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Balancing Waste Collection Routes

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ABSTRACT

Approximately 10 per cent of every American community's budget is spent to collect and dispose of its solid waste. This paper examines the collection of residential waste using the team approach with load packer trucks. Utilizing the variables number of collection trucks, helpers, families serviced, stops, tons of waste collected, and total haul mileage to the incinerator, a stepwise multiple linear regression analysis was performed to predict the work content of 40 collection areas in the City of Cincinnati, Ohio. The multiple coefficients of correlation and determination are 0.88 and 0.77, respectively, with a standard error of 4 per cent of the average daily work time. The results are valuable for evaluating present collection operations.

Introduction

Local governments responsible for solid waste management know that a serious solid waste problem exists in our society. Approximately 10 per cent of every American community's budget is spent to collect and dispose of its solid waste. According to Richard D. Vaughan, former Assistant Surgeon General and Acting Commissioner, Solid Waste Management Office, "A recent study indicates that Americans spend $4.5 billion annually for solid waste management, and that even this sum is inadequate to insure against environmental pollution from solid waste sources. Approximately 75 per cent

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of the cost of solid waste management is attributable to the collection process . . . ."[1]

Much attention has been directed toward the general problem of fixed-path route optimization.[2-10] Applications of the fixed-path concept to waste collection have been reported for Baton Rouge, Louisiana,[11] Rockville, Maryland,[12] and Winnetka, Illinois,[13] all requiring large-scale computers for data storage and analysis. Many municipalities employ the team approach to waste collection rather than well-defined fixed-path routes because of simplicity and the ability of a team to respond to daily and even hourly changes in collection requirements.

This article examines the collection of residential waste using the team approach with load packer trucks, and describes a simple but rational methodology for evaluating and balancing the work content within the collection team areas of a complex metropolitan region.

Problem Definition

The refuse collection systems used by municipal agencies differ widely as a result of the complexity of the collection problem and the variation in local conditions and requirements. One common method of organizing the work is to divide a city into districts which provide approximately one day's work for one crew or a team of several crews. The method utilizing several crews is called the "reservoir route method" because it provides for a central overflow route among a group of several routes. Typically, three, four, or five routes are laid out in an area around a central route, and the entire group constitutes a working team under the direction of a district foreman. All crews assigned to a given district work until all stops are collected within the entire district.

This team approach not only provides management with greater flexibility and the capacity to deal with hourly operational problems (e.g., changes in disposal site assignment, equipment breakdown . . .), but also offers a time incentive to the crew members since they are free to go when all stops in their district have been collected. However, the existence of the time incentive compels management to balance work content of the team route assignments or be confronted with employee dissatisfaction.

Due to differences in employee efficiency and effectiveness, the equalization of work content involves more than simply equalizing reported work times. It is necessary to establish a rational basis for estimating work content and thereby evaluate the degree of imbalance existing in team route assignments.

The macroscopic approach to be described here consists of statistically relating the recorded work time for each team collection area to defined collection variables for that area: tons collected, number of trucks, number of

dwelling units serviced, number of helpers, number of stops, and total haul mileage to the incinerator.[14] Work time is defined as the time elapsed from 7:00 a.m. to the 43 time[15] minus 30 minutes for lunch. Distance to the incinerator is the map distance (horizontal plus vertical) from the approximate center of the subdistrict (i.e., district-day) to the assigned incinerator.

Distributions of 43 times taken from the sample 10-week period are examined according to district team and day of the week in Figure 1, and Table 1, respectively. When examined by district (Figure 1), we see a noticeable inequality in the day-to-day variation of 43 times. While the day-to-day variations for districts 5, 8, and 9 are each less than one-half hour, the variations for districts 7 and 10 are one hour or more. More importantly, the wide variation in the average 43 time (Figure 1) suggests an inequality in

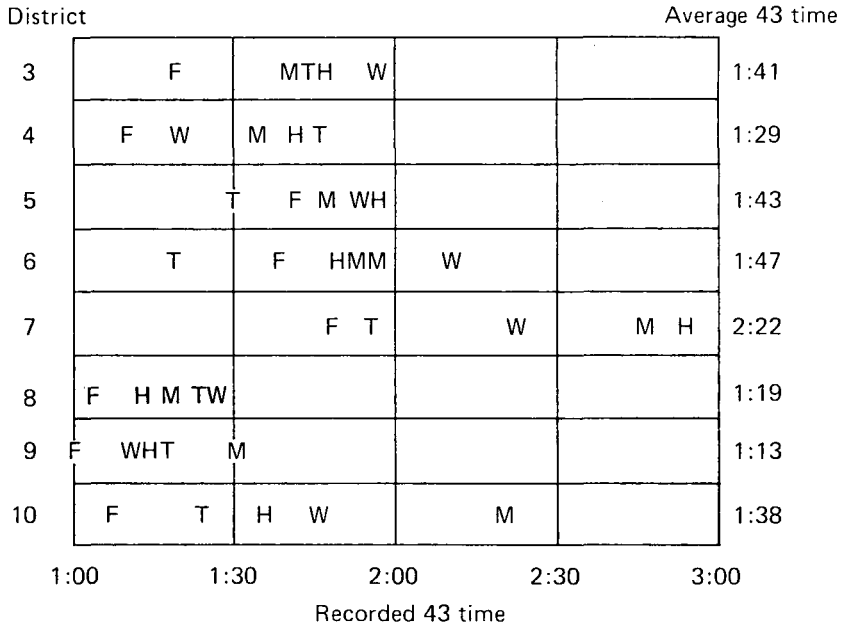

Figure 1. Distribution of 43 times by district.

Table 1. 43 Times Averaged by Day of the Week.

	Mon.	*Tues.*	*Wed.*	*Thurs.*	*Fri.*
Average recorded 43 times	1:51	1:33	1:43	1:43	1:20

team work content. The average 43 time for district 7 (2:22 p.m.) is over one hour later than that for districts 8 (1:19 p.m.) and 9 (1:13 p.m.).

The apparent inequality in work content was recognized by division management and provided the impetus for this analysis. When 43 times are averaged by week day (Table 1) rather than by district, Monday shows the longest reported work time–Friday the shortest.

Analysis

In order to examine the consistency of the reported time data, a stepwide multiple linear regression analysis was performed using an IBM 360/65 computer. The result is the following equation computing the work time, T_W, in minutes for each subdistrict:

$$T_W = 2.57(T) + .347(L) - 3.43(H) - .00516(F) + .0124(S) - 6.93(Tr) + 260.96 \quad (1)$$

where,

T = Average number of tons
L = Average number of loads times the distance to nearest incinerator
H = Number of helpers
F = Number of families
S = Number of stops
Tr = Number of trucks

The resulting order of variables (according to their correlation importance), together with the coefficients of correlation and determination, and standard errors, are given in Table 2. Note from Table 2 that the single best indicator of recorded work time for a subdistrict is *total tonnage;* the next best is loads times distance, or *total mileage to incinerator.* With these two variables alone, the coefficient of correlation is 0.81 and the standard

Table 2. Coefficients and Standard Errors Resulting from Historical Collection Time Analysis.

Step number	*Variable entered*	*Multiple* R	R^2	*Standard error of estimation (minutes)*
1	T	0.77	0.60	16.7
2	L	0.81	0.65	15.9
3	H	0.85	0.72	14.4
4	F	0.86	0.74	14.0
5	S	0.87	0.76	13.8
6	Tr	0.88	0.77	13.7

error is less than 16 minutes. Step-by-step addition of helpers, families, stops, and trucks, increases the coefficient of correlation to 0.88 and decreases the standard error to 13.7 minutes.

In Equation 1 a positive constant multiplied times the variable indicates that the work time increases with the variable (e.g., tons), while a negative constant indicates a decrease in work time with an increasing variable (e.g., helpers or trucks). The final constant is large (260.96 minutes) and represents a fixed work time independent of the variables. The large constant suggests that the range of application of the equation might be quite limited because of the nonlinearity or the exclusion of important collection variables. Thus, caution should be exercised in attempting to predict the effect of a major change in a subdistrict on its work time.

Equation 1 agrees with the reported work times for 46 per cent of the subdistricts within 10 minutes (± 3.0 per cent of the average work time for all subdistricts) and for 82 per cent of the subdistricts within 15 minutes (± 4.5 per cent). The largest difference is +30.4 minutes which may be compared to the total time spread between the earliest and latest reported times of 109 minutes.

The calculated 43 times are compared to the recorded 43 times averaged by district team in Table 3 and by day in Table 4. The by-district comparison together with field knowledge of the characteristics of the city's districts is valuable in suggesting additional collection variables which could be considered (for example, traffic, terrain, and economic factors). The by-day comparison is interesting in that the Monday residual of +14 minutes suggests the need of a morale factor for Mondays.

Conclusions:

The statistical approach described above should be considered as a first approximation to the complex problem of predicting work content in a

Table 3. 43 Times Averaged by District Team.

District number	*Average 43 time (recorded)*	*Average 43 time (calculated)*	*Residual (minutes)*
3	1:41	1:49	-8
4	1:29	1:19	+10
5	1:43	1:38	+5
6	1:47	1:49	-2
7	2:22	2:19	+3
8	1:19	1:18	+1
9	1:13	1:23	-10
10	1:38	1:34	+4

Table 4. 43 Times Averaged by Day of the Week.

	Mon.	*Tues.*	*Wed.*	*Thurs.*	*Fri.*
Average 43 time (recorded)	1:51	1:33	1:43	1:43	1:20
Average 43 time (calculated)	1:37	1:42	1:45	1:43	1:25
Residual (minutes)	+14	-9	-2	0	-5

collection area. It relies entirely on past records without regard to the microscopic details of the collection procedure.

The results are valuable for evaluating existing collection operations, but lack the predictive capability necessary for long-range planning.

The following conclusions are indicated:

1. The macroscopic approach utilizing linear regression techniques exposes a predictability in the recorded time data that one might not have anticipated.
2. The approach can be used to confirm imbalance and to provide a basis for making certain adjustments in work assignments.
3. The methodology can be applied to other collection organizations desiring a simple and quick analysis of their collection route assignments.

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15. The 43 time is recorded when the last can is collected in a district.