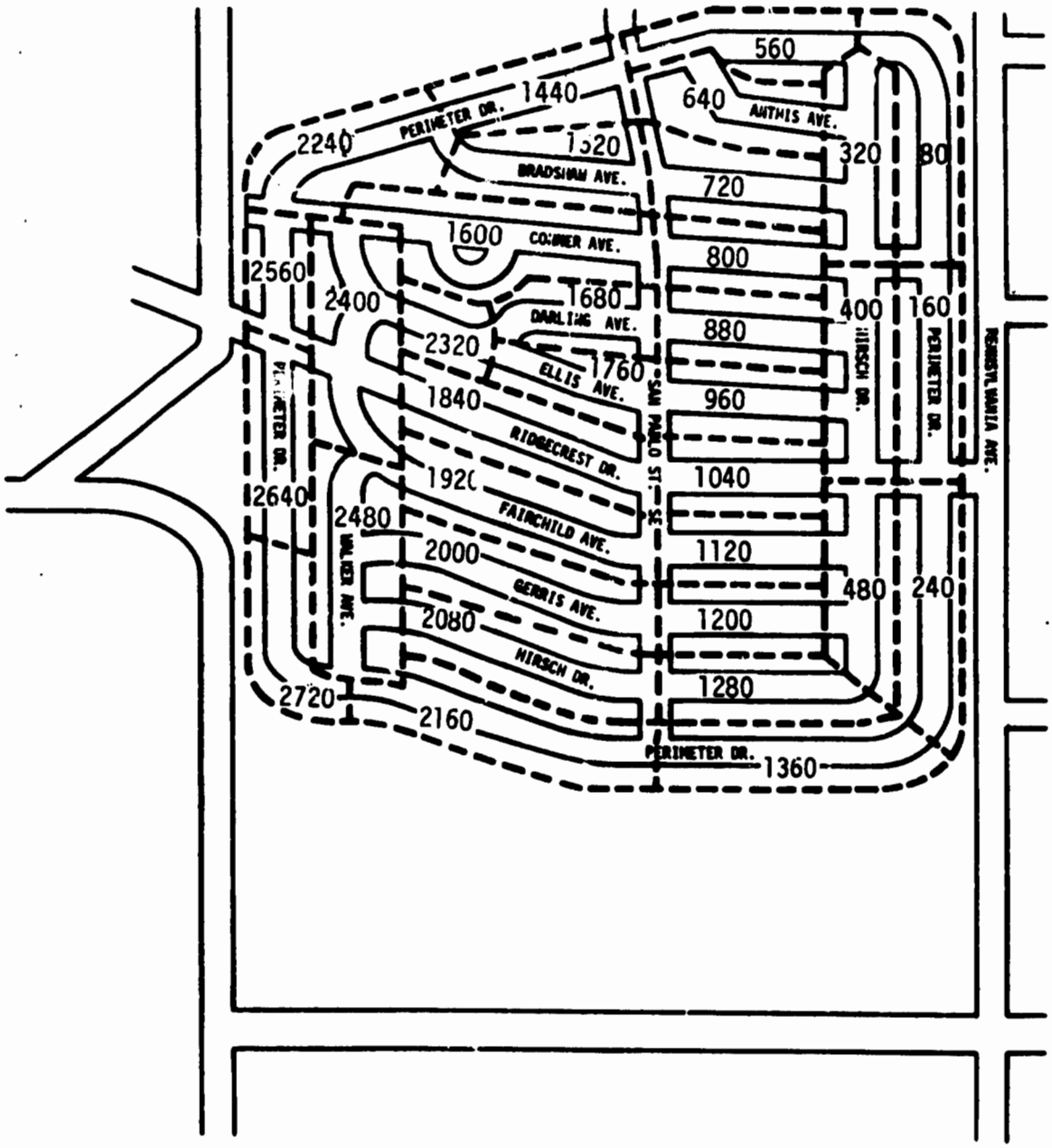
SECTION V
CONCLUSIONS AND RECOMMENDATIONS

The VSP is useful in refuse-collection vehicle scheduling. It removed one trip from Kirtland (East) refuse collection and reduced the mileage in the Carswell paper-collection route. On large problems, the main difficulty with the VSP is that it does not necessarily produce the minimum number of trips nor explicitly give the path for each trip. On small problems, like Carswell, the savings may not be worth the effort. Other lesser inadequacies will be present with any-size problem (e.g., there is no provision for one-way streets, and the same speed limit is used for travel both with and without refuse in the collection area). Once the traversal path has been determined, refuse-collection vehicle drivers can easily produce the route maps by inking the route on a street map, but considerable effort is required to produce report-quality maps for publication. The most important need is for a program which always produces the minimum number of trips and also indicates the path for traversing the route. It would also be desirable that the program draw the maps.

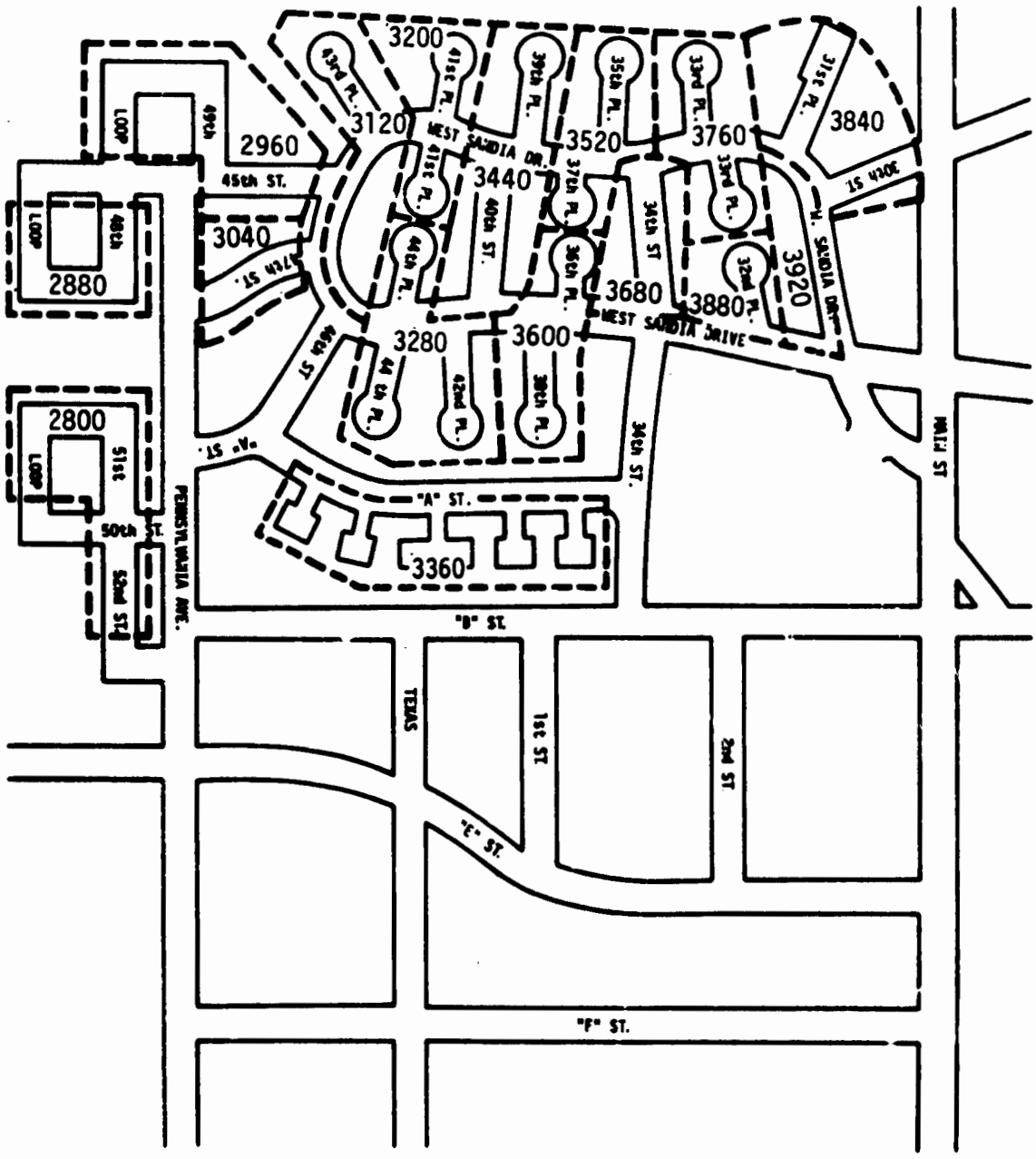
There are organizations which perform refuse-collection scheduling. The U.S. Army's Civil Engineering Research Laboratories in Champaign, Illinois, perform this service for $15,000 per base; commercial organizations may charge more. If more than about six bases are to be scheduled, it would be more cost effective to write a computer program specifically to perform Air Force base refuse-collection scheduling and run the program at an Air Force facility. This program should achieve the minimum number of trips and should utilize some distance-minimizing criteria in producing the actual path to be used; also, it should take one-way streets into account and produce maps.

APPENDIX A

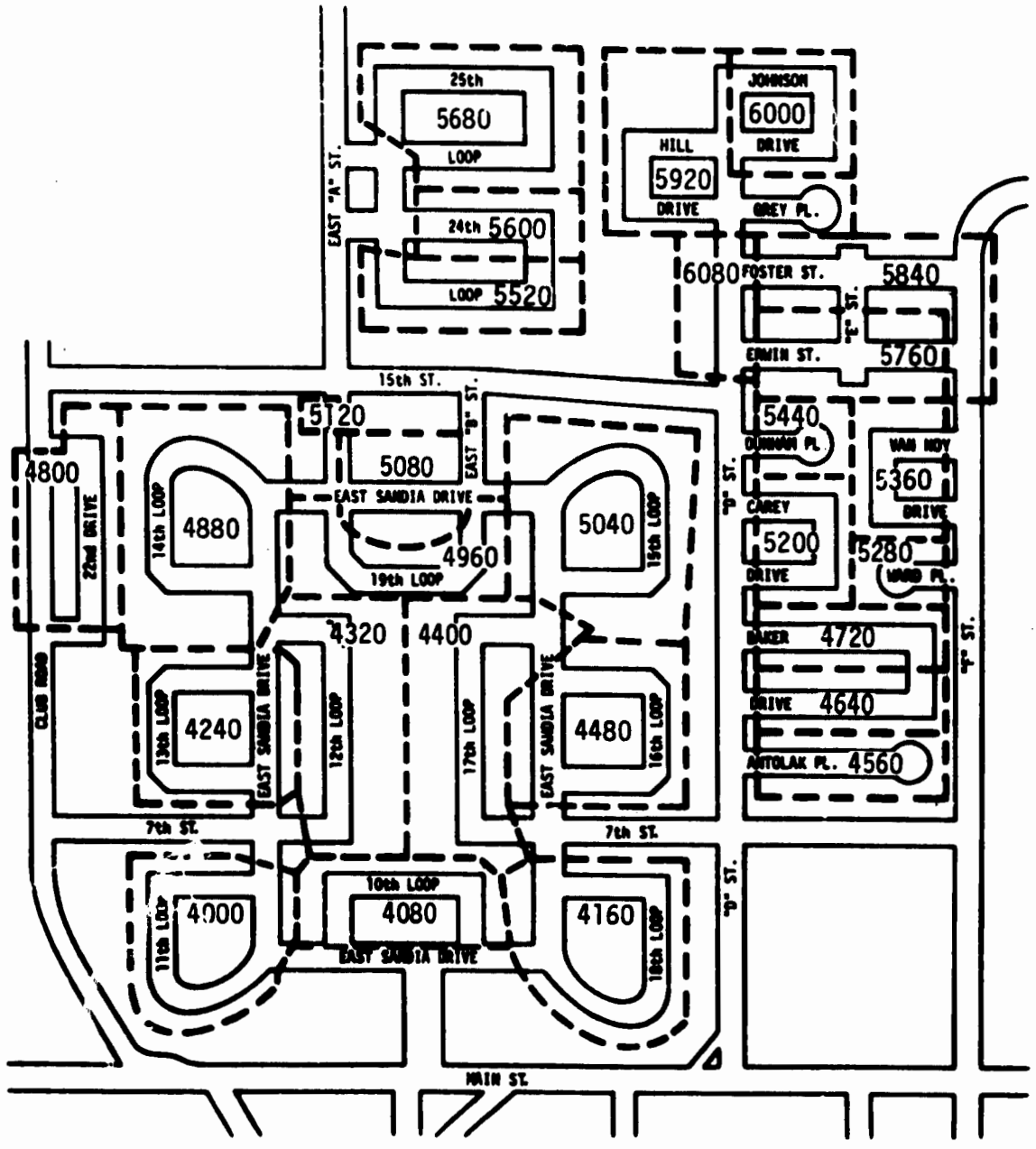
ZONE MAPS FOR KIRTLAND AIR FORCE BASE (EAST)



Kirtland Air Force Base (East) - Map 1



Kirtland Air Force Base (EAST) - Map 2



Kirtland Air Force Base (East) - Map 3

APPENDIX B

ADJUSTED SINGLE-TRIP ROUTE FOR CARSWELL AIR FORCE BASE

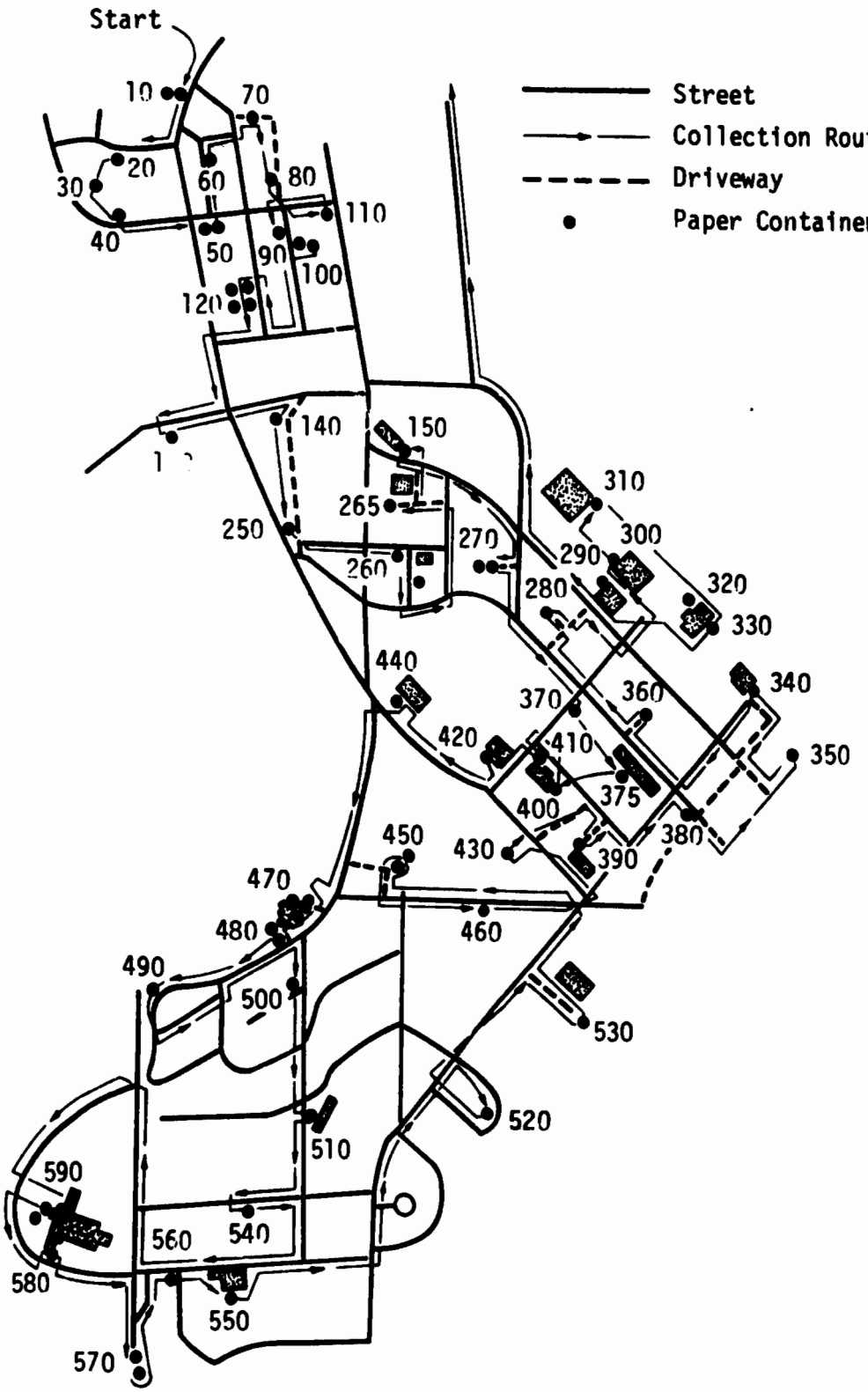
Base Civil Engineering Yard (Start)

10	470	310
20	480	320
30	490	330
40	500	160
50	510	170
60	540	220
70	590	200
80*	580	240
110*	570	230
90	560	180*
100	550	190*
120	520	660
130	530	650
140	450*	670
250	460*	690
260	430	700
265	390	680
150	380	640
270	350	610
370	340	600
375	360**	620
400	280	630
410	290	Unload
420	300	Base Civil Engineering Yard (Stop)
440		

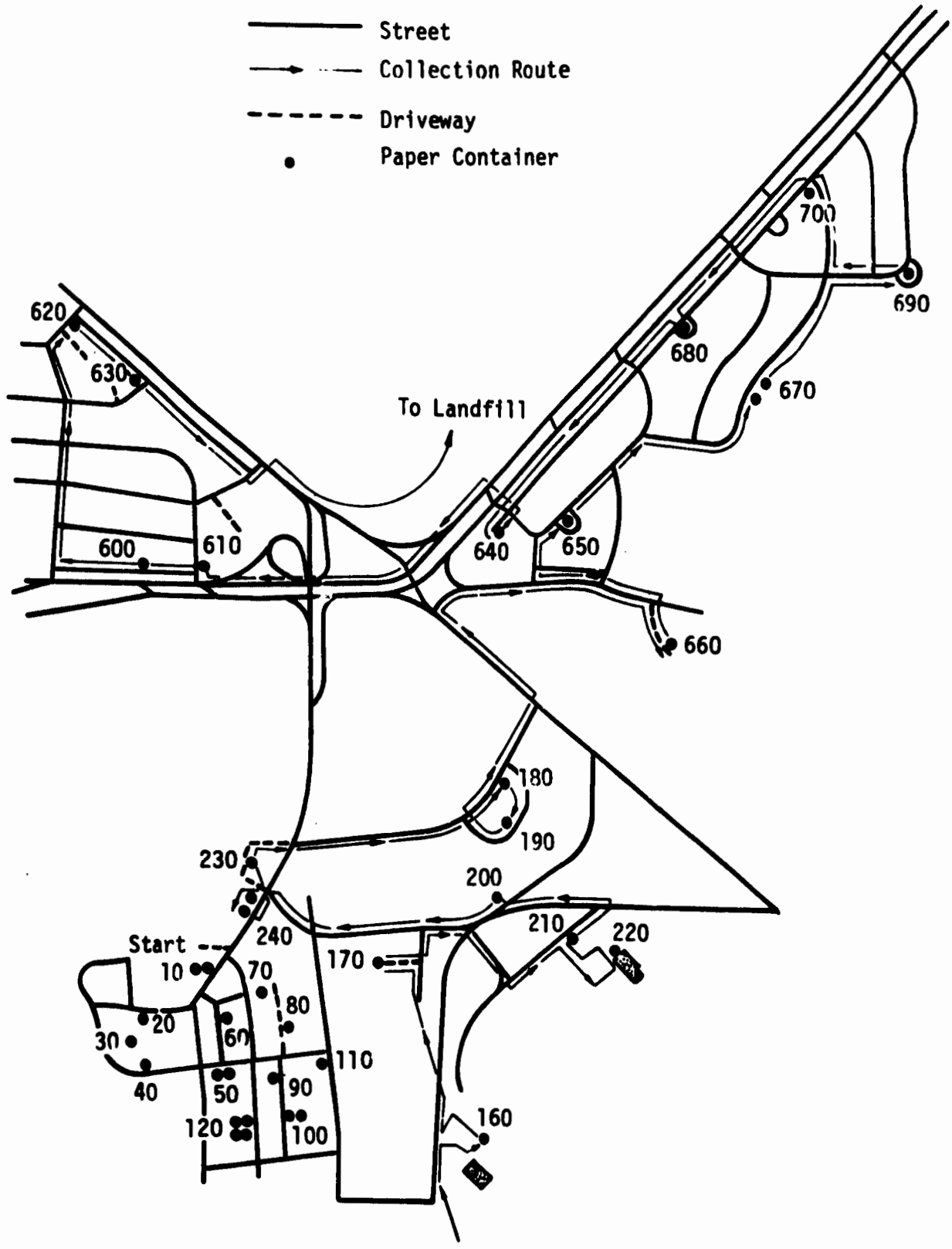
*Order differs from computer-generated route.

**First trip ends at zone 360 for the two-trip route.

ZONE NUMBERS IN ORDER OF COLLECTION



Start of Route


Street
Collection Route
Driveway
Paper Container
620
630
600
610
To Landfill
640
650
660
680
670
700
690
180
190
230
200
210
220
240
Start
10
70
170
80
20
60
30
110
40
50
90
120
100
160
End of Route

APPENDIX C

LINK WRITING PROGRAM

```
//JOBLIB   DD      DSN=DEY.LOAD,DISP=SHR,VOL=SER=CRFVSP,UNIT=2314
//COM      EXEC  LFORTGCG
//FORT.SYSIN  DD  *

C         LINK WRITING PROGRAM

      DIMENSION CARD(20), LEN(7), NODE(8)

C         COPY FIRST 3 CARDS
      DO 40  I=1,3
      READ (5,20) CARD
   20 FORMAT(20A4)
   40 WRITE (2,20) CARD

C         READ CONVERSION FACTOR TO CHANGE MAP UNITS TO 0.01 MILES.
C         DEFAULT VALUE IS 1.0 MAP UNIT (E.G., 1/16 INCH) PER 0.01 MILE.
      READ (5,60) CONV
   60 FORMAT(F10.3)
      IF (CONV .LE. 0.) CONV=1.
      J=2
      NN=0
  100 NN=NN+J
      READ (5,120,END=300) (NODE(I),LEN(I),I=1,7),NODE(8),ISPD
  120 FORMAT(16I5)
      DO 140 I=1,7
      LEN(I)=LEN(I)*CONV+0.5
      IF (LEN(I) .EQ. 0) LEN(I)=1
      IF (NODE(I+1) .LE. 0) GO TO 160
  140 J=I
  160 IF (ISPD .LE. 0) GO TO 240
C
      WRITE (2,220) (NODE(I),NODE(I+1),LEN(I),ISPD,I=1,J)
  220 FORMAT(     I5,2I7,I5)
      GO TO 100
  240 CONTINUE
      WRITE (2,260) (NODE(I),NODE(I+1),LEN(I),I=1,J)
  260 FORMAT(     I5,2I7)
      GO TO 100
  300 CONTINUE
      CALL EXIT
      END
/*
//GO.FT02F001  DD  DSN=&&LINKS,DISP=(,PASS),UNIT=SYSW,
//            SPACE=(1600,(200,50)),DCB=(BLKSIZE=1600,LRECL=80,RECFM=FB)
```

```
//GO.SYSIN  DD  *
TITLE  KAFB (EAST) REFUSE COLLECTION  --  80 ZONE VERSION
OPTIONS        1111
LINKS             5

00001  10410001    1910002    6410003    7010015    2210038    2010039    1910040    30
10001   7210042    3810041    1210040    1710045    1910044    1710039               30
10002   5310042    1710046    1700020    6710049    3510045    4910046               30
10049   1910048    3510044    1610043                                                 25
10038   1810043    3810047    1010048                                                 25
10003   0410005    0510008    12 1840    1110021    07 1040    0810033    0510037
10041   0410037    10  240    18 1360    1010025    11 2160    1110012
10011   11 2080    1110024    09 1280    0910035
10010   11 2000    1110023    07 1200    0810035
10009   11 1920    1010022    07 1120    0810034
10004   08 2240    0710013    07 1440    0710016    0510026    06  560    0710027
10026   07  640    0810028
10013   08 1520    0710017    07  720    0810029
10004   0510006    11 1600    1010018    07  800    0810030    0510036
10006   0610007    05 2320    0510014    06 1760    0610020    07  960    0810032
10014   07 1680    0610019    07  880    0810031
10007   03 2400    0210008    0610009    0710010    02 2480    0310011    0510012
10015   2310016                                                                     15
10016   0810017    0510018    0510019    0510020    0610021    0510022    0510023    10
10023   0510024    0510025                                                          10
10027   0510028    02  320    0310029    0510030    0210031    03  400    0510032
10032   0510033    0510034    03  480    0210035
10027   09   80    0910036    08  160    0710037
10004   04 2560    0510005    08 2640    13 2720    0610012
10038   0510257    0410057    0510056    0610055    1110054    0910053               25
10257   1410051    15 2800    1710056
10053   0410050    14 2880
10050   17 2960    0410052
10053   0310052    1010059    02 3120    0310060    06 3040    0610054
10060   0410061    1210058    0710055
10057   1710063    1410043                                                          25
10063   1510065    2110074    0510075    0510076    1010047                       25
10058   12 3360    1210065    0410068    0710069
```

```
10061   35 3280  1910062   20 3600  1310064  0410067  1410068
10064   1210065
10067   15 3880  1410071   0510073
10059   19 3200  30 3440   36 3520  1510066  14 3760  26 3840  0310070
10070   12 3920  0910071
10066   07 3680  0610067
 3440   1210062
10073   1710074                                                      25
10070   0810072
10079   0910073  1510072   2710084  1710085                          25
10084   1510284                                                      25
10284   11 4800  1110299
10299   28 5120  1110118   1910100                                   25
10090   0410065  15 4320   1510120  0410091  12 4240  1210090  0810091
10085   0410082  15 4000   1010077  0710082
10077   0610078  0610079   0610080  12 4080  1210078
10080   0610081  12 4160   1510093  0610081
10086   1010087  0510089   1910089                                   25
10075   1910087                                                      25
10092   0610093
10093   0410086  15 4400   1510122  0510093  12 4480  1210092  0410086
10122   0410096  13 5040   1410097  0610096
10120   0410098  13 4880   1410099  0610098
10099   0510094  06 5080   0610095  0610097
10118   0910095  11 4960   1110094  09 5120
 5120   1410112  0910114                                           25
10112   0410116                                                   25
10116   14 5520  13 5600   0810116
10114   17 5680
10076   1910088                                                   25
10114   0510116
10088   20 4560  32 4640   13 4720  27 5200  25 5440  1210100   310102
10048   1910089  1910124
10124   06 5280
10124   15 5360  1810126   06 5760  1410102  04 6080  0310104
10126   12 5840  1410104   0610106  27 5920  0710108  13 6000
10106   0510108
/*
```

APPENDIX E

CONTROL CARDS FOR NETWORK-ANALYSIS AND SAVINGS-SORT PROGRAMS

```
//NATO      EXEC    PGM=DEY10,REGION=60K
//DEY1PTS   DD      UNIT=SYSW,SPACE=(CYL,(1,1))
//DEY1ULK   DD      UNIT=SYSW,SPACE=(CYL,(1,1))
//DEY1SLK   DD      UNIT=SYSW,SPACE=(CYL,(1,1))
//DEY1TD1   DD      UNIT=SYSW,SPACE=(CYL,(4,1))
//DEY1TD2   DD      UNIT=SYSW,SPACE=(CYL,(4,1))
//DEYDIST   DD      UNIT=SYSW,SPACE=(CYL,(4,1)),DISP=(,PASS),DSN=&&DIST
//DEYSAVG   DD VOL=SER=CRFVSP,UNIT=2314,SPACE=(CYL,(10,1)),DISP=(,PASS),
//          DSN=SAV80
//SYSPRINT DD SYSOUT=A,DCB=BLKSIZE=121
//SYSIN   DD   DSN=&&LINKS,DISP=(OLD,DELETE)
```

```
//SSORT     EXEC    PGM=DEYSORT,REGION=36K
//DEYSAVG   DD  DSN=SAV80,DISP=(OLD,PASS)
//DEYSORIN  DD      UNIT=SYSW,SPACE=(CYL,(10,1))
//SYSPRINT  DD      SYSOUT=A
```

APPENDIX F

DELIVERY CARD WRITING PROGRAM

```
C
C
      DIMENSION CARD(20), IN(10), IZ(10)
      DATA QUIT/'DELC'/
C
C        READ TIME PER STOP (MINUTES)
      READ (5,10) TPS
   10 FORMAT(F10.6)
C
      DO 40 I=1,10
      READ(5,20) CARD
   20 FORMAT(20A4)
      IF (CARD(1) .EQ. QUIT)GO TO 100
      WRITE(1,20) CARD
   40 CONTINUE
      PRINT 60
   60 FORMAT('1NO *DELCARDS* ON FIRST 10 CARDS')
      CALL EXIT
  100 CONTINUE
  120 READ (5,140,END=240) (IZ(I),IN(I),I=1,10)
  140 FORMAT(10(I5,I3))
         DO 200 I=1,10
         NN=IN(I)
         IF (NN .LE. 0) GO TO 240
         ITIM=NN*TPS+0.5
         WRITE (1,180) IZ(I),NN,ITIM
  180    FORMAT(1HD,I5,I5,5X,2H13,42X,I3)
  200    CONTINUE
      GO TO 120
  240 ENDFILE 1
      REWIND 1
      CALL EXIT
      END
```

APPENDIX G

SCHEDULE FOR KIRTLAND AIR FORCE BASE (EAST)

****
* *
* ROUTE NUMBER 1 *
* *
****

ZONE NUMBER	CUSTOMER NUMBER	QUANTITY	STOP TIME HRS	STOP TIME MINS	ARRIVAL TIME RANGE DAY	ARRIVAL TIME RANGE HOUR	DAY	HOUR
4800	12	156	0	06	1	8.09	1	8.09
5680	23	299	0	12	1	8.19	1	8.19
5520	16	209	0	08	1	8.34	1	8.34
5600	13	169	0	07	1	8.44	1	8.44
5120	1	13	0	01	1	8.52	1	8.52
5760	22	286	0	11	1	8.56	1	8.56
5840	23	299	0	12	1	9.09	1	9.09
5920	14	182	0	07	1	9.25	1	9.25
6000	18	234	0	09	1	9.34	1	9.34
6080	5	65	0	03	1	9.46	1	9.46
5440	8	104	0	04	1	9.52	1	9.52
5200	16	208	0	08	1	9.59	1	9.59
4720	17	221	0	09	1	10.10	1	10.10
4640	14	182	0	07	1	10.20	1	10.20

ROUTE SUMMARY

ASSIGNED VEHICLE TYPE = 10

	DAY	HOUR
EARLIEST START =	1	8.00
LATEST START =	1	8.00

VEHICLE CAPACITY = 2700

ASSIGNED TOTAL LOAD = 2626

ONE VEHICLE COVERS ROUTES 1, 2

NUMBER OF CALLS = 14

MILEAGE = 118.8 MILES

	HRS	MINS
TRAVEL TIME =	0	55
ROUTE TIME =	2	39
LOADING TIME =	0	05

****
* ROUTE NUMBER 2 *
****

ZONE NUMBER	CUSTOMER NUMBER	QUANTITY	STOP TIME HRS	STOP TIME MINS	ARRIVAL TIME RANGE DAY HOUR	DAY HOUR
960	21	273	0	11	1 10.50	1 10.51
1760	17	221	0	09	1 11.03	1 11.04
1680	16	208	0	08	1 11.14	1 11.15
880	20	260	0	10	1 11.24	1 11.25
800	21	273	0	11	1 11.36	1 11.37
720	23	299	0	12	1 11.49	1 11.50
320	17	221	0	09	1 12.02	1 12.03
640	23	299	0	12	1 12.13	1 12.14
560	20	260	0	10	1 12.26	1 12.27
80	27	351	0	14	1 12.38	1 12.39

ROUTE SUMMARY

ASSIGNED VEHICLE TYPE = 10

	DAY	HOUR
EARLIEST START =	1	10.44
LATEST START =	1	10.45

VEHICLE CAPACITY = 2700

ASSIGNED TOTAL LOAD = 2665

ONE VEHICLE COVERS ROUTES 1. 2

NUMBER OF CALLS = 10

MILEAGE = 60.5 MILES

	HRS	MINS
TRAVEL TIME =	0	29
ROUTE TIME =	2	15
LOADING TIME =	0	05

****
* ROUTE NUMBER 3 *
****

ZONE NUMBER	CUSTOMER NUMBER	QUANTITY	STOP TIME HRS	STOP TIME MINS	ARRIVAL TIME RANGE DAY	HOUR	DAY	HOUR
4080	22	286	0	11	1	8.08	1	8.18
4000	27	351	0	14	1	8.23	1	8.33
4320	20	260	0	10	1	8.41	1	8.51
4240	25	325	0	13	1	8.55	1	9.05
4880	26	338	0	13	1	9.12	1	9.22
4960	18	234	0	09	1	9.29	1	9.39
5080	7	91	0	04	1	9.41	1	9.51
5040	26	338	0	13	1	9.48	1	9.58
4400	21	273	0	11	1	10.05	1	10.15

ROUTE SUMMARY

ASSIGNED VEHICLE TYPE = 10

	DAY	HOUR
EARLIEST START =	1	8.00
LATEST START =	1	8.10

VEHICLE CAPACITY = 2700

ASSIGNED TOTAL LOAD = 2496

ONE VEHICLE COVERS ROUTES 3, 4

NUMBER OF CALLS = 9

MILEAGE = 96.7 MILES

	HRS	MINS
TRAVEL TIME =	0	46
ROUTE TIME =	2	24
LOADING TIME =	0	05

****
* ROUTE NUMBER 4 *
****

ZONE NUMBER	CUSTOMER NUMBER	QUANTITY	STOP TIME HRS	STOP TIME MINS	ARRIVAL TIME RANGE DAY HOUR	DAY HOUR
2720	12	156	0	06	1 10.45	1 10.55
2640	23	299	0	12	1 10.53	1 11.03
1840	3	416	0	16	1 11.07	1 11.17
1920	32	416	0	16	1 11.26	1 11.36
1040	21	273	0	11	1 11.44	1 11.54
400	16	208	0	08	1 11.57	1 12.07
480	17	221	0	09	1 12.07	1 12.17
160	22	286	0	11	1 12.18	1 12.28
240	27	351	0	14	1 12.30	1 12.40

ROUTE SUMMARY

ASSIGNED VEHICLE TYPE = 10

	DAY	HOUR
EARLIEST START =	1	10.39
LATEST START =	1	10.49

VEHICLE CAPACITY = 2700

ASSIGNED TOTAL LOAD = 2626

ONE VEHICLE COVERS ROUTES 3, 4

NUMBER OF CALLS = 9

MILEAGE = 59.9 MILES

	HRS	MINS
TRAVEL TIME =	0	28
ROUTE TIME =	2	11
LOADING TIME =	0	05

****
* ROUTE NUMBER 5 *
****

ZONE NUMBER	CUSTOMER NUMBER	QUANTITY	STOP TIME HRS	STOP TIME MINS	ARRIVAL TIME RANGE DAY	ARRIVAL TIME RANGE HOUR	DAY	HOUR
1120	20	260	0	10	1	8.06	1	8.27
1360	28	364	0	14	1	8.19	1	8.40
2160	31	403	0	16	1	8.36	1	8.57
2080	31	403	0	16	1	8.54	1	9.15
1280	21	273	0	11	1	9.12	1	9.33
1200	20	260	0	10	1	9.25	1	9.46
2000	31	403	0	16	1	9.37	1	9.58
2480	18	234	0	09	1	9.54	1	10.15

ROUTE SUMMARY

ASSIGNED VEHICLE TYPE = 10

	DAY	HOUR
EARLIEST START =	1	8.00
LATEST START =	1	8.21

VEHICLE CAPACITY = 2700

ASSIGNED TOTAL LOAD = 2600

ONE VEHICLE COVERS ROUTES 5, 6

NUMBER OF CALLS = 8

MILEAGE = 59.5 MILES

	HRS	MINS
TRAVEL TIME =	0	27
ROUTE TIME =	2	09
LOADING TIME =	0	05

****
* ROUTE NUMBER 6 *
****

ZONE NUMBER	CUSTOMER NUMBER	QUANTITY	STOP TIME HRS	STOP TIME MINS	ARRIVAL TIME RANGE DAY HOUR	DAY HOUR
3360	10	130	0	05	1 10.42	1 11.03
3600	16	208	0	08	1 10.52	1 11.13
3280	20	330	0	13	1 11.04	1 11.25
3440	25	325	0	13	1 11.20	1 11.41
3520	17	221	0	09	1 11.37	1 11.58
3760	15	195	0	08	1 11.50	1 12.11
3680	13	169	0	07	1 12.01	1 12.22
3880	8	104	0	04	1 12.10	1 12.31
3920	9	117	0	05	1 12.17	1 12.38
3840	13	169	0	07	1 12.24	1 12.45

ROUTE SUMMARY

ASSIGNED VEHICLE TYPE = 10

	DAY	HOUR
EARLIEST START =	1	10.35
LATEST START =	1	10.56

VEHICLE CAPACITY = 2700

ASSIGNED TOTAL LOAD = 1976

ONE VEHICLE COVERS ROUTES 5, 6

NUMBER OF CALLS = 10

MILEAGE = 92.5 MILES

	HRS	MINS
TRAVEL TIME =	0	45
ROUTE TIME =	2	04
LOADING TIME =	0	05

****
* ROUTE NUMBER 7 *
****

ZONE NUMBER	CUSTOMER NUMBER	QUANTITY	STOP TIME HRS	STOP TIME MINS	ARRIVAL TIME RANGE DAY HOUR	DAY HOUR
2560	14	182	0	07	1 8.04	1 8.12
2240	24	312	0	12	1 8.13	1 8.21
1440	19	247	0	10	1 8.27	1 8.35
1520	23	299	0	12	1 8.40	1 8.48
1600	32	416	0	16	1 8.54	1 9.02
2320	14	182	0	07	1 9.12	1 9.20
2400	18	234	0	09	1 9.20	1 9.28

ROUTE SUMMARY

ASSIGNED VEHICLE TYPE = 10

	DAY	HOUR
EARLIEST START =	1	8.00
LATEST START =	1	8.08

VEHICLE CAPACITY = 2700

ASSIGNED TOTAL LOAD = 1872

ONE VEHICLE COVERS ROUTES 7, 8, 9

NUMBER OF CALLS = 7

MILEAGE = 48.7 MILES

	HRS	MINS
TRAVEL TIME =	0	21
ROUTE TIME =	1	34
LOADING TIME =	0	05

****
* ROUTE NUMBER 8 *
****

ZONE NUMBER	CUSTOMER NUMBER	QUANTITY	STOP TIME HRS	STOP TIME MINS	ARRIVAL TIME RANGE DAY HOUR	DAY HOUR
3040	14	182	0	07	1 9.53	1 10.00
3120	18	234	0	09	1 10.01	1 10.08
3200	17	221	0	09	1 10.12	1 10.19
2960	29	377	0	15	1 10.24	1 10.31
2880	22	286	0	11	1 10.42	1 10.49
2800	28	364	0	14	1 10.58	1 11.05

ROUTE SUMMARY

ASSIGNED VEHICLE TYPE = 10

	DAY	HOUR
EARLIEST START =	1	9.47
LATEST START =	1	9.54

VEHICLE CAPACITY = 2700

ASSIGNED TOTAL LOAD = 1664

ONE VEHICLE COVERS ROUTES 7, 8, 9

NUMBER OF CALLS = 6

MILEAGE = 74.7 MILES

	HRS	MINS
TRAVEL TIME =	0	27
ROUTE TIME =	1	32
LOADING TIME =	0	05

****
*
* ROUTE NUMBER 9 *
*
****

ZONE NUMBER	CUSTOMER NUMBER	QUANTITY	STOP TIME HRS	STOP TIME MINS	ARRIVAL TIME RANGE DAY HOUR	DAY HOUR
4560	16	208	0	08	1 11.39	1 11.47
4160	28	364	0	14	1 11.52	1 12.00
4480	24	312	0	12	1 12.10	1 12.18
5280	7	91	0	04	1 12.28	1 12.36
5360	13	169	0	07	1 12.34	1 12.42

ROUTE SUMMARY

ASSIGNED VEHICLE TYPE = 10

	DAY	HOUR
EARLIEST START =	1	11.31
LATEST START =	1	11.39

VEHICLE CAPACITY = 2700

ASSIGNED TOTAL LOAD = 1144

ONE VEHICLE COVERS ROUTES 7, 8, 9

NUMBER OF CALLS = 5

MILEAGE = 92.8 MILES

	HRS	MINS
TRAVEL TIME =	0	36
ROUTE TIME =	1	21
LOADING TIME =	0	08

****
*
* FLEET UTILIZATION SUMMARY
*
****

VEHICLE TYPE	CAP.	MAX.VEH.TIME HRS	MINS	NO. OF VEHICLES
10	2700	3	00	4

TOTAL FLEET CAPACITY
10800

) INDICATES MULTIPLE TRIPS FOR ONE VEHICLE

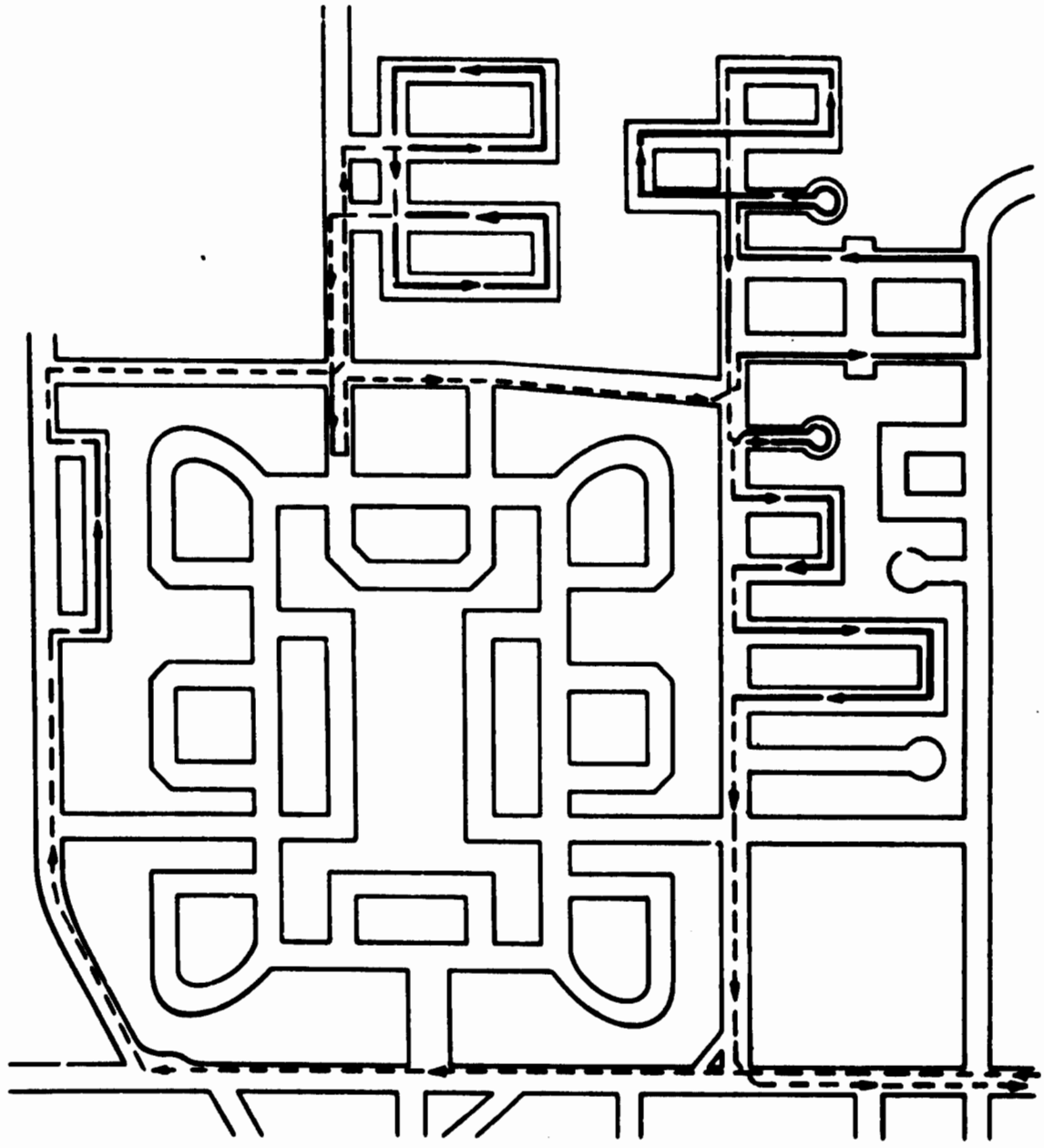
ROUTE NUMBER	IND.	ASSIGNED TOT.LOAD	MILEAGE MILES	TRAVEL TIME HRS	MINS	ROUTE TIME HRS	MINS	NO.OF CALLS
1))		2626	118.8	0	55	2	39	14
2)		2665	60.5	0	29	2	15	10
3))		2496	96.7	0	46	2	24	9
4)		2626	59.9	0	28	2	11	9
5))		2600	59.5	0	27	2	9	8
6)		1976	92.5	0	45	2	4	10
7))		1872	48.7	0	21	1	34	7
8))		1664	74.7	0	27	1	32	6
9)		1144	92.8	0	36	1	31	5
TOTALS		19669	704.1	5	14	18	9	78

APPENDIX H

MAPS OF PROGRAM-GENERATED ROUTES FOR KIRTLAND AIR FORCE BASE (EAST)

———Refuse Collection

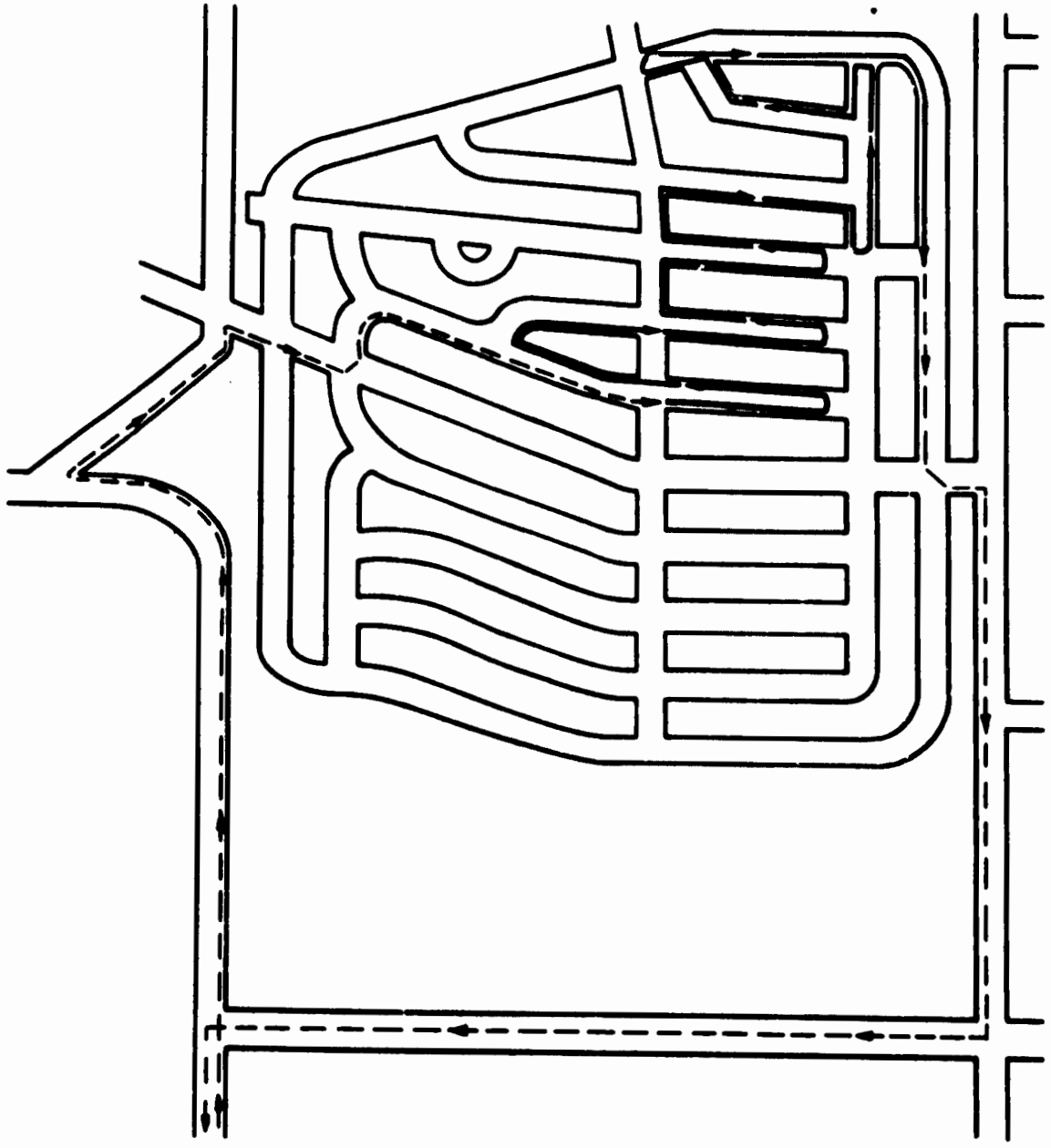
– – – –Travel Without Collection



Truck 1, Trip 1

——— Refuse Collection

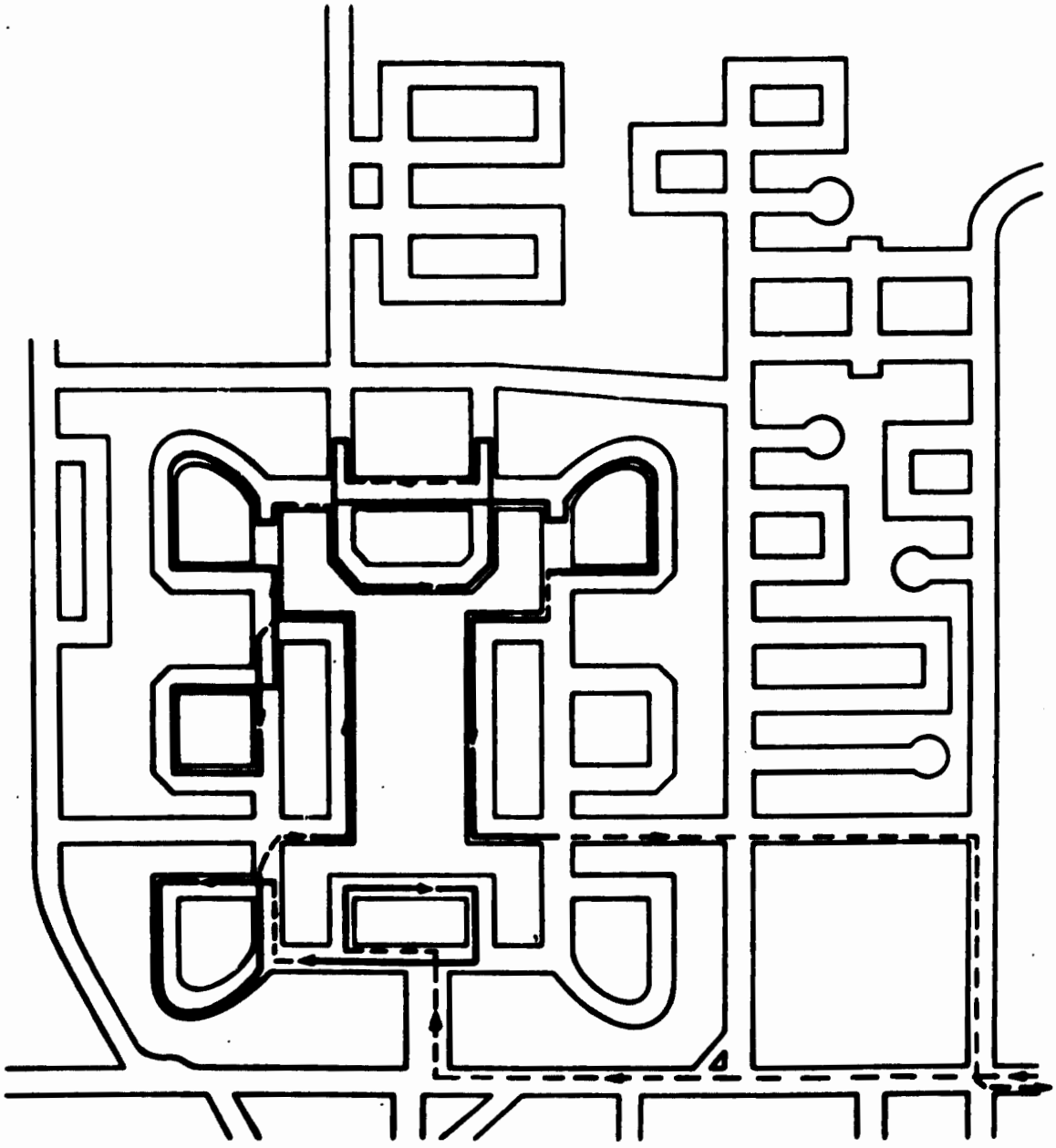
– – – – Travel Without Collection



Truck 1, Trip 2

———Refuse Collection

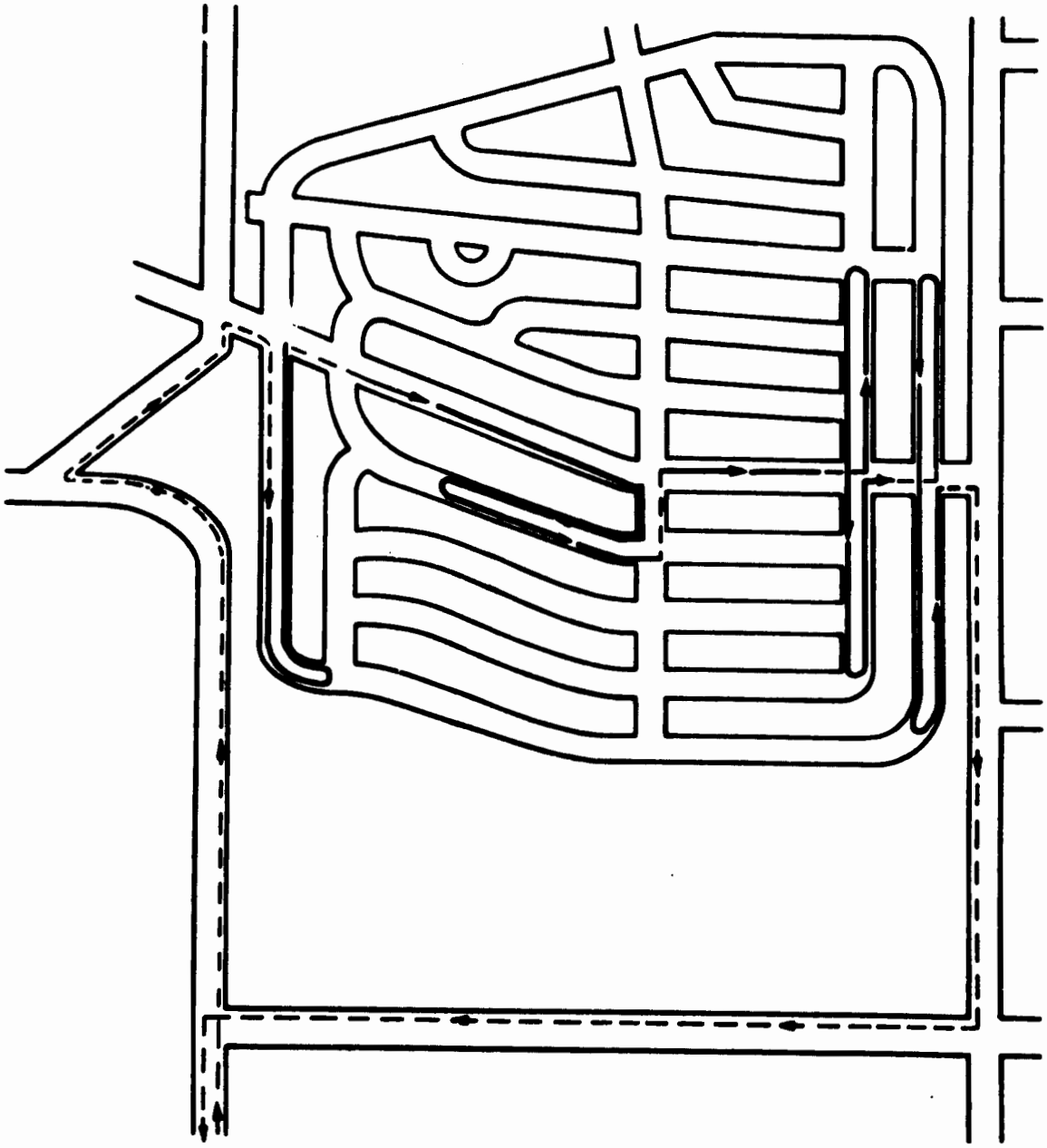
- - - -Travel Without Collection



Truck 2, Trip 1

——— Refuse Collection

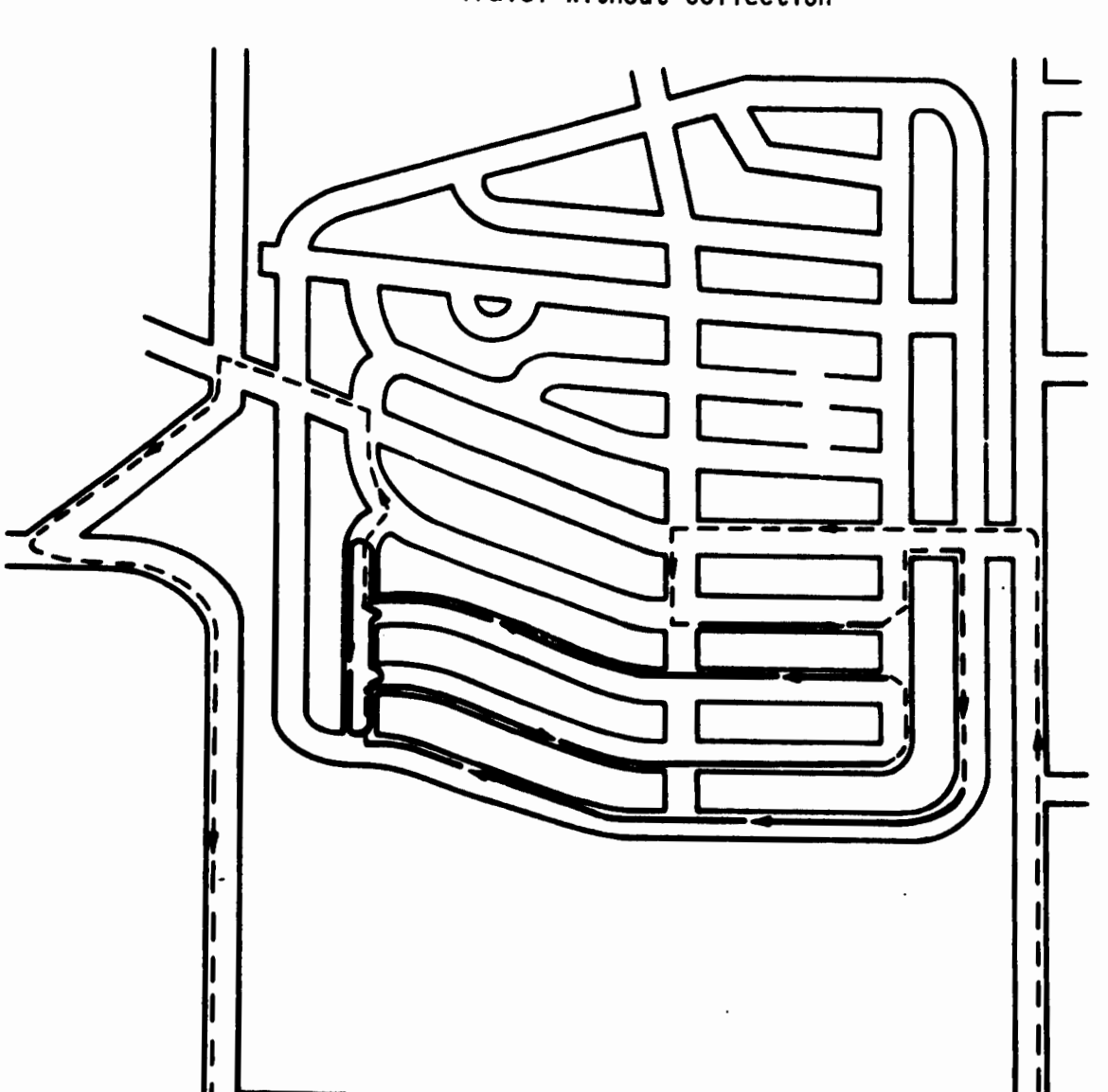
– – – – Travel Without Collection



Truck 2, Trip 2

——— Refuse Collection

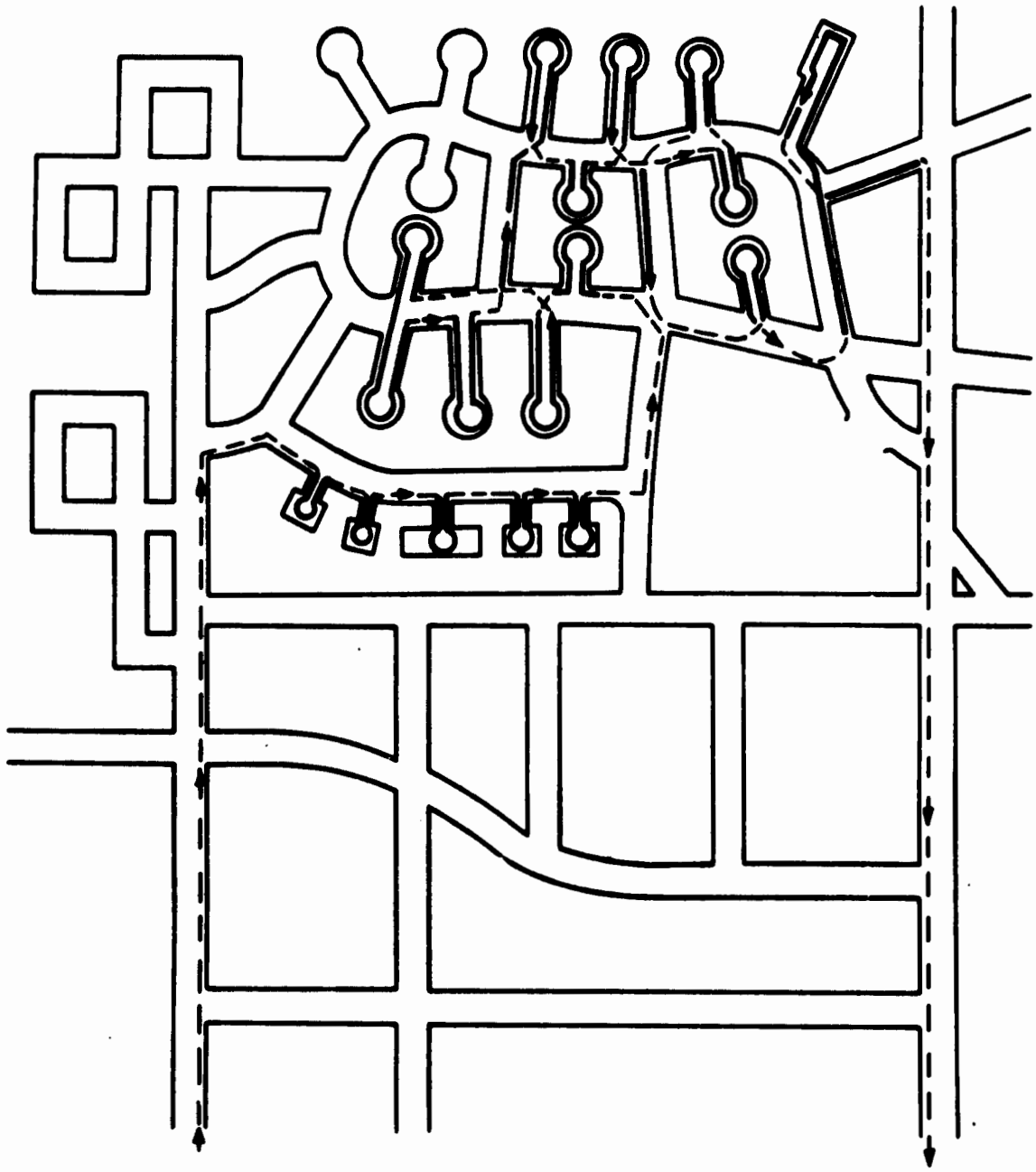
- - - - Travel Without Collection



Truck 3, Trip 1

——— Refuse Collection

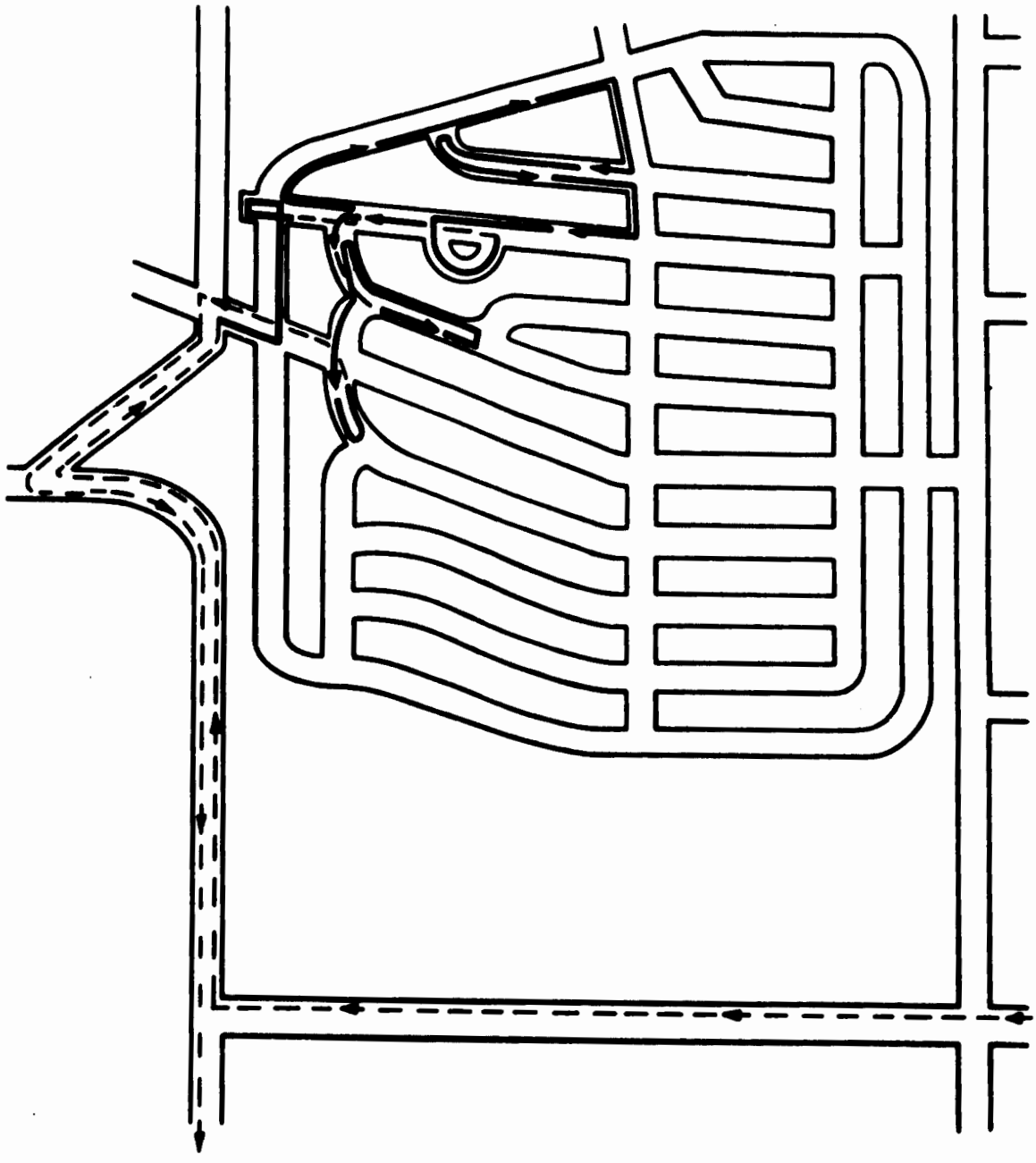
- - - - Travel Without Collection



Truck 3, Trip 2

———Refuse Collection

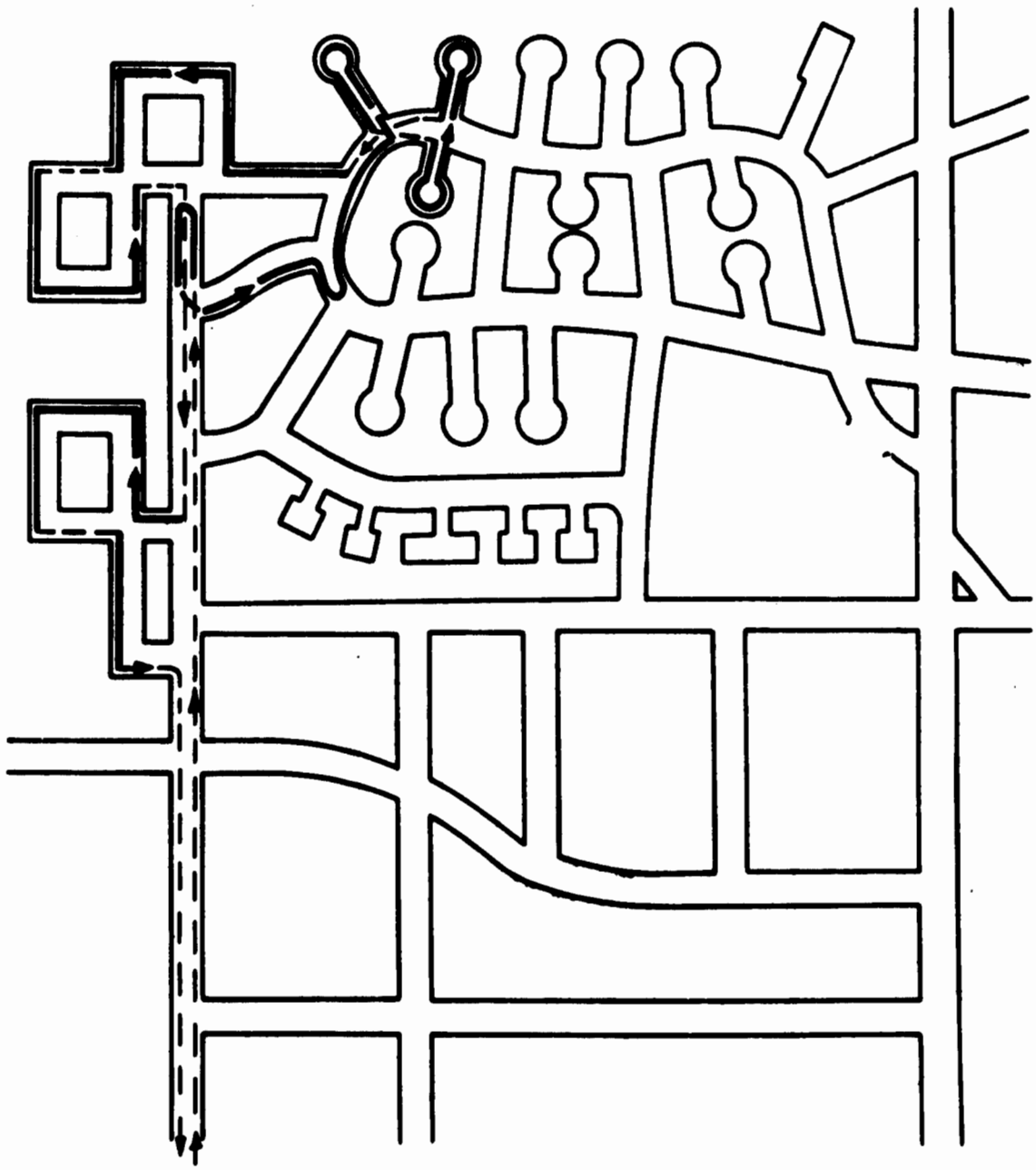
- - - -Travel Without Collection



Truck 4, Trip 1

———Refuse Collection

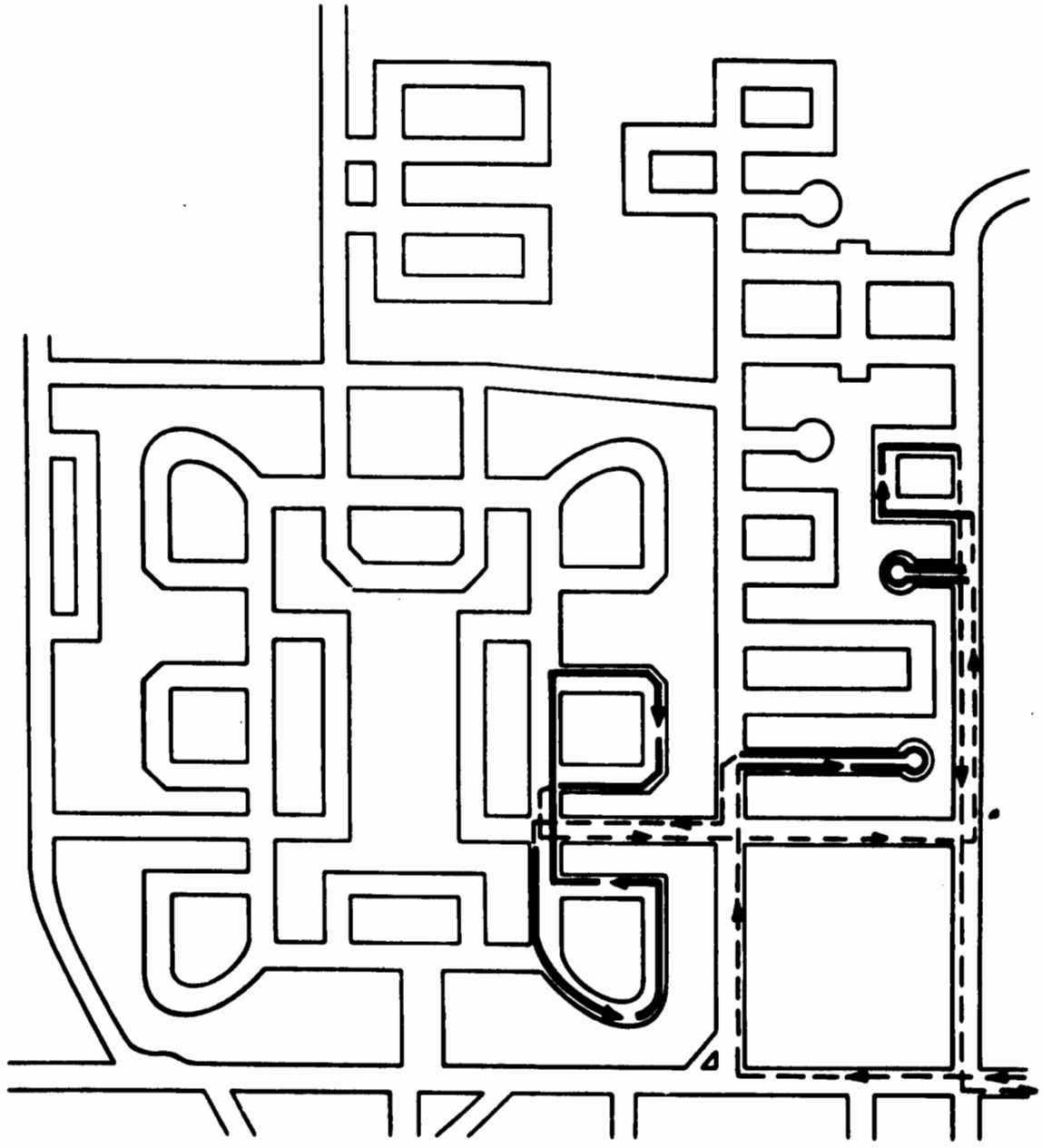
- - - -Travel Without Collection



Truck 4, Trip 2

———Refuse Collection

– – – –Travel Without Collection



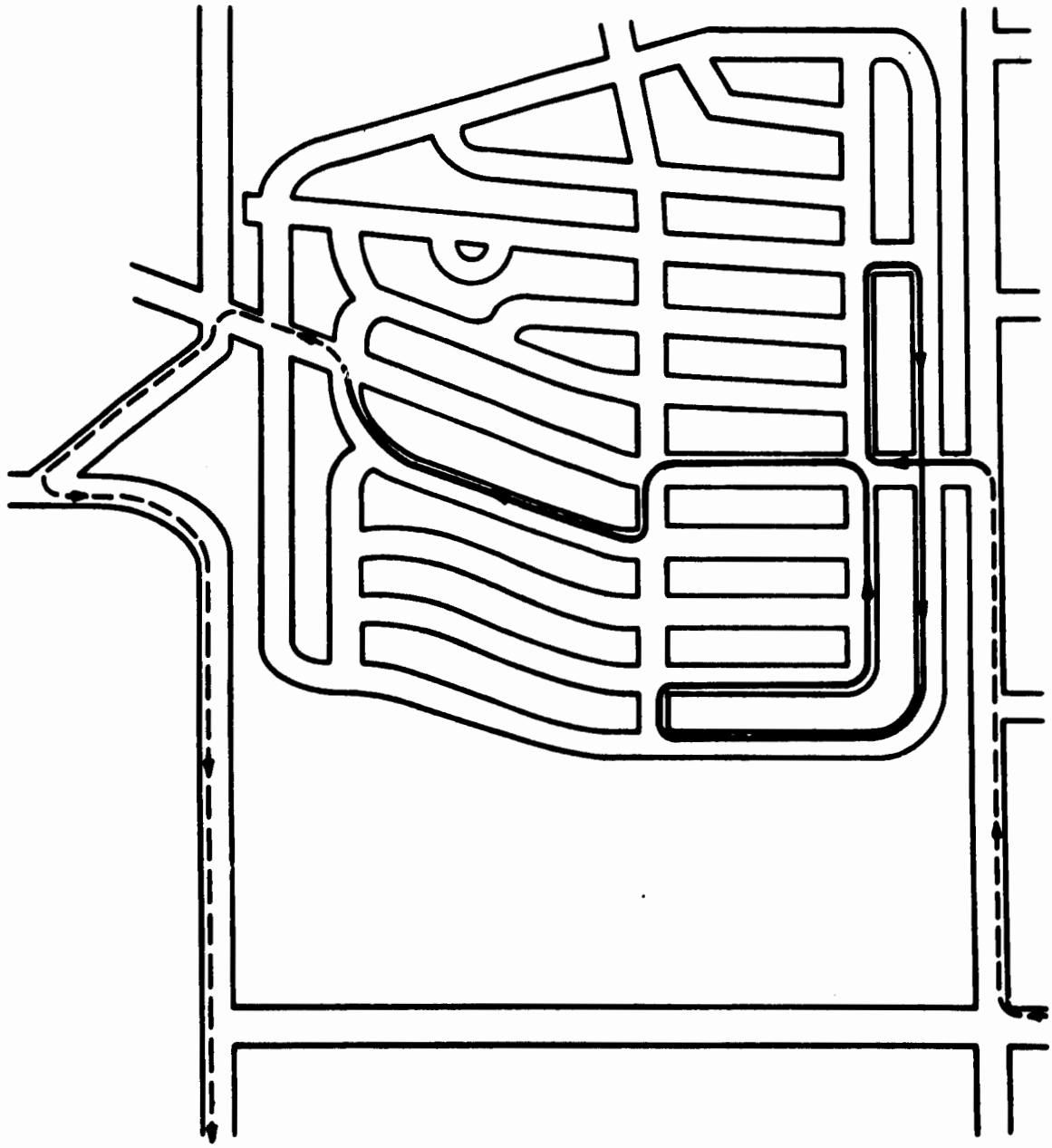
Truck 4, Trip 3

APPENDIX I

HAND-ADJUSTED ROUTE MAPS FOR KIRTLAND AIR FORCE BASE (EAST)

———Refuse Collection

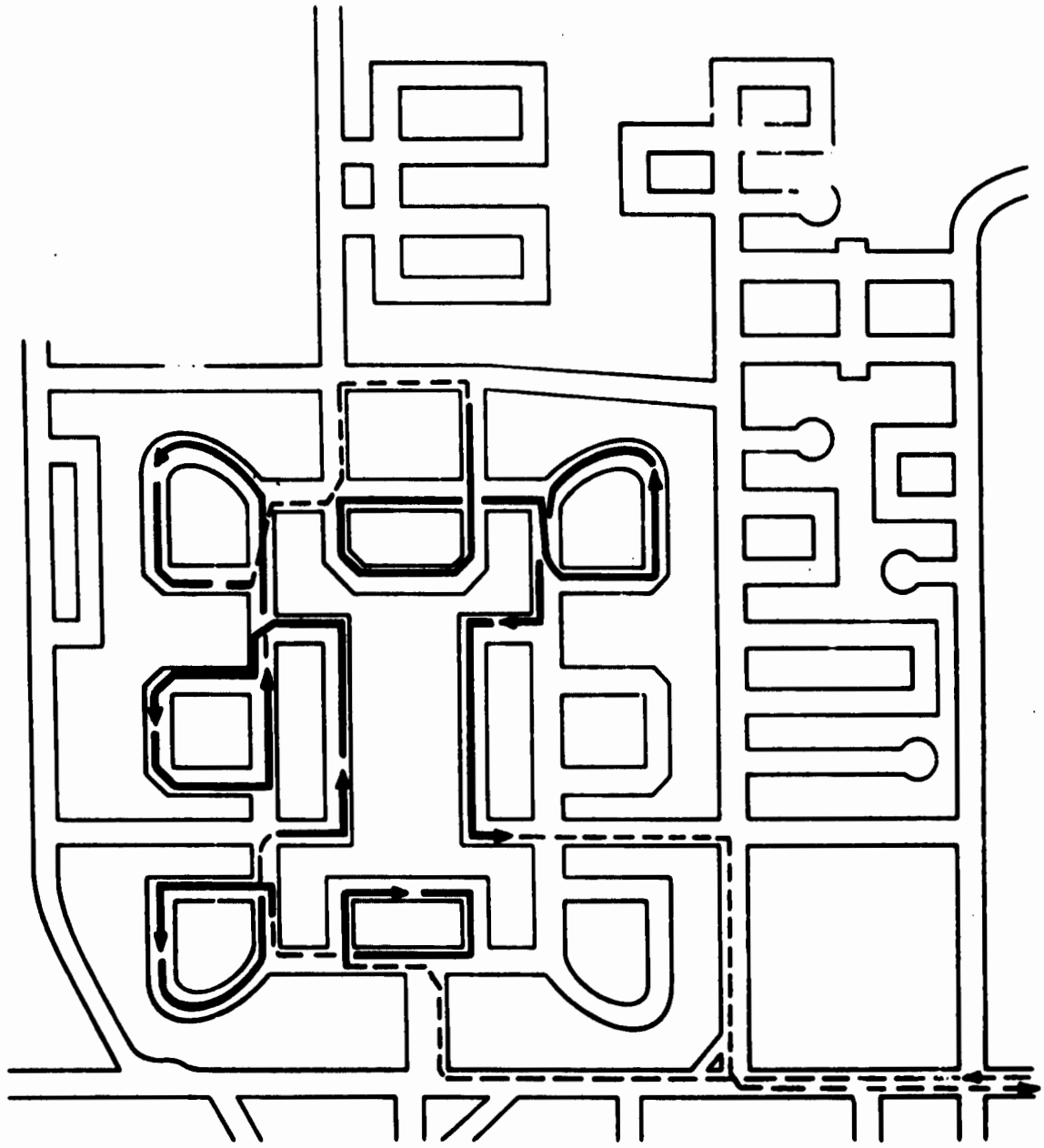
- - - -Travel Without Collection



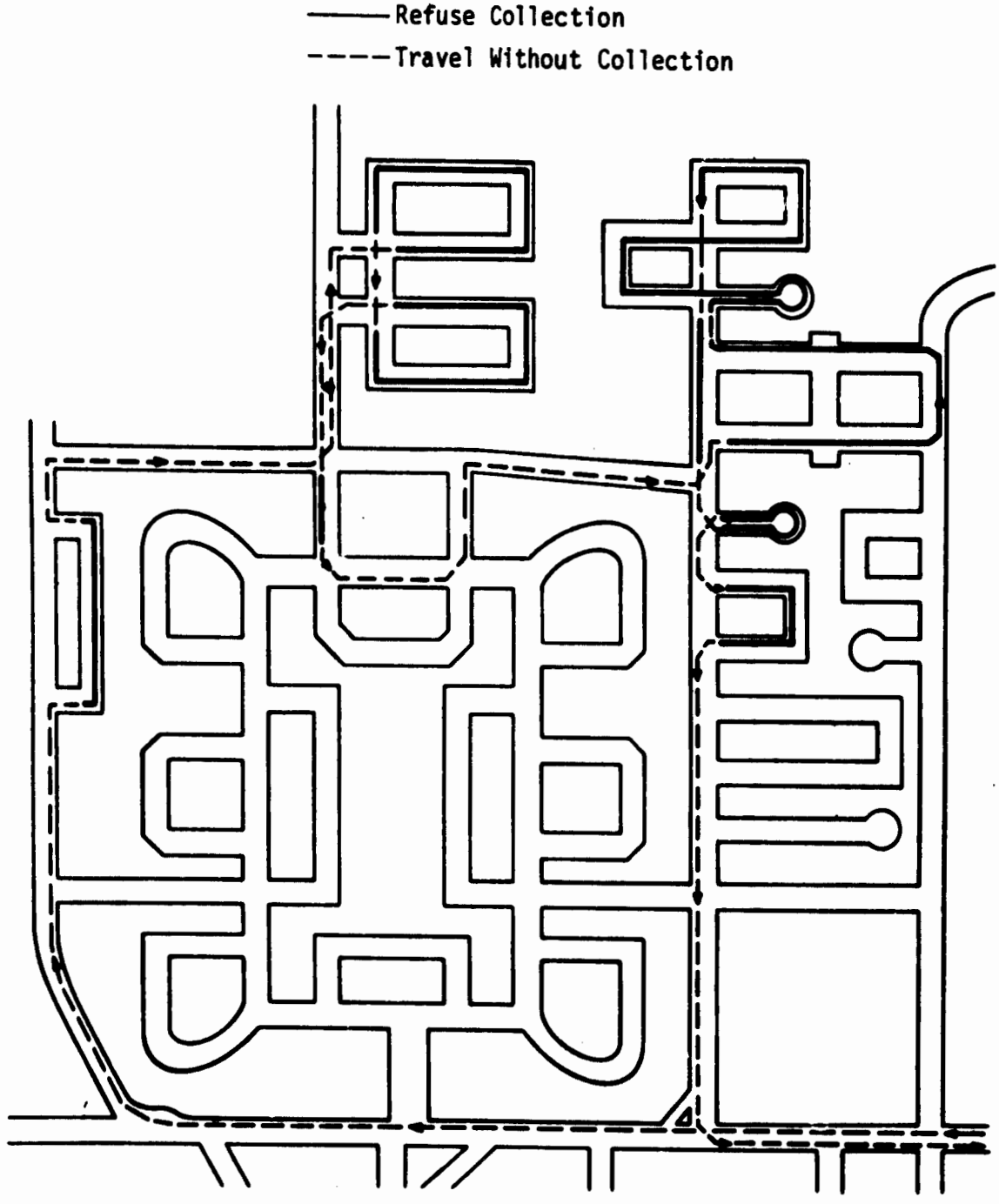
Truck 1, Trip 1

———Refuse Collection

– – – –Travel Without Collection



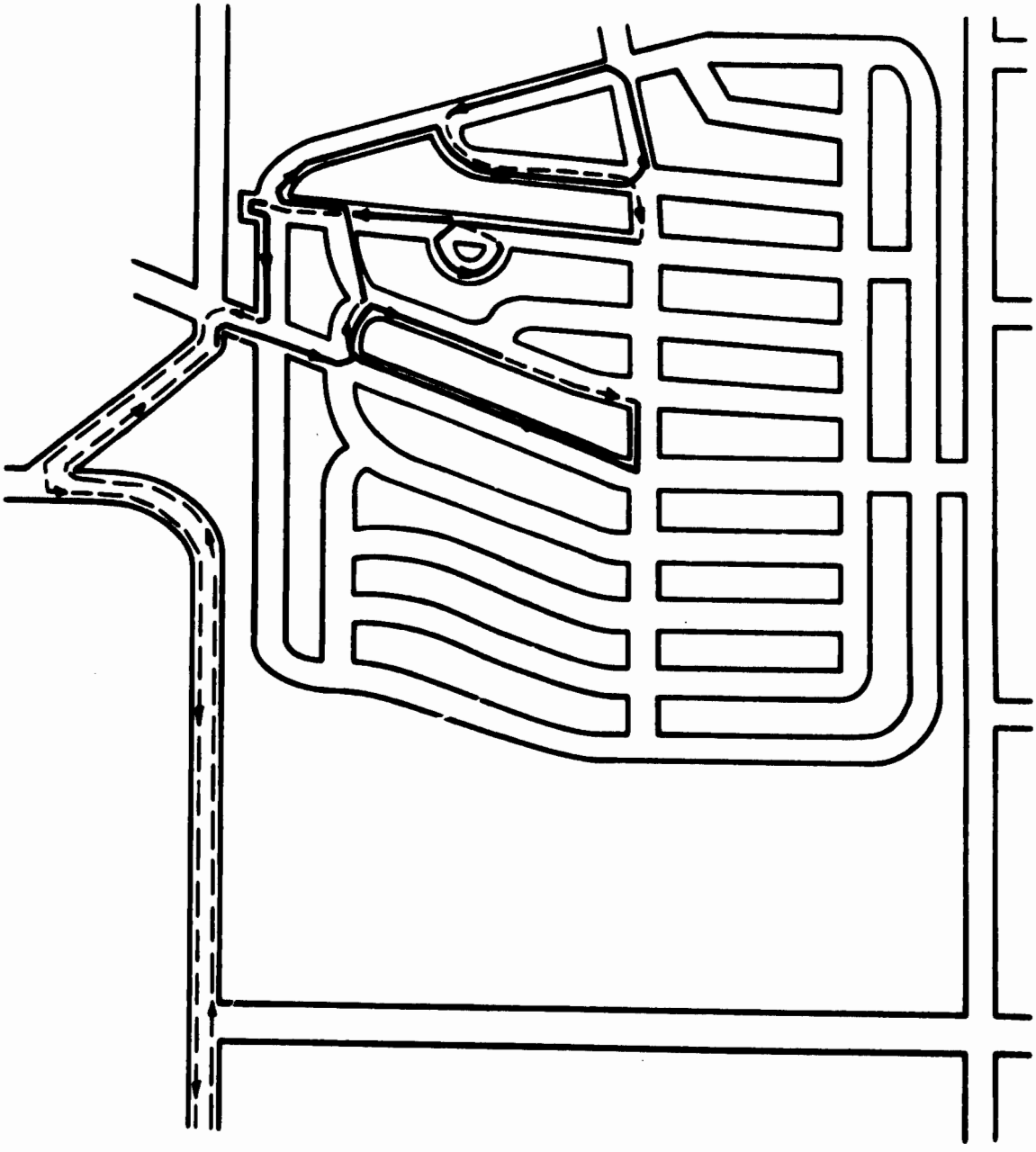
Truck 1, Trip 2



Truck 2, Trip 1

——— Refuse Collection

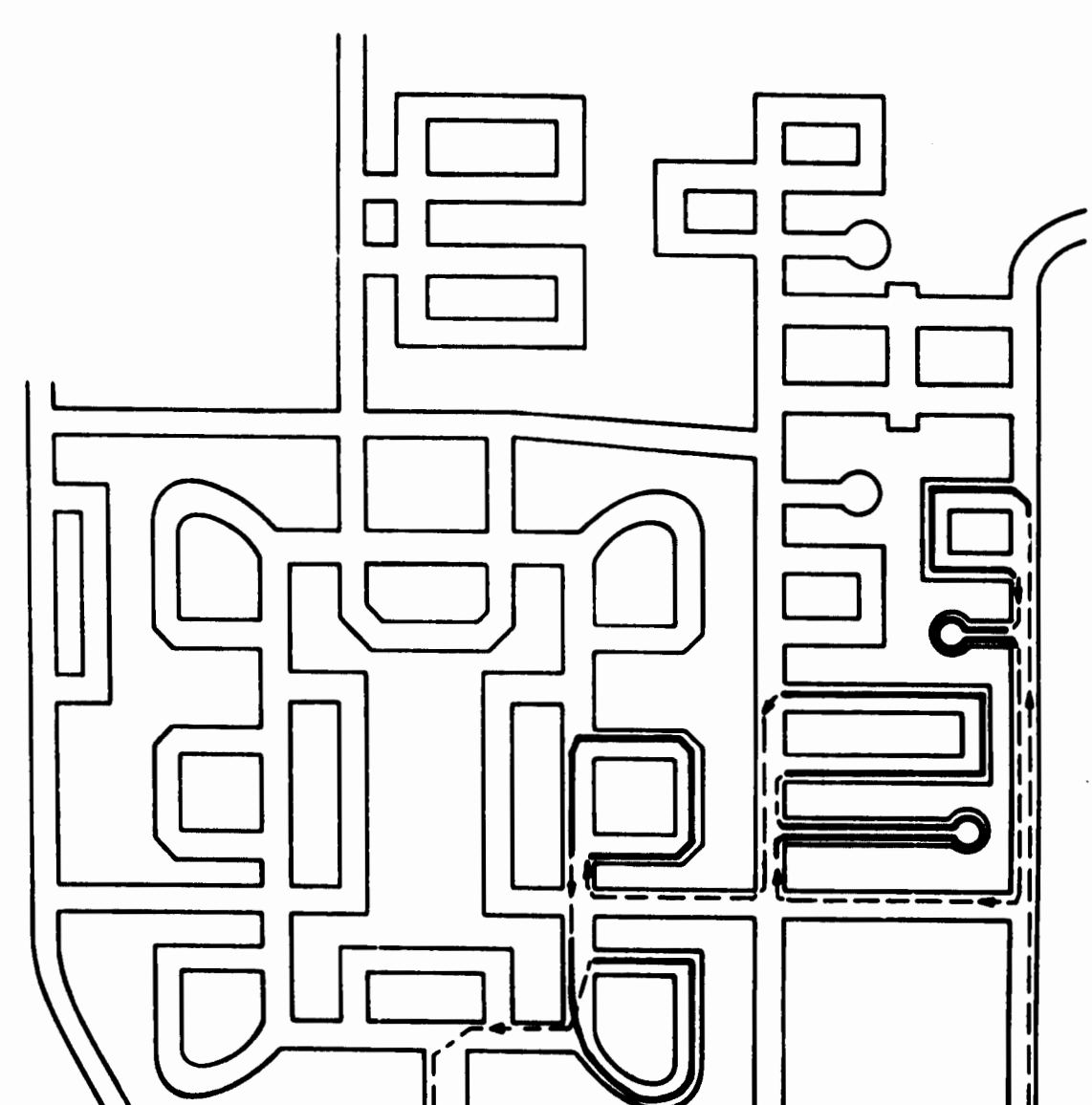
- - - - Travel Without Collection



Truck 2, Trip 2

———Refuse Collection

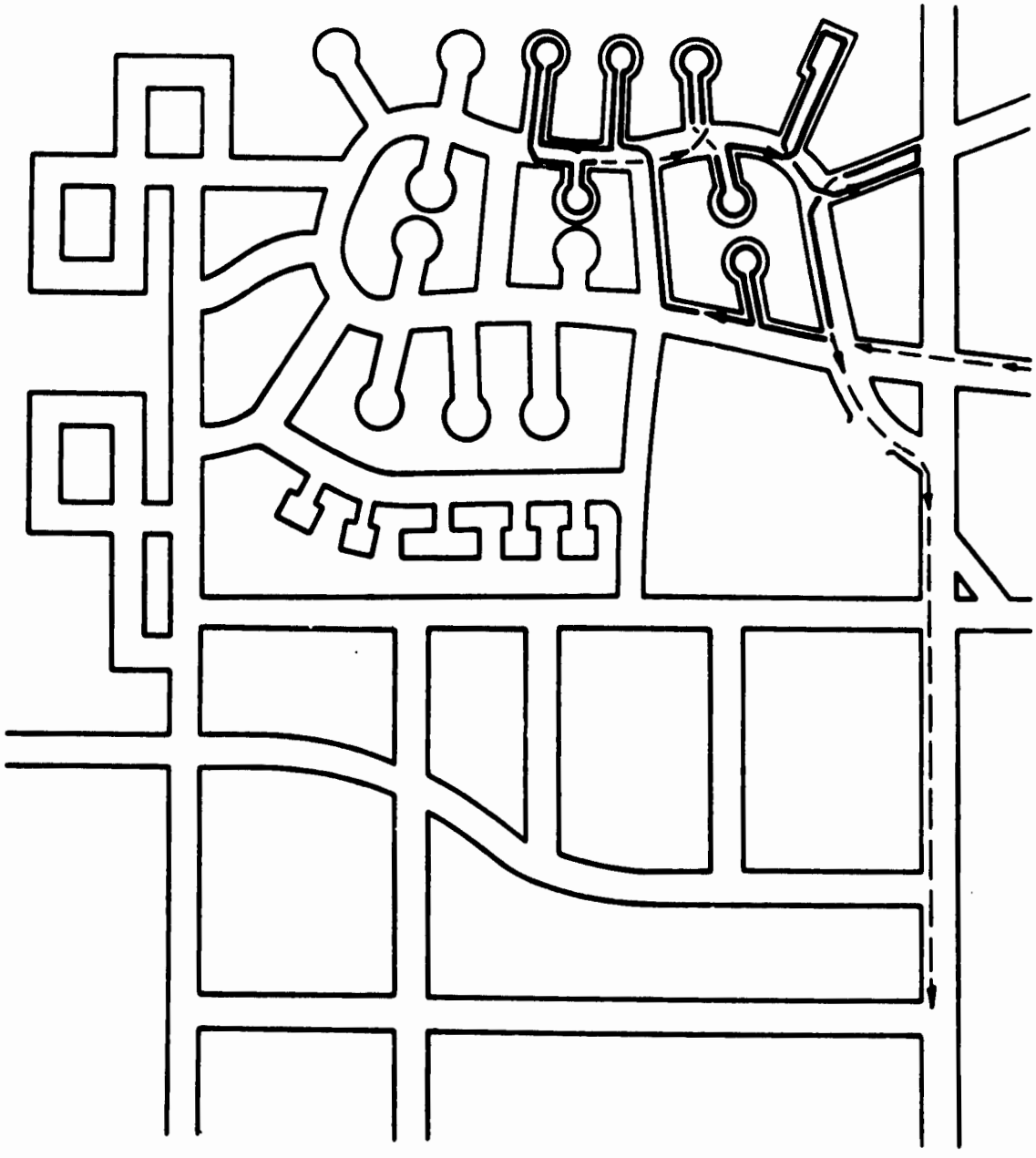
- - - -Travel Without Collection



Truck 3, Trip 1 (Start)

———Refuse Collection

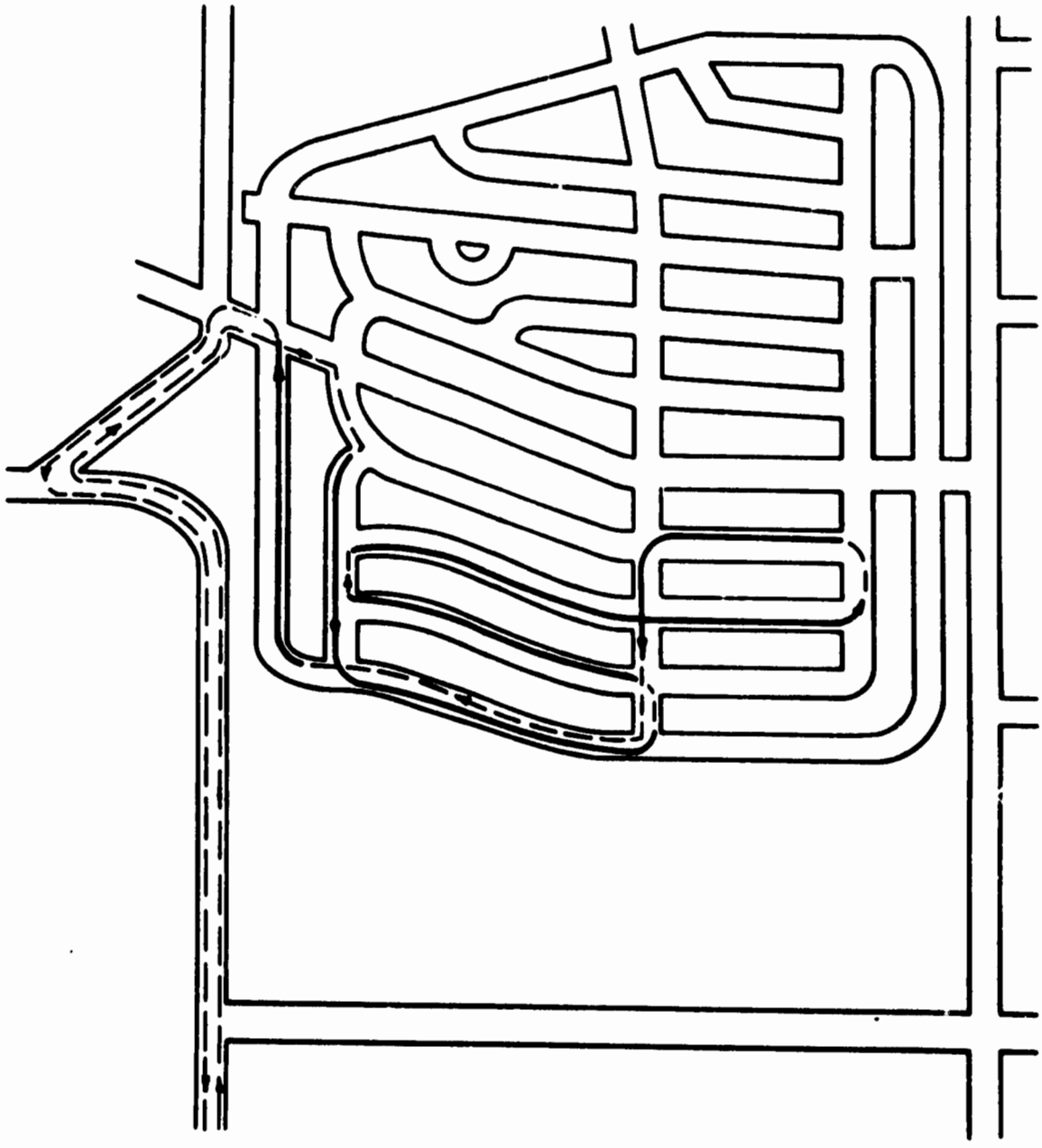
- - - -Travel Without Collection



Truck 3, Trip 1 (End)

———Refuse Collection

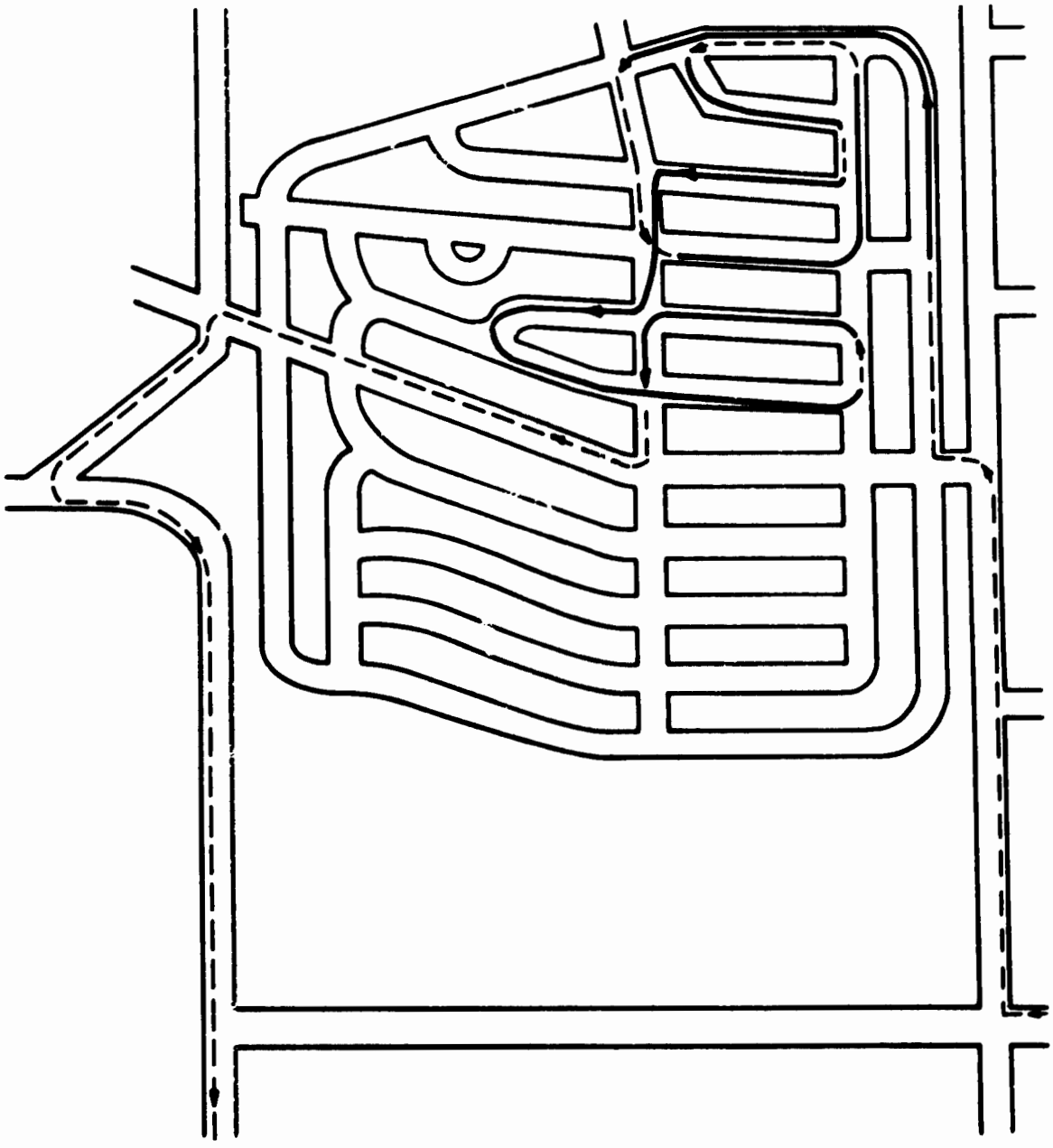
– – – –Travel Without Collection



Truck 3, Trip 2

———Refuse Collection

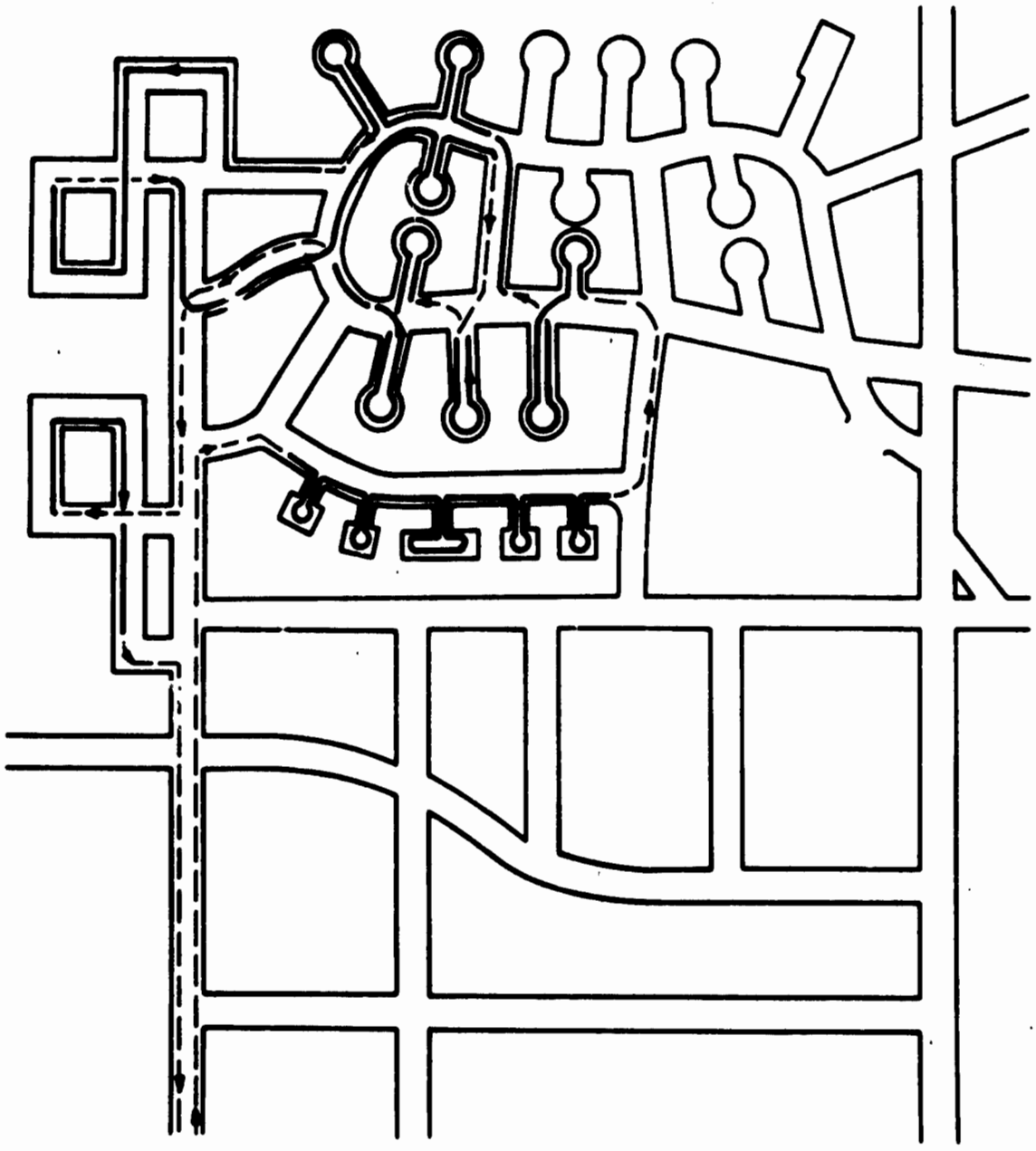
– – – –Travel Without Collection



Truck 4, Trip 1

——— Refuse Collection

- - - - Travel Without Collection



Truck 4, Trip 2

INITIAL DISTRIBUTION

USAF/PREV-P	1
ADC/DEV	1
AFLC/DEM	1
AFSC/DEV	1
ATC/DEM	1
MAC/DEEE	1
CINCSAC/DEPV	1
CINCUSAFE/DEPV	1
USAFA/DEV	1
AFIT/DEM	1
AUL	1
AFCEC/XR	1
AFCEC/EV	7
USA CERL	1
Dept of Army/DARD-ARE-E	1
4902 CES/DEEE	1
Ch of Nav Op, Environ Protection Div, OP-45	1
NCEL, Code 25111	1
Nav Ship R&D Cntr (Code 3021)	1
Tech Transfer Staff (EPA)	1
Ofc of R&D (EPA)	1
Nat'l Science Foundation, Wash D.C.	1
TAC/DEEV	1
CINCPACAF/DEMU	1
DDC/TCA	12
Univ of New Mexico, Technical Applications Center	1
7CSG/DEEV	1

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