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SYSTEMS SIMULATION AND SOLID WASTE PLANNING

A Case Study

National Environmental Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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SYSTEMS SIMULATION AND SOLID WASTE PLANNING: A CASE STUDY

by

Robert M. Clark

and

James I. Gillean

Program Element 1D2065

National Environmental Research Center
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REVIEW NOTICE

The National Environmental Research Center, U. S. Environmental Protection Agency, has reviewed this report and approved its publication.

FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and

- a search for ways to prevent contamination and to recycle valuable resources.

This publication of the National Environmental Research Center, Cincinnati, reports on work related to the application of systems analysis techniques to urban solid waste management. These techniques when properly applied can be powerful tools for bringing difficult environmental management problems under control. The work cited in this publication illustrates the successful application of the systems approach to solid waste management in Cleveland, Ohio.

A. W. Breidenbach, Ph.D.
Director
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ABSTRACT

Adequate solid waste management planning is one of the major problems facing most medium-to-large urban communities in the United States. Increasing waste generation, difficulties in labor-management relations, decreasing land resources, increasing effluent standards, rising cost, and uncertain technology are only a few of the problems facing today's solid waste managers.

A technique which is often suggested as a means of bringing these kinds of problems under control is the so called "systems approach." This phrase as generally used is often vaguely defined and is many times totally meaningless. The work cited in this report is a successful application of systems analysis to solid waste management problems in Cleveland, Ohio, and is intended to illustrate the power of the "systems approach" when properly applied. It is hoped that the work cited in this report will be helpful to other communities in the solution of their solid waste management problems.

SYSTEMS SIMULATION AND ITS APPLICATION TO SOLID WASTE PLANNING

A CASE STUDY

by

Robert M. Clark[1] and James I. Gillean[2]

INTRODUCTION

Adequate solid waste management planning is one of the major problems facing most medium-to-large urban communities in the United States. Increasing waste generation, difficulties in labor-management relations, decreasing land resources, increasing effluent standards, rising costs, and uncertain technology are only a few of the problems facing today's solid waste managers.

A number of analytical tools, including management information systems, simulation, and mathematical models, are available that can be applied to solve these and related problems.

Many studies have explored the application of deterministic and simulation modeling to urban solid waste management problems (4)(7). Several recent papers have applied these techniques to routing and

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facility location with the use of either assumed data or data collected on a one-time basis (2)(5)(6). These approaches have been useful for demonstrating the potential of "systems" or operations research techniques for assisting the solid waste manager in making important operational decisions. None of the studies, however, have considered the problem of obtaining continuous data and utilizing it, together with mathematical models, for making "on-line" decisions. This paper reports on the results of a project in Cleveland, Ohio, in which reliable, uniform, and continuous data collection is combined with a dynamic simulation model to form a system for making short- and long-term management decisions. A system composed of five basic components has been established:

1. A mechanism for the collection of continuous, uniform, and reliable data on the solid waste management operation;

2. An analysis of the variables that have a significant effect on the solid waste system, such as present and expected changes in population trends and distribution, and changes in transportation systems;

3. A simulation or resource allocation model using the continuous data as input and incorporating variables that significantly affect the system;

4. A mechanism for exercising the model and utilizing its results for making immediate or long-range decisions; and,

5. The capability to compare the models' predictions with continuous data.

As a result of the system's implementation, the city has taken several steps to bring Cleveland's solid waste management problems under control. They have

1. Reduced service from back yard to curb side;

2. Developed an on-line management information system;

3. Developed a simulation model for short- and long-term planning purposes;

4. Reduced the number of routes from 224 to 138;

5. Developed a plan for short- and long-term capital investment for collection and disposal; and,

6. Investigated new disposal alternatives for the city's waste.

By implementing the project's recommendations, they have saved $9 million in 2 years. This represents a change from over $14 million, when the project was initiated, to a current budget of approximately $9 million. To understand the problems and successes associated with this effort, it is necessary to know something of the history and political climate that influenced the development of the system.

THE SITUATION IN CLEVELAND

In most large American cities, the population is reluctant to vote for additional taxes and yet either demands more services or refuses to relinquish the services they already have. Faced with demands for higher wages as well as increases in the purchase price of equipment, facilities, and other non-labor-related items, many cities have an eroding tax base. As middle- and upper-income families move to the suburbs taking with them needed tax revenue, lower-income families who produce less tax revenue but who require just as many services take their place. The condemnation of property for highways and other non-taxable uses also reduces potential income for the city.

A similar situation developed in Cleveland. This, coupled with the defeat of a much-needed tax levy, created a financial impact felt in all city departments; nowhere was the impact more acute than in the department responsible for the collection and disposal of solid waste. The City of Cleveland's Division of Waste Collection and Disposal was moving waste from the point of generation, transporting it to the disposal point, and disposing of it with no effort required by the general citizenry.

Shortly before this financial crisis, however, the city initiated a cooperative program with the U. S. Environmental Protection Agency (EPA) in which data from Cleveland were used as a source for a national solid waste data network. Working with the Division of Waste Collection and Disposal, EPA began collecting data on a regular basis in October 1970(3). Two routes were selected for continuous evaluation, and data were obtained from the collection vehicle operator on each route in the form of daily reports.

The Commissioner of the Waste Collection and Disposal Division, faced with a number of difficult decisions regarding possible reductions in service levels, was able to use several months worth of data available from the two routes being monitored within the city. Their six-man crews giving back-yard, once-per-week service could be compared with other systems using the two routes being evaluated within the EPA pilot network.

After careful review of the preliminary monitoring data for these sample routes, back-yard service was eliminated and the collection crew was reduced by two men, leaving one driver and three laborers. Several months later, the crew was reduced to two laborers. Data collected on both routes from October 1970 through May 1971 are shown in Table 1. On these two routes, the cost per ton for waste collected for an average day dropped from close to $30.00 to approximately $13.00, with an estimated annual savings of over $4 million per year.

These national network data proved so valuable that a project was initiated to collect similar data from all of the city's routes. The city using an EPA local and regional planning grant developed an on-line solid waste management information system (1).

DATA SYSTEM DEVELOPMENT

To develop the information system properly, the

TABLE 1. COLLECTION COSTS (in dollars) FOR TWO SAMPLE ROUTES

Month 1970 to 1971	Crew size	Equipment cost/day	Manpower cost/day	Total cost/day	Cost/ton	Weekly cost/ residence served
			Route No. 1			
Oct.	6	18.64	194.88	213.52	30.30	.499
Nov.	6	16.69	194.88	211.57	36.50	.494
Dec.	6	20.72	194.88	215.60	34.81	.501
Jan.	4	19.72	130.56	150.28	22.50	.351
Feb.	4	22.16	130.56	152.72	20.40	.356
Mar.	4	19.13	130.56	149.69	20.19	.350
Apr.	3	24.85	98.48	115.33	14.50	.270
May	3	23.85	98.88	123.73	14.14	.289
			Route No. 2			
Oct.	6	27.32	194.88	222.20	26.10	1.011
Nov.	6	25.15	194.88	220.03	26.19	1.005
Dec.	6	34.07	194.88	228.95	27.00	1.041
Jan.	4	37.57	130.56	168.13	16.60	.765
Feb.	4	37.42	130.56	167.98	17.00	.763
Mar.	4	39.12	130.56	169.68	15.21	.771
Apr.	3	37.62	98.48	128.10	11.28	.583
May	3	29.12	98.88	128.00	12.64	.581

organization and management of the Division of Waste Collection and Disposal was completely analyzed. After the organizational study was completed, the data system was designed and implemented.

Organizational Study

The Division, whose purpose is to provide service to slightly less than 250,000 family units, is composed of personnel, vehicles, and facilities. The Commissioner in charge of the Division supervises six station superintendents with subordinate foremen as shown in Figure 1.

There is no preassigned number of foremen in each station: station 100 has three foremen, whereas station 400 has six foremen. Each foreman is responsible for collecting waste from the routes assigned to him. Figure 2 shows the general organization of station 100; as indicated, each foreman may supervise a different number of crews (i.e., foreman 110 supervises three crews, whereas foreman 130 supervises five crews).

The collection crew is usually composed of a driver and two waste collectors who, upon arrival at the route, work until the vehicle is filled to capacity or until the day's effort is completed. If the vehicle is filled before the route is completed, the driver takes the load to the disposal point and returns to the route. Upon completion of the route, the driver unloads at the city's incinerator if he has a partial load, or at a private landfill if he has a full load and has time remaining in the working day to make the round trip. On some occasions, he is instructed to return to the motor pool with the partial load if time becomes a critical factor.

As part of the organization study, numerous interviews were conducted with the staff of the Division. Employee records were searched for data pertinent to systems operations: e.g., unexcused absences and collector's age. (The average age of the waste collectors was 49.2 years, which seems high when compared to other similar occupations.) Cost data was collected on use and maintenance of vehicles and on facilities and equipment for maintenance. Examples of some of the maintenance data acquired in the study are shown in Figure 3.

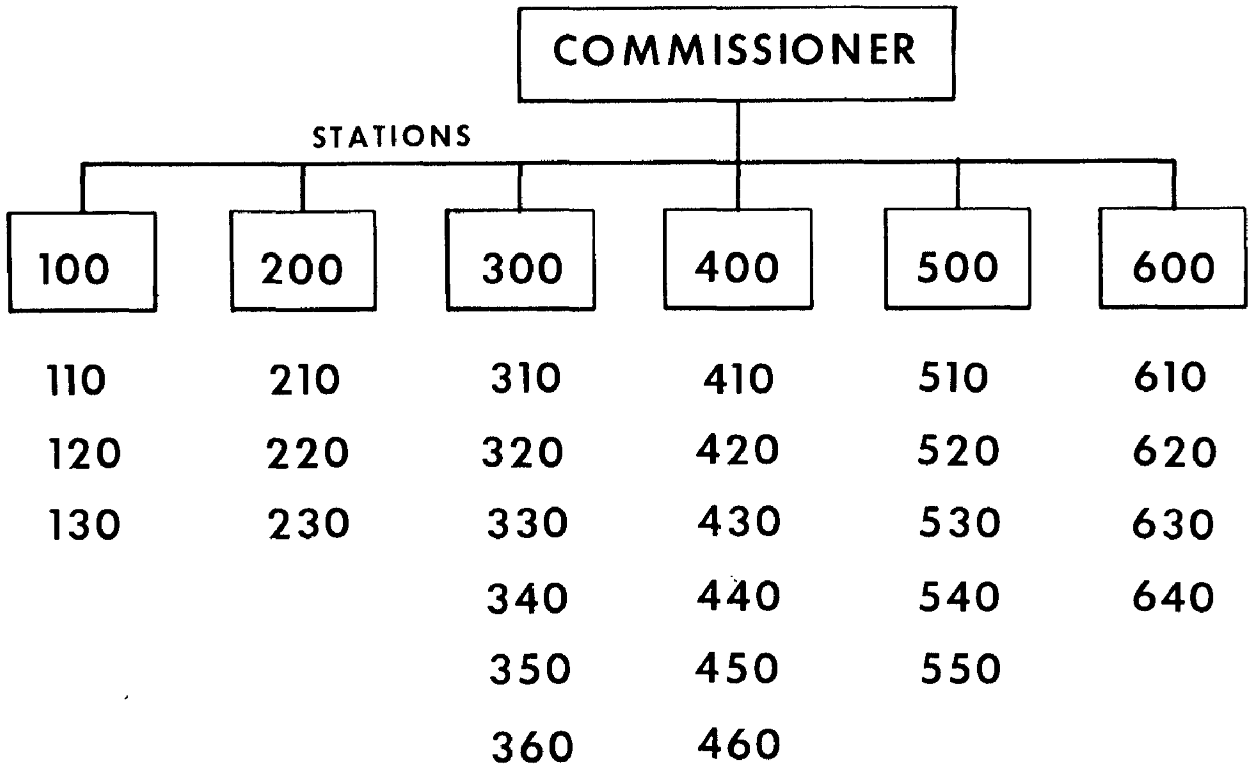

Figure 1 Organization of Division of Waste Collection and Disposal, Cleveland, Ohio.

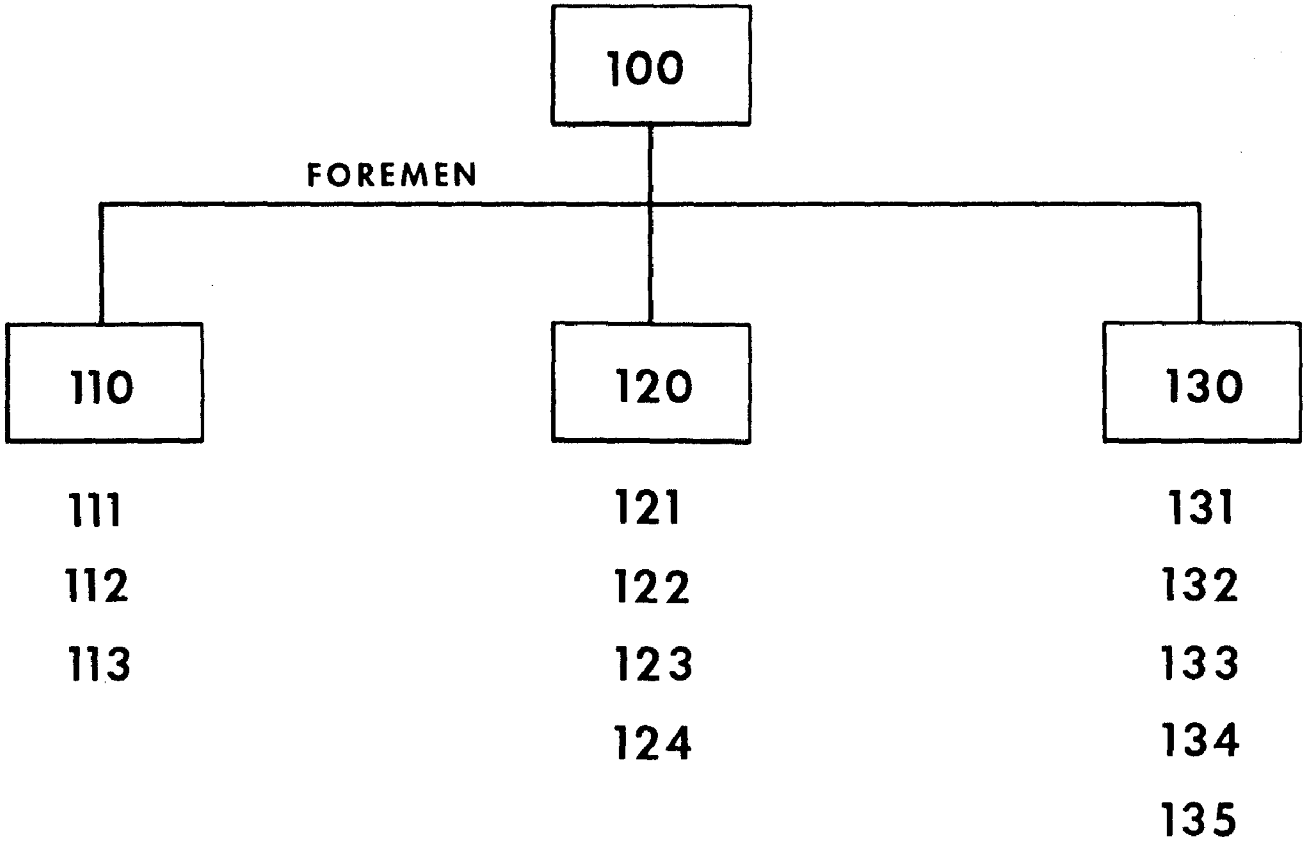

Figure 2 Organization of One of Six Stations Within the Cleveland, Ohio, Division of Waste Collection and Disposal.

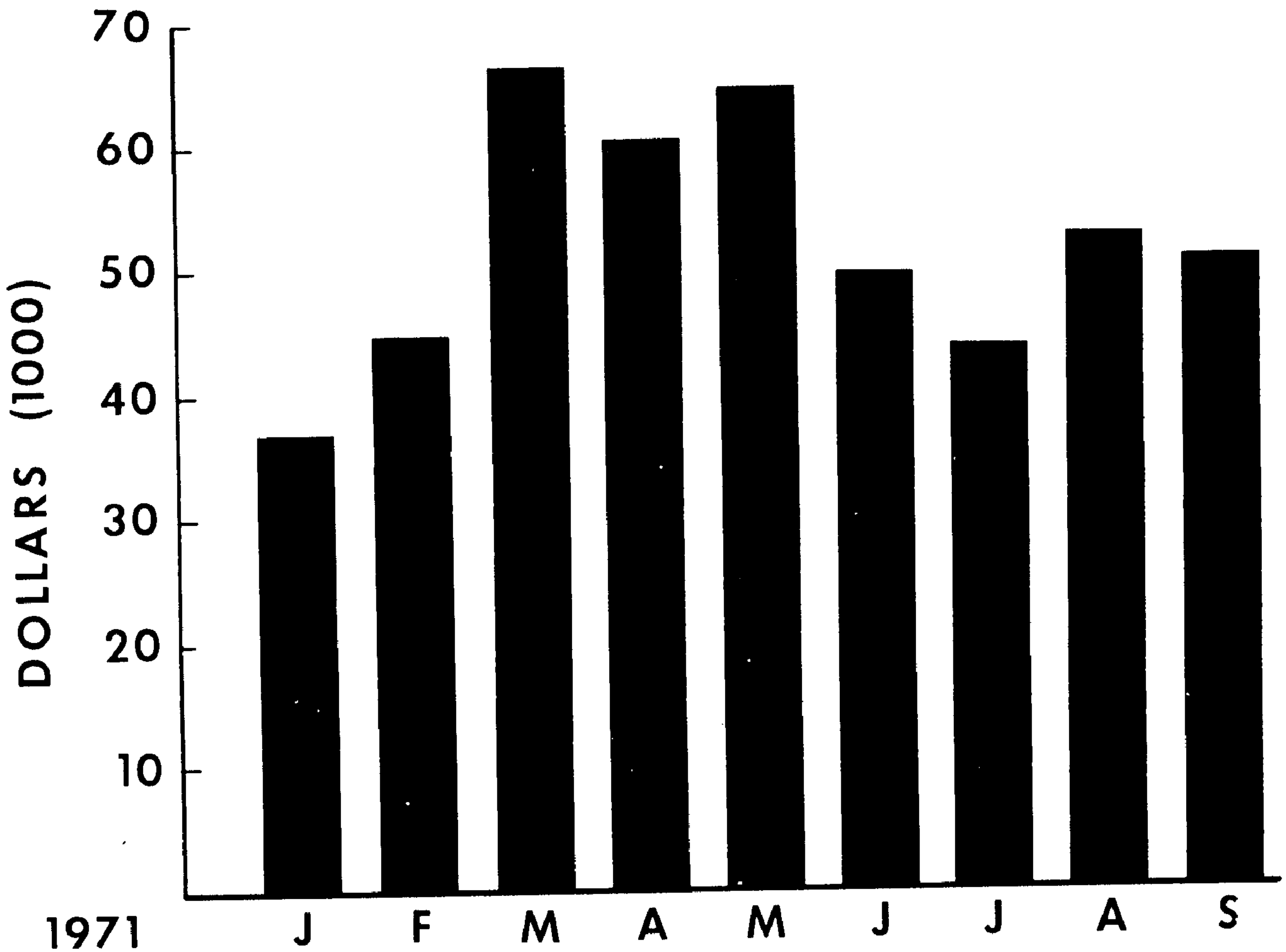

Figure 3 Vehicle Maintenance Costs.

This information provided important background data for development of the management information system. As part of the system development, the outputs needed to satisfy management requirements were determined. After the output requirements were specified, input data to produce the required outputs were identified. A data processing system was developed, and the management information system was implemented.

Output Requirements

Thorough review management requirements indicated three general data information categories for output requirements: route, collection, and cost.

The types of information generated by the system are shown in Figure 4. Information from each route foreman and station is computed on a daily average for a week. In addition to the daily averages, the foreman or station may sum the values related to the routes where deemed meaningful.

Critical data from each station's report are consolidated to provide the weekly commissioner's report with sums and daily averages for the over-all daily collection. In addition to the tabulated information, certain exceptional information for the five highest routes and the five lowest routes is printed out for:

- Average weight collected per day;
- Average time spent collecting per day;
- Homes served per collection crew;
- Collection time per home;
- Collection time per 100 pounds;
- Working time to paid time;
- Incentive cost per day;
- Cost per ton; and,
- Cost per home per week.

CLEVELAND
DIVISION OF COLLECTION AND DISPOSAL

ROUTE INFORMATION

ROUTE NUMBER	DAYS OF DATA USED	AVERAGE VEHICLE SIZE (CU YD)	VEHICLE TYPE			MOTOR POOL TO ROUTE (PER DAY)		COLLECTION OPERATION (PER DAY)		TRANSPORT OPERATION (PER DAY)		WEIGHT PER DAY (POUNDS)
						(MILES)	(MIN)	(MILES)	(MIN)	(MILES)	(MIN)	
611.	3.	20.	RL			4.5	20.7	4.0	226.7	15.5	96.0	20660.
612.	5.	19.	RL			2.7	21.0	5.7	198.4	15.0	122.0	21460.

CLEVELAND
DIVISION OF COLLECTION AND DISPOSAL

COLLECTION INFORMATION

ROUTE NUMBER	HOMES SERVED PER COLLECT	WEIGHT PER HOME PER COLLECT (POUNDS)	PERSONS SERVED PER COLLECT	GENERATE PER PERSON PER DAY (POUNDS)	COLLECT TIME PER HOME (MIN)	COLLECT TIME PER 100LB (MIN)	COLLECT TIME TO TOTAL TIME (MIN)	ACTUAL TIME TO PAID TIME (MIN)	LOADS PER WEEK			WEIGHT PER CU YD 1ST LOAD (POUNDS)
									INCIN	LAND FILL	XFER STA	
611.	439.	47.0	1410.	2.1	0.52	1.10	0.66	0.72	0.	5.	0.	621.
612.	286.	74.9	919.	3.3	0.69	0.92	0.58	0.71	6.	3.	0.	664.

CLEVELAND
DIVISION OF COLLECTION AND DISPOSAL

COST INFORMATION
(DOLLARS)

ROUTE NUMBER	COST TO ROUTE PER DAY	COST TO COLLECT PER DAY	COST TO XPORT PER DAY	TOTAL EQUIP COST PER DAY	TOTAL MANPWR COST PER DAY	TOTAL COST PER DAY	INCENT COST PER DAY	COST PER LOAD	COST PER TON	COST PER HOME PER WEEK	COST PER PERSON PER WEEK
611.	8.04	88.16	37.34	35.85	97.68	133.53	27.81	80.12	12.93	0.30	0.09
612.	8.17	77.23	47.49	35.22	97.68	132.90	28.21	73.83	12.39	0.46	0.14
613.	8.36	87.50	43.03	41.61	97.68	139.29	12.87	5[illegible].72	10.06	0.43	0.13

Figure 4 Computer Printouts Indicating the Types of Cost, Collection, and Route Information Gathered for the Solid Waste Management Pilot Study.

Input Requirements

When the specified outputs were precisely established, the inputs needed to produce them were determined. Forms were developed to log the necessary data that would become the major inputs to the system. Figure 5 illustrates the forms used to collect information relating to vehicle identification and maintenance, crew size, number of homes served, discharge point, and other critical data. The data system was developed so that data could be key punched directly from the daily collection forms. The flow of data into the system and resulting outputs are shown in Figure 6.

System Implementation

In September 1971, as the data collection system was implemented (except for the computer program), inconsistencies and errors were logged so that corrective action could be initiated. The data were then transcribed to cards, checked, and run through a debugging process.

In November 1971, the total implementation of the system was completed including installation of the computer program in the City of Cleveland's Data Processing Center.

NONSOLID WASTE INFLUENCES

An attempt was made to define all of those nonsolid waste factors that have an impact on the solid waste management function. For example, population trends and densities and dwelling unit densities have a significant impact. Transportation networks, including changes in street mileages and the location of major arteries and expressways, must be considered. On-going or planned urban renewal projects have a significant impact on population (location, numbers, and densities) and, therefore, are significant for solid waste planning. State laws and city and county ordinances have a potential impact on solid waste management. Some of these statistics for Cleveland are:

DAILY COLLECTION ROUTE INFORMATION

ROUTE ______ DATE ______ CREW ______

VEHICLE: NO. ______ SIZE ______ FUEL(GAL) ______ OIL(QT) ______

NO. HOMES SERVED ______

	TIME	MILES	WEIGHT	DISCHARGE POINT *
LEAVE MOTOR POOL				
START COLLECTION				
LEAVE ROUTE FOR DISCHARGE POINT				
AT DISCHARGE POINT				
ARRIVE BACK ON ROUTE				
LEAVE ROUTE FOR DISCHARGE POINT				
AT DISCHARGE POINT				
ARRIVE BACK ON ROUTE				
LEAVE ROUTE FOR DISCHARGE				
AT DISCHARGE POINT				
RETURN TO MOTOR POOL				

			MAINTENANCE-PROBLEM (Circle Number)
LUNCH-START (LEAVE ROUTE) -FINISH (ARRIVE ROUTE)			1 Brakes,wheels,tires 2 Cooling or exhaust sys 3 Electrical sys
MAINTENANCE-START -FINISH			4 Fuel sys 5 Packer 6 Power or steering sys 7 Other

*ENTER NUMBER

1-INCINERATOR
2-LANDFILL
3-TRANSFER

REMARKS:

Figure 5 Sample Daily Data Collection Form Completed by Collection Vehicle Operator.

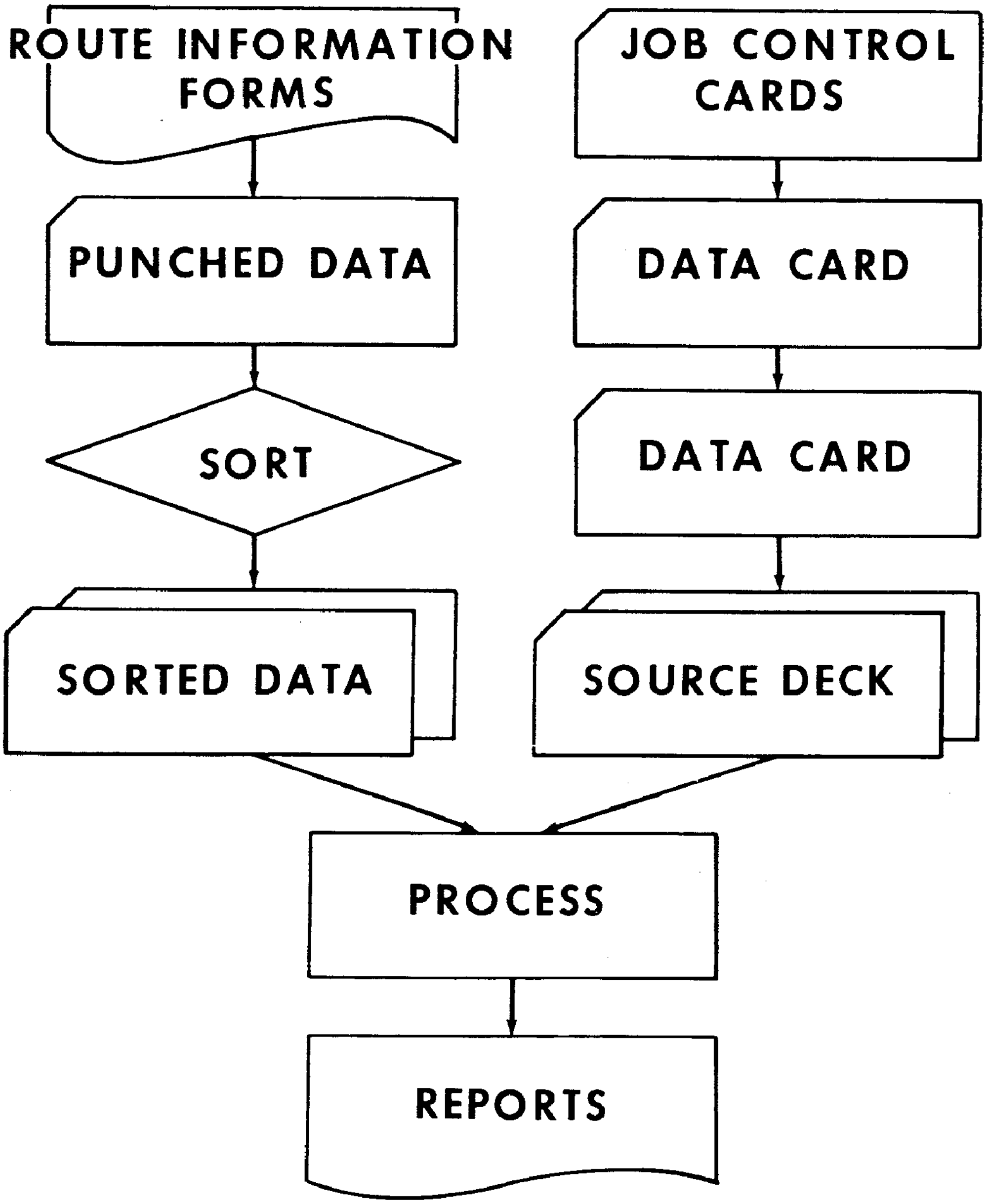

Figure 6 Management Information System Flow Chart

Population	648,082
Dwelling units	212,486
Persons/dwelling unit	3.05
Land area (square mile)	67.52
Population density (population/square mile)	9,598
Dwelling unit density	3,147
Miles of streets (collection/week)	3319.5
Dwelling units/mile of collection	64.0

Demographic Profile

Demography is the science of population movement and trends, and since the location of people has an important impact on the solid waste management function, demography is, important to solid waste management. The population of Cleveland that was over 900,000 in 1950 has declined steadily to approximately 750,000 in 1970 (Figure 7). It is expected to stabilize at 740,000 over the next 20- to 30-year period. Figure 8 shows family distribution by stations in 1970. Interestingly, there appears to be a natural division of the city into two components. Stations 200, 300, and 400 on the east, and stations 500 and 600 on the west, contain the majority of the solid waste sources.

Numerous changes are proposed in the transportation network for the city. Figure 9 shows the existing major arteries and some proposed highways, and Figure 10 shows new urban renewal and neighborhood development areas that will have an impact on the solid waste management function.

As part of the background study of Cleveland, the city, county, and state ordinances, regulations, and laws affecting solid waste were searched. The one county regulation concerned disposal. Three of the state laws concerned rules and enforcement and seven concerned disposal. Of the 42 city ordinances and regulations, 12 concerned rules and enforcement; 6, containers; 6, vehicles; 11, disposing; 1, charges, and 6, miscellaneous subjects.

The demographic, transportation and neighborhood development data were compiled along with data from the management information system to provide the following input information for the simulation model:

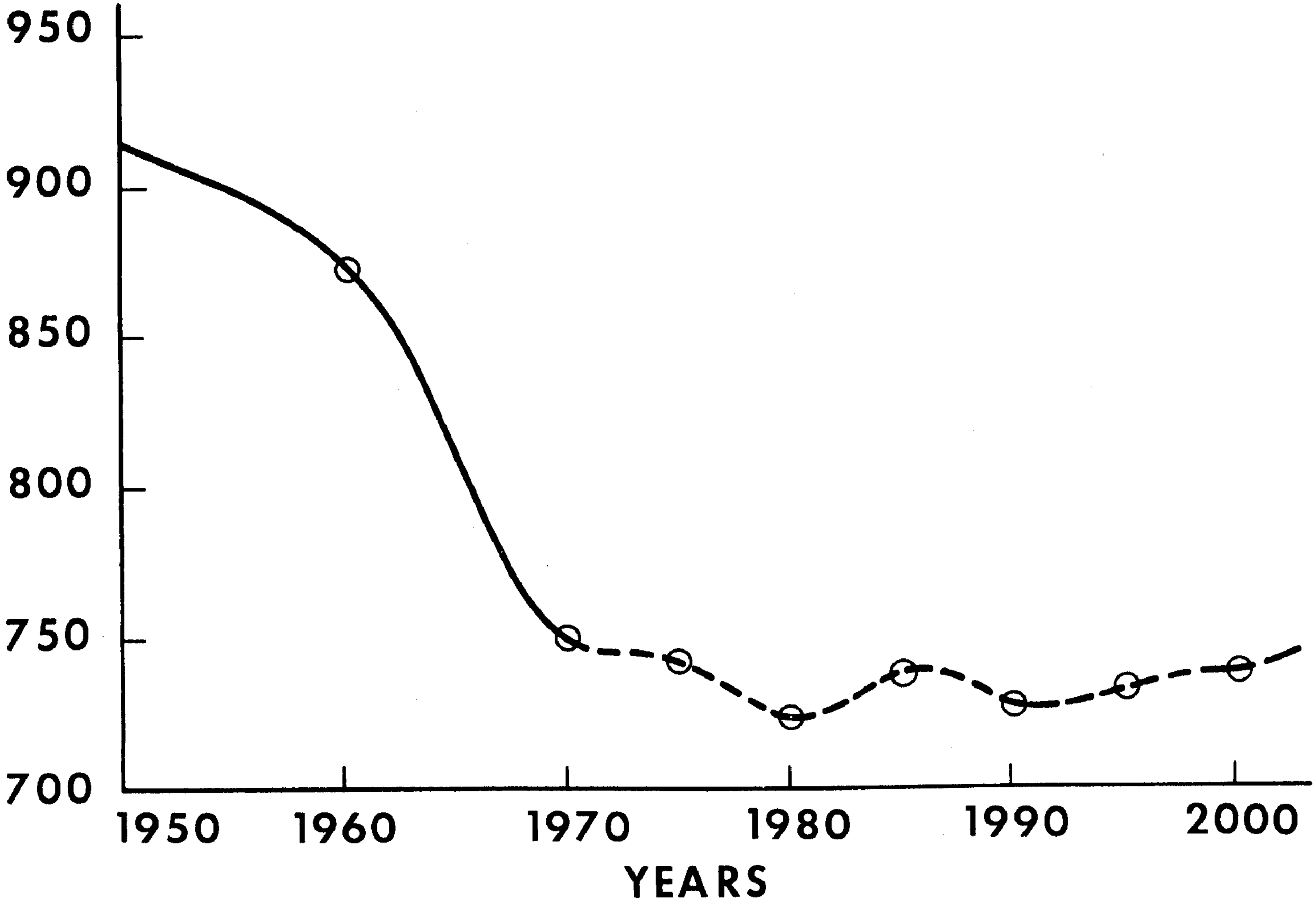

Figure 7 Population Trends for Cleveland, Ohio.

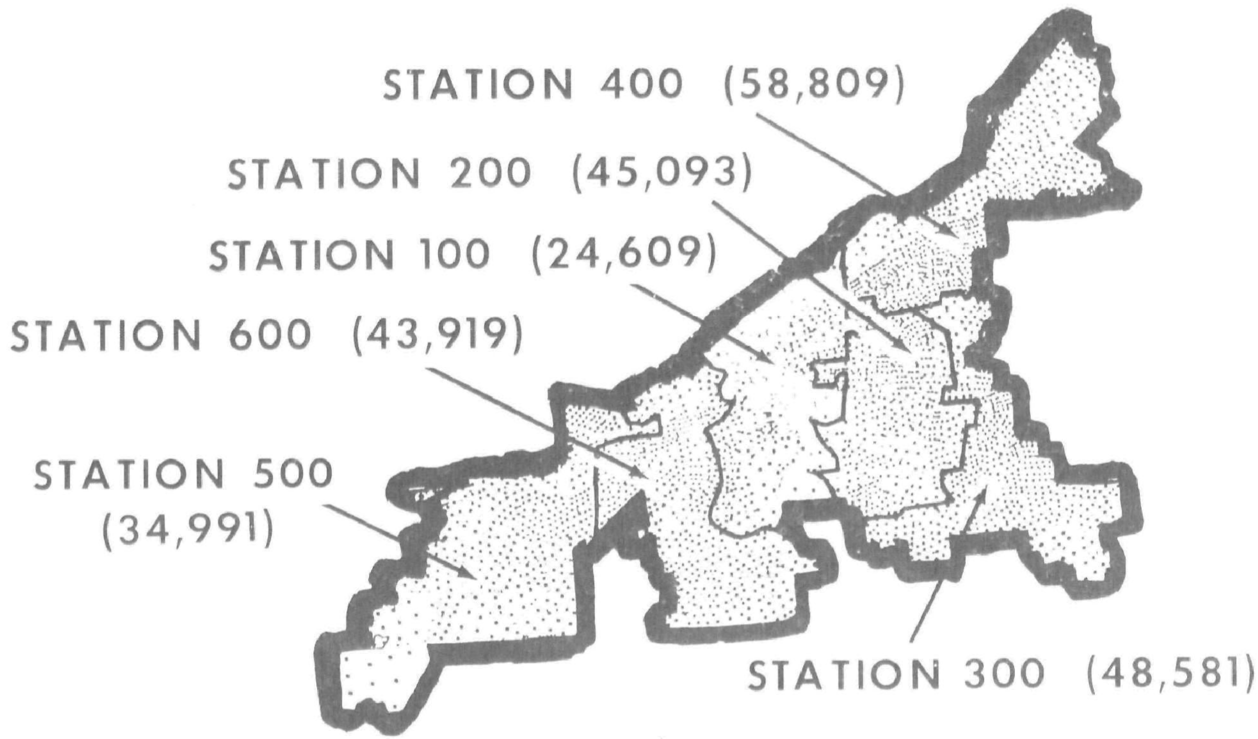

Figure 8 Distribution of Families Within Each of the Six Waste Collection Subdivisions in Cleveland, Ohio, October 1970. Each dot (.) Represents 100 Households.

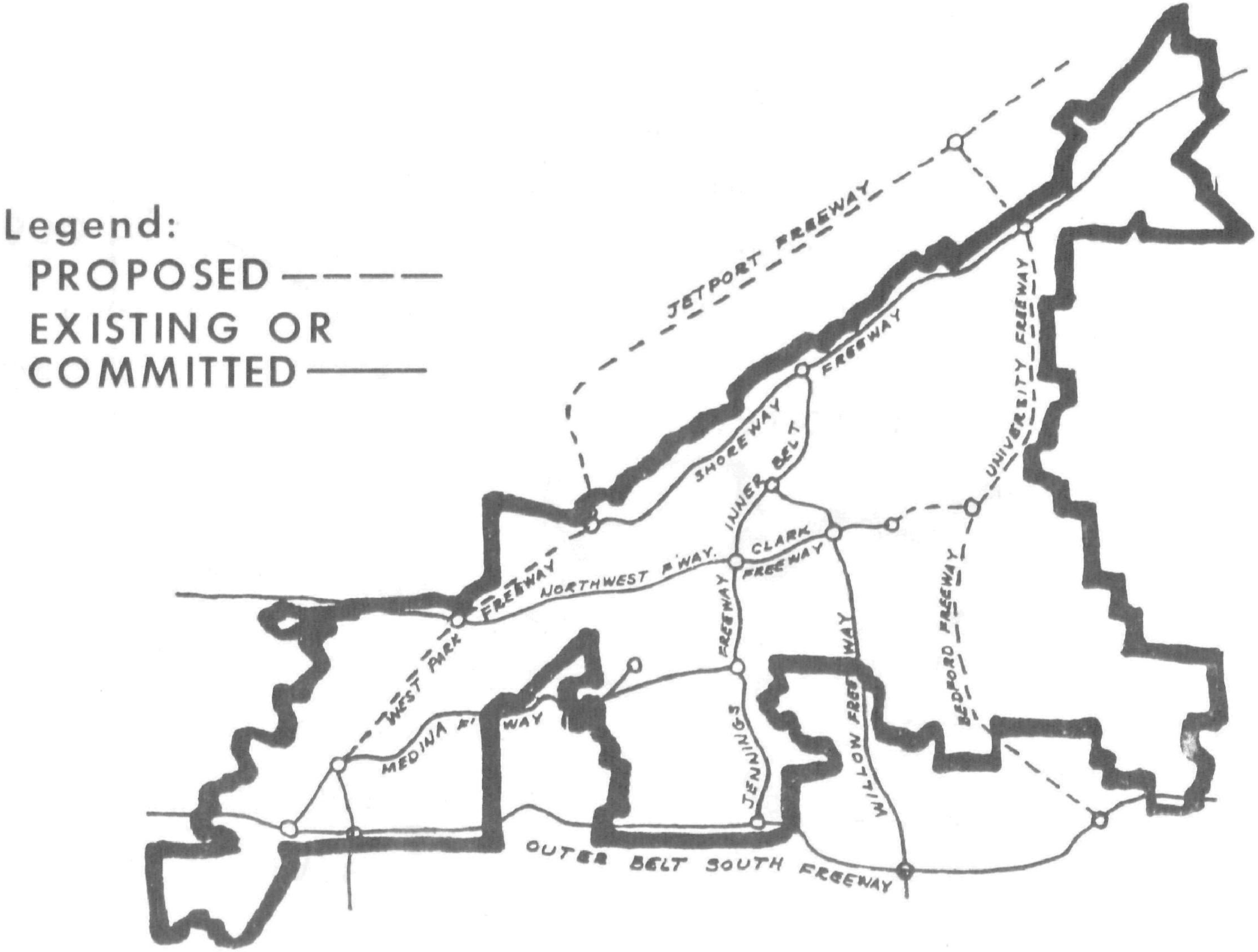

Figure 9 Major Transportation Arteries, Cleveland, Ohio.

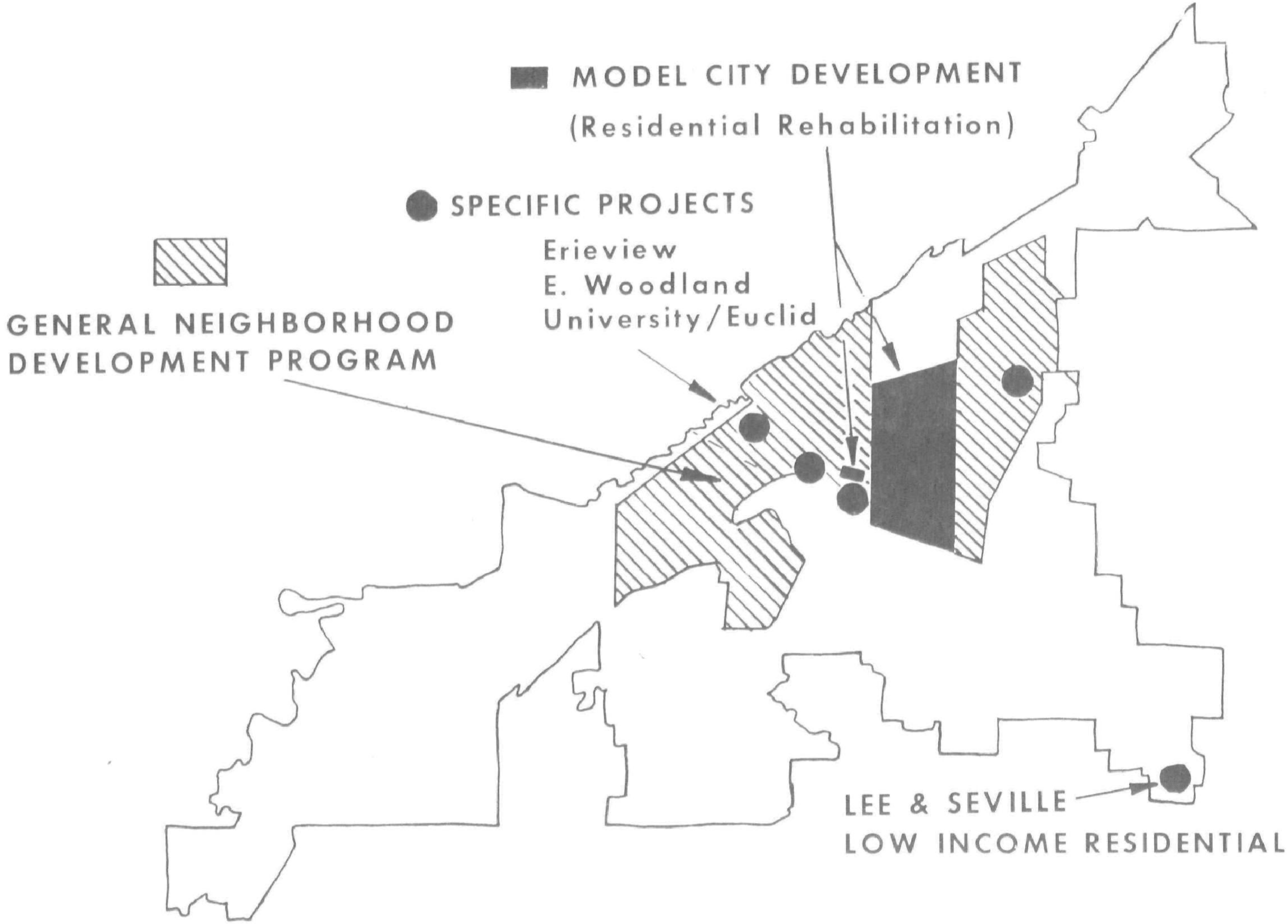

Figure 10 Urban Renewal Projects in Cleveland, Ohio.

- Generation data, composed of population, dwelling unit, density, weight, and cost information;

- Collection data, including distances, volume, pickup time, route identification, vehicle type, and crew size and costs;

- Transport data, related to distance, time, and speeds; and,

- Disposal data, such as distance traveled, offload time, disposal site, and related costs.

MODEL DEVELOPMENT

The model consists of five master programs each of which corresponds to the basic operation in the solid waste collection and disposal activity: input data logic, truck generation logic, collection logic, transportation logic, and disposal logic. In a flow diagram, the way in which the model simulates the system is illustrated (Figure 11).

The input data consist of the basic statistics that describe the system. For example, solid waste generated, truck size, crew size, number of homes served, collection time, and transport miles are all input data to the model and are, therefore, fixed for each simulation run. The values for each of these categories may change depending on the type of collection system being modeled.

The model then indicates the number of trucks needed each day to collect the solid waste; this number is based on the number of routes being considered, which in turn, is based on the assumed amount of solid waste generated per day. An 8-hour working day was used as the base line for comparing various types of collection systems. When the complete cycle of collection and disposal was considered, however, a week's effort was used for evaluating the various alternatives.

The collection logic assumes a set of work rules

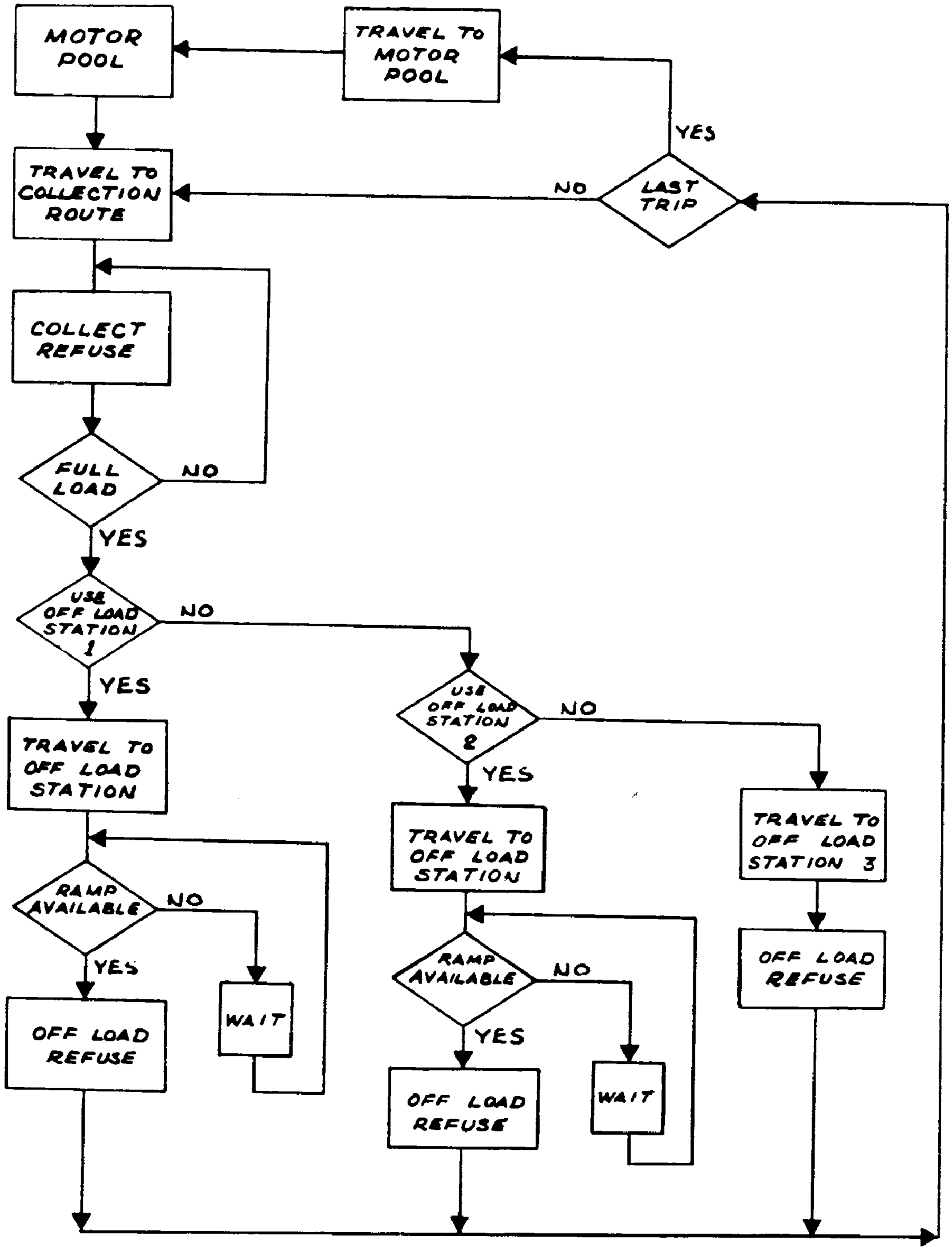

Figure 11

Flow Diagram of Model Logic Simulating Basic Operation of the Cleveland, Ohio, Solid Waste Collection and Disposal Activity.

and contains the supporting data to be used for a specified collection system. For example, when a two-man collection system, which consists of a truck, a driver, and a helper, is being considered, the assumptions are: that the driver will assist the helper for approximately 60 percent of the time spent collecting on the route; that, for this assistance, the driver receives a wage adjustment; that, the collection rate in the model varies from 1.1 pounds per second per man to 2.5 pounds per second per man; and that the walking rate for the collectors between pickup point was assumed as 2 feet per second.

When a truck has been filled to capacity, it enters the transportation logic routine. This routine assigns a disposal point and an associated transportation distance to the truck based on its position on the route when the collection task is completed.

When a truck has made its trip to the disposal or unloading point, the vehicle enters the disposal logic routine. At the offload point, the truck is assigned to an unloading lane where it may enter a queue or unload immediately depending on the conditions at the offload point. After the vehicles are empty, their return to the motor pool or to the collection route depends on their having completed their assigned service routes, or on the time of day, or on both.

The routines were used to model the performance of an individual truck and crew as well as the performance of the entire system. The first step in the modeling process was to assume a three-man crew and a rear-loading packer collecting over a typical route using the collection logic. Various dwelling densities were assumed, and a long- and a short-haul option were considered. The long-haul option was rejected as a reasonable alternative for Cleveland. Next, the collection logic was used to test various collection systems until several good ones were found. The disposal logic was used to test the good collection systems to determine various transfer station configurations. Once these configurations were determined, the truck generation logic was used to estimate the required fleet size for the entire city. This procedure was followed with the numerous variations in the input data.

Programming and Validation

A General Purpose Simulation System (GPSS) Language, Version V, was used to program the model. Input data and work rules reflected current operations in Cleveland.

For purposes of validating the model, the current system was simulated with the use of input data that describe the present operation. Results from the model are compared with data collected from the management information system (Table 2). Output data from the model include : (1) volume and/or weight of solid waste handled; (2) miles traveled; (3) collection times; (4) travel time; (5) weight handled by each disposal point; (6) queueing conditions at offload ramps; and, (7) number of homes collected.

SYSTEM EVALUATION

After the model had been conceptualized, programmed, and validated, it was used to evaluate various alternatives that might be considered for current and future use in the City of Cleveland. Part of this effort was devoted to modifications to the present system that might make it a more efficient operation.

Collection System Evaluation

Various collection configurations were evaluated during the course of this study. Figure 12 shows a schematic diagram of some of the alternatives that were considered. For each collection configuration, the effects of dwelling unit density, pickup location, generation rate, vehicle size, and crew size were evaluated. For example, the effectiveness of a scooter system with a two-man crew, serving dense multi-family dwellings was compared with a mother truck with a satellite vehicle (M/ST), using a two-man crew, serving a low-density single-family home neighborhood with normal generation rates. Each of the alternatives shown in the schematic diagram was considered under

TABLE 2.

SIMULATION OUTPUT COMPARED WITH COLLECTED DATA FOR STATION 100

Route No.	Simulated data (lb collected/day)	Collected data (lb collected/day)	Percent difference
111	12,984	12,606	3.0
112	14,252	13,968	2.0
113	7,680	7,404	3.7
121	9,660	9,583	0.8
122	13,483	13,547	0.5
123	20,045	19,750	1.5
124	19,222	18,956	1.4
131	17,955	17,968	0.1
132	22,800	23,548	3.2
133	22,108	22,314	0.9
134	21,509	20,836	3.2
135*	--	--	--

*Route information not usable.

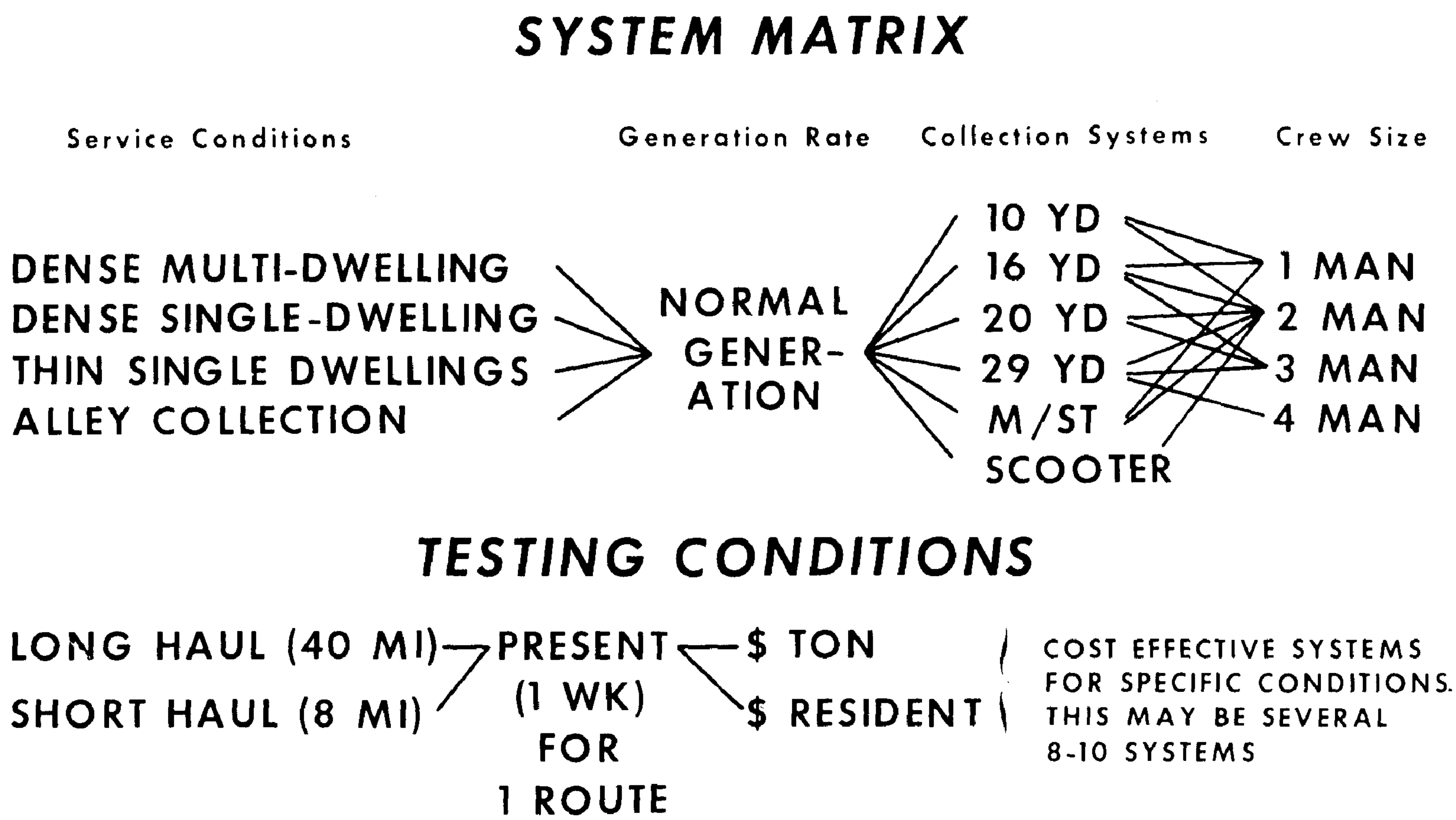

Figure 12 Schematic of Alternative Collection Configurations Considered.

long-haul (40 miles) and short-haul (8 miles) conditions when serving one route with once-per-week collection. Immediately this analysis showed the short-haul situation was far superior for all of the alternatives considered. The ratio of the total weight collected with a short haul to total weight collected with long haul is approximately two to one. With these results, the long-haul alternative was eliminated from future consideration.

The criteria used to rate each of the systems were: (1) ratio of pickup time to transport time; (2) dollar per ton; (3) dollar per residence; and, (4) "optimum termination point." The first three items are self-explanatory, and the final item is defined as the physical point at which the collection effort terminated in an 8-hour working day. Highest ratings were given to the vehicle/crew combinations that could complete the work load in an 8-hour day. The best system was assigned a rank of one, the next best system two, and so on. Table 3 summarizes the rankings achieved by the various systems considered.

The 29-yard truck with a 2-man crew (29-2), and the 10-yard truck with a 1-man crew (10-1) had the best performance capability. This choice was made under average conditions for waste generation. To test the capacity of these two alternatives for collecting under extreme conditions, a peak generation day was assumed. After routes were restructured and brought within optimum length, simulation runs were made under maximum generation conditions.

Another test was made to see if these two collection systems together could accomplish the service responsibility better than either system alone. The 29-yard truck was assigned the task of collecting dense multi-family dwellings, and the 10-yard truck was given sparsely-settled areas. This combined system proved to be efficient but no more efficient than either system alone.

Based on several subjective considerations, the 29-2 configuration was declared optimum. The 29-yard truck with a 2-man crew allows for more flexibility

TABLE 3.

COMPARISON OF COLLECTION PATTERNS,

RATING VARIOUS VEHICLE AND CREW SIZES

Ranking or system	Vehicle and crew size (configurations)	Negative points accrued
1	10-1	50
2	29-2	66
3	16-1	81
4	29-3	83
5	20-2	88
6	10-2	101
7	M/ST-1	115
8	20-3	120
9	29-4	123
10	16-2	130
11	M/ST-2	141
12	16-3	150

than a 10-1 system. Union rules and safety requirements are more consistent with a 29-2 system than with a 10-1 system.

Offloading Site Evaluation

After the most efficient collecting system had been identified, an evaluation was made to determine the best offloading sites. A schematic diagram outlines the variables considered in this determination (Figure 13).

The topography of the Cleveland area dictated the possibility of dividing the city into two general route groups: the area currently in stations 500, 600, and the western part of station 100; and the area currently in stations 200, 300, 400, and the eastern part of station 100 (Figure 8).

The western district developed favorably into a 36-route configuration, offloading at the Ridge Road landfill, and the eastern district, into a 53-route, offloading at a landfill at 34th and Broadway (due east of the West 3rd facility and halfway into the district) (Figure 14). At this time, it was determined that a motor pool would be located at both landfills to eliminate travel time after the last offload. The constraints on the simulation runs were: (1) the truck must make at least one but no more than two offload trips; (2) collections must be made at a peak generation period; (3) the number of homes must be a maximum; and (4) the task must be accomplished with a 40-hour work week, with 1.5 to 2.0 hours remaining on the fifth day for general truck maintenance, and a 0.5-hour period remaining on each of the other 4 days to wash the trucks. Simulation runs were made with the use of the 29-2 truck/crew configuration and with pickup times varied from 36 to 52 seconds. The number of homes to be serviced was set at 83,016 in the western district and at 129,470 in the eastern district. The results of these runs were within the framework of the conditions stated above.

Another variation was examined in which the offload destination was changed from 34th and Broadway to the Garden Valley site 2 miles northeast of the

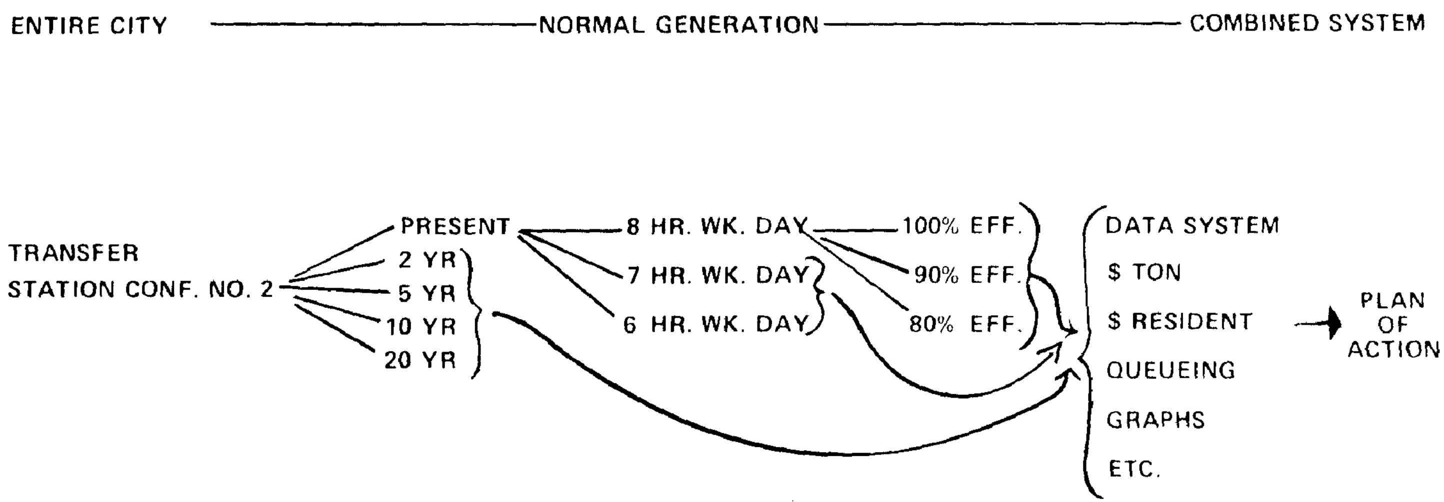

Figure 13 Matrix Indicating Variables Considered When Determining the Best Unloading Sites.

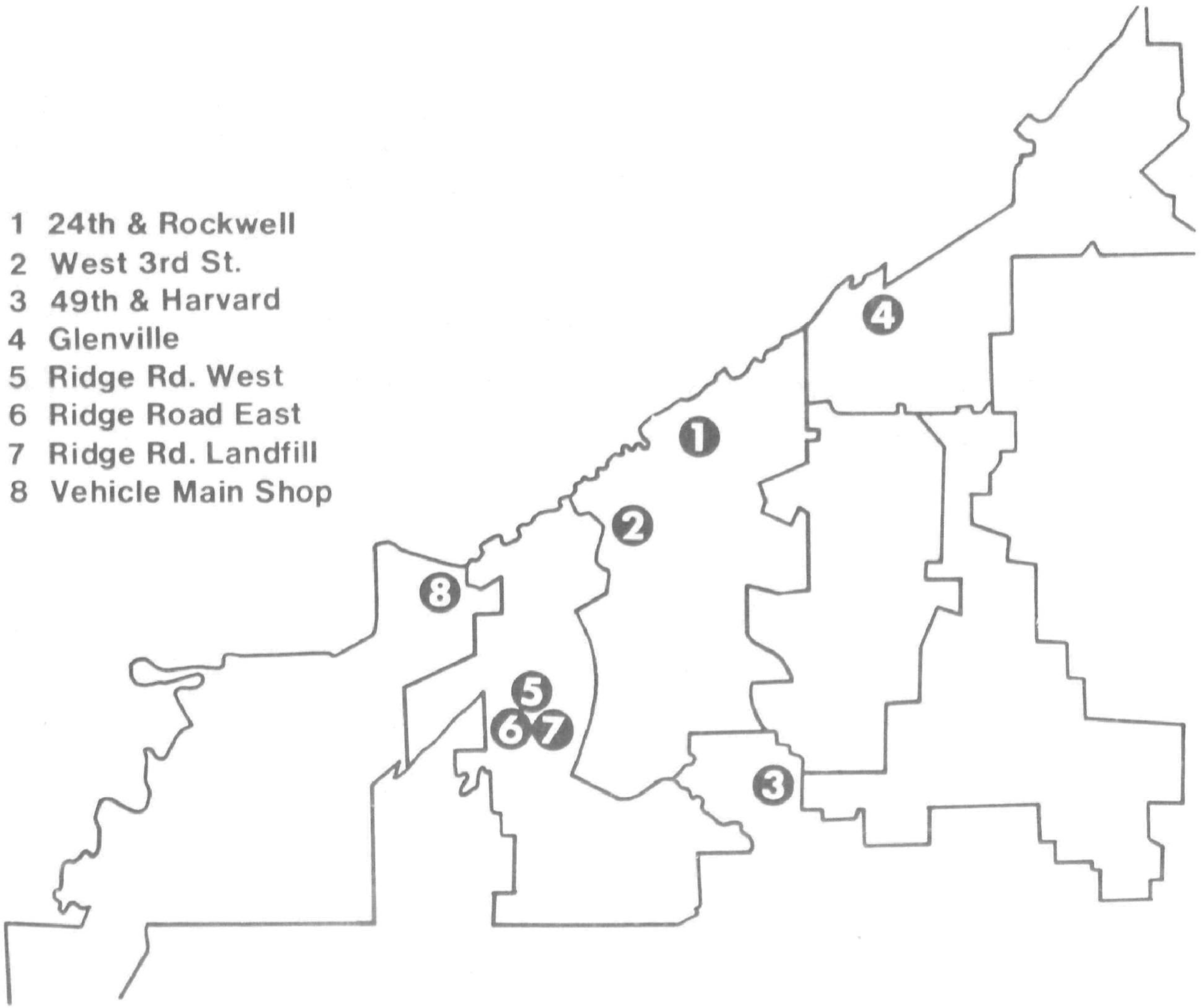

Figure 14 Locating City-owned Property Used by the Cleveland Division of Waste Collection and Disposal.

49th and Harvard facility (Figure 14). This change naturally constituted a variation in total transport miles: however, the model indicated that the variation was not significant. Again, the results were positive, falling well within the required conditions previously stated.

Careful consideration indicated the best off-loading configuration would be to use the Rockside landfill as a terminal and disposal point for the proposed westside division and the Garden Valley site as a terminal and transfer station for the eastside division. The waste would be transported in vans from Garden Valley to the Rockside landfill for final disposal.

Entire City Evaluation

A schematic diagram illustrates variables for the simulation model for the entire city (Figure 15). To check the results of the model, the 92-route configuration, with the 29-2 configuration and the most efficient disposal alternatives, were simulated. The simulation results indicate that this total configuration could easily handle the city's solid waste problem.

STUDY RESULTS

The results of the simulation study combined with the management information system have been spectacular. In 1970, the total complement of employees of the Cleveland Waste Collection and Disposal Division reached a maximum of 1,825. With the use of data obtained in EPA's pilot data network, the number of personnel actually collecting waste on the route was reduced 50 percent. Service in collection operations was changed from back yard to curb side.

After the management information system and simulation model were developed, the total number of routes was reduced from 224 to 138. The total personnel complement now numbers approximately 600 employees. The annual budget has declined from $14.3 million to approximately $9.0 million in 1972.

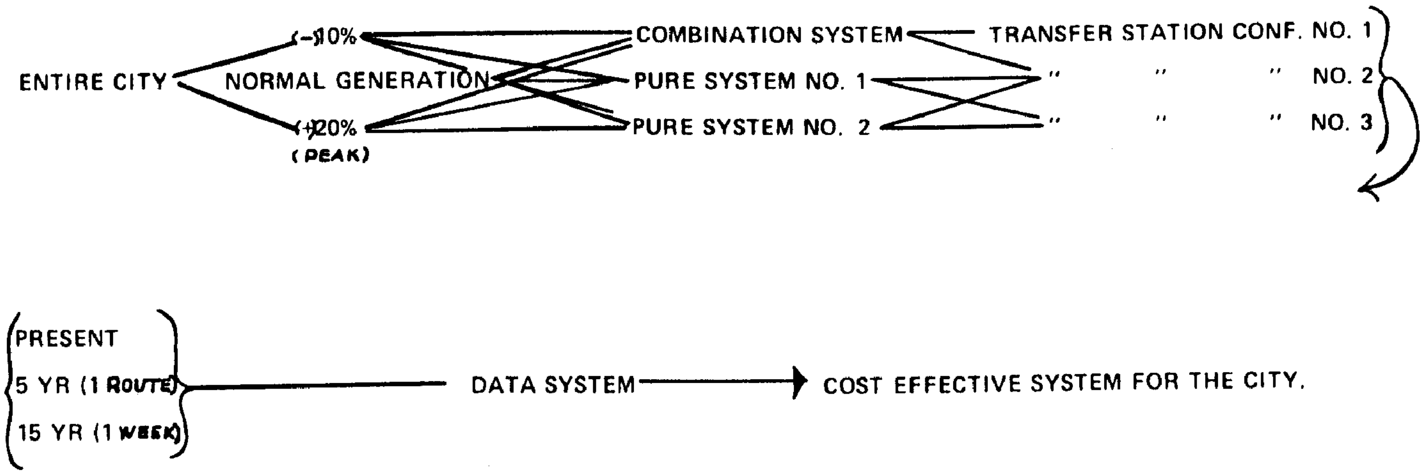

Figure 15 Matrix Indicating Variables Considered for Simulation of City-wide Collection and Disposal System.

The simulation model has been used for both short-term and long-term analysis. In the short term, it was used to restructure existing routes to achieve the budget reduction. In the long term, it has been used to develop the following solid waste management plan:

- The city will be broken into two divisions for solid waste collection. These two divisions are identified as the Westside District (identified numerically as 100) and the Eastside District (identified numerically as 200).

- The ultimate minimum route configuration will be 92 (36 in District 100 and 56 in District 200).

- Motor-pool terminals will be located at the offload sites to maintain a high collection-to-transport time ratio.

- Large-capacity, side-loading, dual-drive, compacting-type vehicles will be purchased for use by one driver and one loader.

- A vehicle maintenance program will be implemented whereby daily servicing and cleaning will be performed by the operating crew and more intensive maintenance will be performed by a welder/mechanic.

As the result of this program, Cleveland's budget, based on 1972 dollars is expected to stabilize at approximately $7.2 million. Figure 16 shows actual and projected changes in numbers of personnel, vehicles and routes, and Figure 17, changes in population, generation (tons), and budget for the city.

City personnel will continue to operate the management information system in conjunction with the simulation model. This study illustrates the power of this approach in effecting and documenting changes in the solid waste system. It is hoped that other communities will be able to use Cleveland's experience as an example for their own solid waste planning activities.

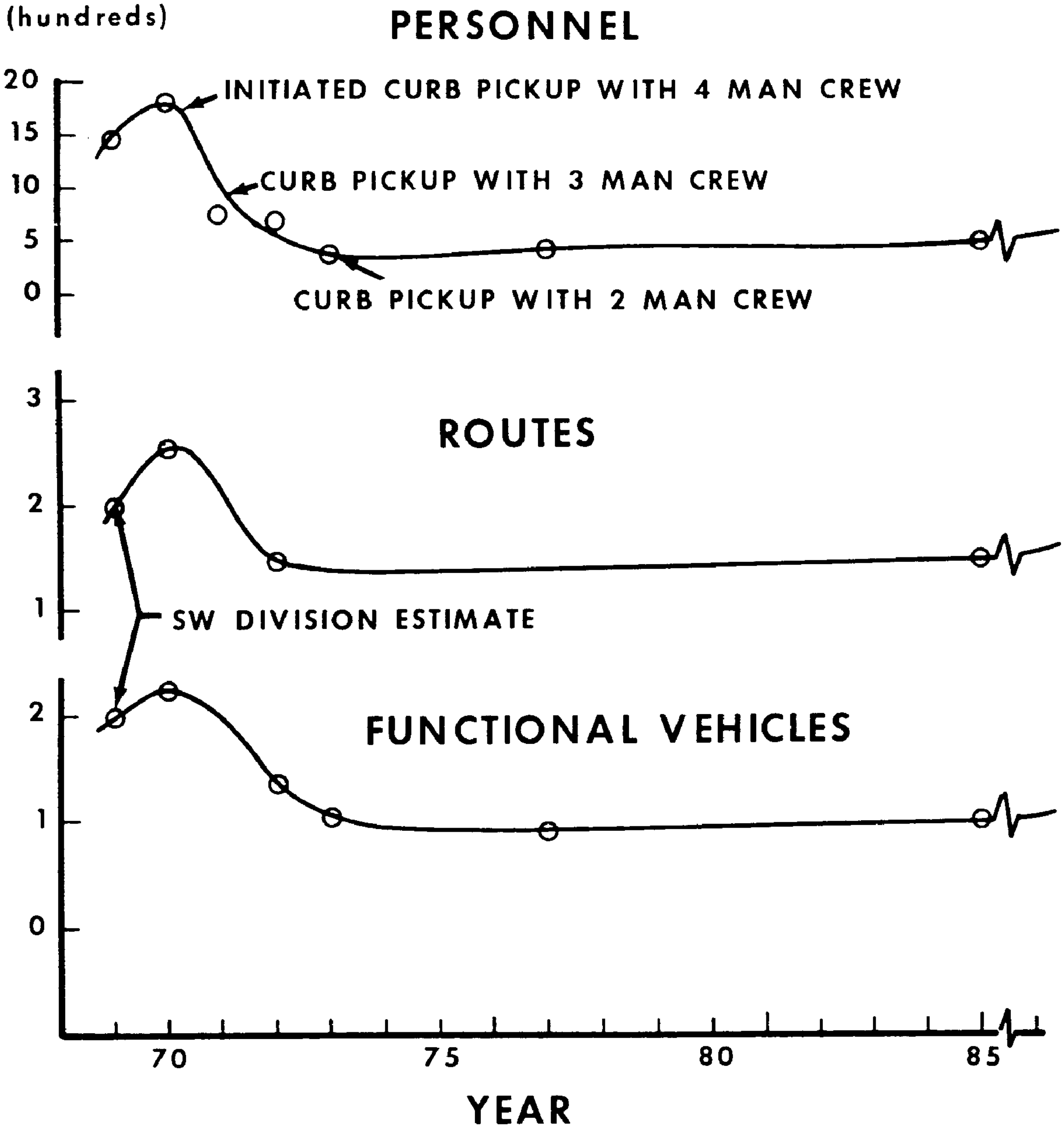

Figure 16

Projected Changes in Personnel, Routes, and Functional Vehicles for the City of Cleveland

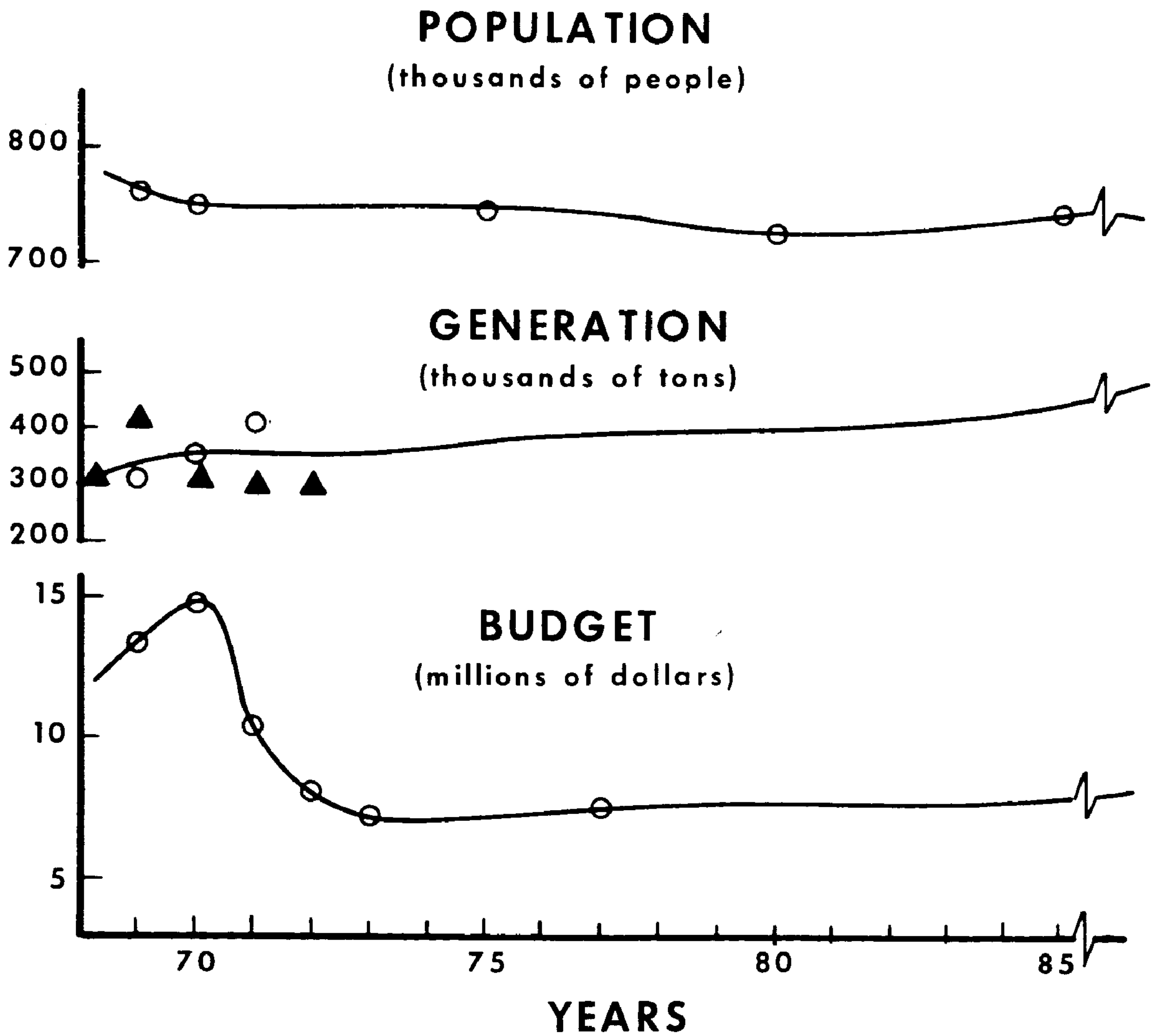

Figure 17

Projected Changes in Population, Generation, and Budget for the City of Cleveland .

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15. Supplementary Notes

16. Abstracts Adequate solid waste management planning is one of the major problems facing most medium-to-large urban communities in the U. S. Increasing waste generation, difficulties in labor-management relations, decreasing land resources, increasing effluent standards, rising cost, and uncertain technology are only a few of the problems facing today's solid waste managers. A technique which is often suggested as a means of bringing these kinds of problems under control is the so called "systems approach." This phrase as generally used is often vaguely defined and is many times totally meaningless. The work cited in this report is a successful application of systems analysis to solid waste management problems in Cleveland, Ohio, and is intended to illustrate the power of the "systems approach" when properly applied. It is hoped that the work cited in this report will be helpful to other communities in the solution of their solid waste management problems.

17. Key Words and Document Analysis. 17a. Descriptors

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17b. Identifiers/Open-Ended Terms

Systems analysis, simulation modeling, and management information systems.

17c. COSATI Field/Group

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