A Taxicab Fare Policy Formula Based on Fuel Consumption Observations

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A new taxicab fare collection methodology is proposed. The formulation developed is based on an urban fuel consumption study performed in Austin, Dallas, and Lubbock, Texas, and in Matamoros, Mexico. The formulation determines the fare as a function of travel distance and time with parameters related to vehicle operating cost, driver's wage, and the taxicab agency's profit and overhead cost. A survey of the 1985 fare-setting policies of taxicab agencies in some major U.S. cities has also been performed. On the basis of the survey results, a comparison is made between the currently used and the proposed fare-determination algorithms. The results of a numerical example indicate that the current practice slightly overestimates the travel time contribution to the fare and underestimates that of the travel distance. Consequently the currently charged fare for a trip in congested traffic conditions (long travel time per unit distance) appears to be overcharging the peak-period customer, whereas the reverse holds for the off-peak traffic conditions. The proposed fare-determination algorithm may be particularly useful to regulatory agencies in inferring a taxi agency's unit profit rate embedded in its fare-pricing policy. In addition, the fuel consumption-based algorithm could be used by regulatory agencies to establish fare guidelines in conjunction with taxicab operating costs and revenues.

Of all the forms of urban mass transit, the taxicab industry alone generates more than 50 percent of the annual revenues in the United States. Yet few analytical relations have been explicitly established for fare calculations in metered taxis. Traditionally, taxi fares have been computed on the basis of an initial cost (flag-drop cost) plus additional charges for the distance traveled and the time elapsed. However, assignment of unit charges to distance traveled and time elapsed have not been based on a systematic framework. In this paper an attempt is made to formulate an analytical rationale for the determination of cost weights for traveled distances and times in taxi fare calculations. Recent vehicular fuel consumption studies for urban street networks *(1–5)* and a survey of fare policies of taxicab companies in some major U.S. cities formed the basis of this formulation.

DEFINITION OF VARIABLES

δ = distance increment (mi) for which the taximeter is programmed to advance the fare;
ΔF_d = fare increment (cents) for each δ mi of travel;
τ = time increment (cents) for which the taximeter is programmed to advance the fare;
ΔF_t = fare increment (cents) for each τ min of travel;
N_d = number of meter advancements due to travel δ mi before τ min is reached;
N_t = number of meter advancements due to traveling τ min before δ mi is reached;
N = total number of meter advancements in a trip ($N = N_t + N_d$);
F = total fare for a trip (cents);
F_0 = flag-drop charge (initial fare displayed by the meter) (cents);
δ_0 = distance (mi) covered by F_0;
τ_0 = time (min) covered by F_0;
x = trip length (mi);
t = trip duration (min);
v_r = mean running speed (mi/min);
v = mean overall speed (mph);
T = trip time per unit distance ($1/v$) [min/mi (t/x)];
ϕ = fuel consumed per unit distance (gal/mi);
k_1 = fuel consumption parameter (gal/mi) representing the fuel consumed to overcome the rolling resistance;
k_2 = fuel consumption parameter (gal/min) representing the time-related fuel losses to the engine;
C_F = fuel cost (cents) for an x-mi, t-min trip;
g = gasoline cost (cents/gal);
C_T = total operating cost of a vehicle (cents) for an x-mi, t-min trip;
R = ratio of C_T to C_F;
p = taxicab company's unit profit and overhead costs (cents/mi per taxicab);
w = unit wage of the taxicab driver (cents/min per taxicab);
t_0 = average slack time (min) between unloading one passenger and loading another; and
x_0 = average slack distance (mi) between unloading one passenger and loading another.

CONVENTIONAL TAXIMETER FARE MECHANISMS

Although taxicabs advertise their fares as a function of traveled distance alone, the taximeter itself is programmed to compute the fare as a function of both distance traveled and time elapsed. The results of a 1985 survey of the fare-pricing policy in some major U.S. cities are shown in Table 1. The distance-related portion of the fare is computed in δ-mi increments, and the time-related part is measured in τ-min increments. During a trip, the meter advances once every δ mi or τ min, whichever is reached first. The fare is then advanced by an amount ΔF_t every time the meter advances because of the time constraint τ and by

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TABLE 1 THE 1985 FARE POLICY IN SOME MAJOR U.S. CITIES

City	First Flag Drop			Each Extra Distance		Each Extra Time	
	Fare (F_0,¢)	Time (τ_0,min)	Dist. (δ_0, mi)	Fare (ΔF_d,¢)	Interval (δ,mi)	Fare (ΔF_t,¢)	Interval (τ,min)
Richmond	120	1.0	1/5	20	1/5	20	1.0
Roanoke	120	1.0	1/6	20	1/6	20	1.0
Dallas	130	0.7	1/10	10	1/10	10	0.7
Austin	110	0.67	1/10	10	1/10	10	0.67
San Antonio	110	0.75	1/10	10	1/10	10	0.75
New York	110	0.5	1/9	10	1/9	10	0.5
Chicago	110	1.0	1/10	10	1/10	10	1.0
Los Angeles	120	1.5	1/2	70	1/2	70	1.5
San Francisco	130	0.5	1/6	20	1/6	20	0.5
St. Louis	130	1.0	1/7	10	1/7	10	1.0
Wash., D.C.	109	0.15	1/10	9	1/10	9	0.15
New Orleans	110	1.0	1/10	10	1/10	10	1.0
Seattle	120	0.45	1/6	20	1/6	20	0.45
Atlantic City	135	1.5	1/5	20	1/5	20	1.5

ΔF_d every time the distant constraint δ is reached. For New York City, for example, $\delta = 1/9$ mi, $\tau = 0.5$ min, $\Delta F_t = 10$ cents, and $\Delta F_d = 10$ cents (Table 1). It may be noted that when the meter advances because of reaching either τ min or δ mi, both the time and distance counters are reset to zero.

Based on the foregoing description, the total fare (F) is computed as

$$F = F_0 + N_t\Delta F_t + N_d\Delta F_d \tag{1}$$

where F_0 is the initial charge for the flag drop, and N_t and N_d are the number of times the meter advances as a result of reaching τ min or δ mi, respectively. As may be noted in Table 1, most taxicab agencies select the lengths of τ and δ so that ΔF_t can be considered approximately equal to ΔF_d; this results in the following fare-setting relation:

$$F = F_0 + N\Delta F \tag{2}$$

where N is the total number of times the meter advances, regardless of the cause, and ΔF is the fare increment per meter advancement. It must be noted that the flag-drop charge (F_0) generally covers the first δ_0 mi or τ_0 min, whichever is reached first, so that N is measured δ_0 mi or τ_0 min after the start of a ride. The flag-drop charge in New York, for example, is 110 cents, which covers the first 1/9 mi or 0.5 min (Table 1). Consequently, the fare determination formula for New York becomes F (cents) = 110 + 10N.

In a highly congested area, most of the N meter advancements would be due to reaching the time limit τ, whereas in noncongested locations or off-peak periods N would consist mostly of meter advancements generated by reaching the distance constraint δ. Ghahraman et al. *(6)* have shown that for a ride of length x mi and duration t min, N can be approximated as

$$N = [(1/\delta) - (1/v_r^\tau)]\ x + (t/\tau) \tag{3}$$

where v_r is the mean running speed during a ride. The taxi fare for a ride may then be computed by combining Equations 2 and 3 to obtain

$$F = F_0 + x\Delta F\ [(1/\delta) - (1/v_r^\tau)] + \Delta F(t/\tau) \tag{4}$$

where v_r is in miles per minute.

This fare approximation (Equation 4) can be employed by the taxicab industry for policy-making purposes regarding the values of δ, τ, F_0, and ΔF through performing sensitivity analyses on the cost and revenue outcome of various strategies. The resulting policy decisions regarding initial and incremental costs F_0 and ΔF must, of course, fall within the limits set by regulatory agencies.

FUEL CONSUMPTION STUDIES

Although the determination of F_0 and ΔF using the foregoing techniques is a sound managerial practice, a more systematic framework may be developed based on analysis of taxicab operational costs. To this end, the results of a series of vehicular fuel consumption observations in urban areas may be applied directly.

Recent studies *(1, 2)* have shown that in urban regimes of speeds less than 35 mph, some 71 percent of the variance in fuel consumption per unit distance (ϕ) is accounted for by a single variable, T, the trip time per unit distance (the reciprocal of mean overall speed, v). This one-variable dependence can then be expressed as

$$\phi = k_1 + k_2T \ (v < \sim 35 \text{ mph}) \quad (5)$$

where k_1 and k_2 are vehicle-dependent parameters. It may be noted that $T = 1/v = t/x$.

The model expressed by Equation 5 offers a simple and moderately accurate means of predicting the fuel consumption for urban speed regimes ($v < \sim 35$ mph) and relatively flat network topography. Moreover, it has the advantage that its parameters can be physically interpreted *(5)*. The parameter k_2, for example, is related to various time-dependent losses, mainly the idle fuel flow, which operates while the vehicle is stopped and coasting; this represents 20 to 50 percent of the time spent in congested urban traffic. The parameter k_2 is affected by the engine type, size, and power. The parameter k_1, on the other hand, is related to the fuel consumed per unit distance to overcome rolling resistance and is mainly a function of the vehicle mass. A set of k_1 and k_2 values is presented for various passenger cars in Table 2. In general, the heavier vehicles display greater values of k_1, whereas the smaller and newer models display lower values of k_2. It must be emphasized that as long as a relatively flat topography exists, the values of the parameters k_1 and k_2 are almost entirely functions of the vehicle itself and not of the operational environment and location.

The 1983–1984 fuel consumption observations in Austin, Dallas, and Lubbock, Texas, as well as in Matamoros, Mexico, showed that in more congested locations (higher T-values) such as Matamoros, a greater amount of fuel is consumed per unit distance. However, the fuel consumption per unit distance under various traffic conditions has indeed been a linear function of T, as suggested by Equation 5. The results of these studies are shown in Figure 1, where each data point represents a 1-mi trip for a 1983 Ford Fairmont six-cylinder automobile with a curb weight of 2,825 lb and a measured idle fuel flow for a warmed-up engine of 0.557 gal/hr. This test vehicle had an automatic transmission with three forward ratios and a 3.3-L displacement engine. It used unleaded gasoline with a minimum octane rating of 87. During the fuel observations the four tires were kept at the maximum allowable cold pressure of 35 psi and the air conditioner–heater was not in operation. The tires were of P175/75R14 size and type. The vehicle was equipped with a Model 1240 Fluidyne precision fuel flow indicator to determine the total fuel used for a trip of a given distance. The fuel meter was installed under the hood. The gasoline line fed through the following parts in sequence: inline

TABLE 2 FUEL CONSUMPTION CHARACTERISTICS OF VARIOUS VEHICLES

Reference	Vehicle	Model Year	Test Mass (lbs)	k_1 (gal/mile)	Idle Fuel Flow Rate (gal/min)	k_2 (gal/min)
Present Study	Ford Fairmont	1983	3125	0.0317	0.0093	0.0090
5,7	British Bedford CF Van	1978	3770	0.0347		0.0082
5,7	British Bedford CF Van	1978	4872	0.0438		0.0083
8	Standard-Sized Car	1975	5050	0.0551	0.0128	0.0153
8	Standard-Sized Car	1974	4980	0.0650	0.0139	0.0166
8	Small Imported Car	1974	2277	0.0256	0.0089	0.0105
8	Intermediate Size Car	1975	3792	0.0496	0.0111	0.0120
8	Large Luxury Car	1974	5474	0.0709	0.0132	0.0172
8	Subcompact Station Wagon	1975	2833	0.0420	0.0073	0.0094
2	Subcompact Car	1973	3620	0.0526	0.0044	0.0070
9	Small Van	1956	2352	0.0209	0.0033	0.0050
9	British Car	1955	3025	0.0447	0.0059	0.0083
10	Empty Minibus	1965	3717	0.0532		0.0055
10	Loaded Minibus	1965	4592	0.0588		0.0063
10	Small British Car	1965	2251	0.0329		0.0084
10	British Car	1964	3258	0.0494		0.0084
11	Australian Station Wagon	1965	3200	0.0362		0.0094
16	Ford Cortina		2667	0.0240		0.0071
17	Ford Escort		2116	0.0172		0.0080
18	Renault R12		2337	0.0298		0.0044

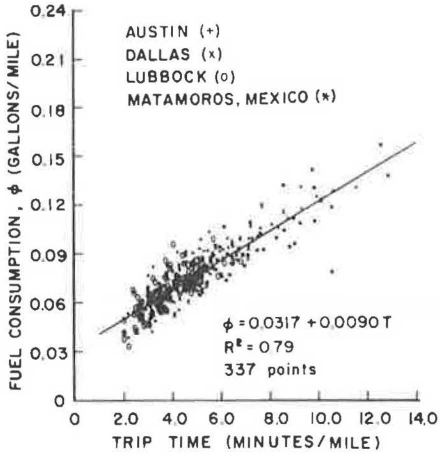

FIGURE 1 Fuel consumption versus trip time, 1983 six-cylinder Ford Fairmont Futura with automatic transmission.

filter, auxiliary electric fuel pump, pressure regulator, glass-walled filter, Fluidyne fuel meter, original mechanical fuel pump, and carburetor.

As is evident from Figure 1, the data for the four cities spread along a fairly linear band, and the regression line that indicates the trend is given by

$$\phi = 0.0317 + 0.0090T \tag{6}$$

with ϕ in gallons per mile, T in minutes per mile, a total of 377 points, and $R^2 = 0.79$. These values of $k_1 = 0.0317$ gal/mi and $k_2 = 0.0090$ gal/min can be compared with the average values over nine vehicles tested in Detroit some years ago *(8)*, namely, $k_1 = 0.0362$ gal/mi and $k_2 = 0.0214$ gal/min. The reductions in the values of these parameters over the years reflect the general improvements in fuel efficiency and idle fuel flow of later vehicle models. This point is further illustrated in Table 2 where k_1 and k_2 values for 15 vehicle models are tabulated. In addition, the values of k_1 and k_2 for the Ford test vehicle in this study fall well within the scatter of the remaining data in Table 2. The data in Table 2 are also graphically presented in a plot of k_1 versus vehicle mass (Figure 2) and k_2 versus the measured idle fuel flow (Figure 3). A linear regression of k_1 versus M, forced through the origin, yields a slope of 1.21×10^{-5}gal/mi-lb (Figure 2) and that of k_2 versus I yields a slope of 1.20 (Figure 3).

FARE DETERMINATION BASED ON FUEL CONSUMPTION

The foregoing fuel consumption results may be used to directly establish a methodology based on fuel consumption for the fare determination of an x-mi, t-min taxi ride. In doing so, it must first be noted that the variable T (= t/x) in Equation 5 by itself accounts for a large part of the traffic dependence of fuel consumption, which in turn constitutes a major portion of the operational cost of a vehicle.

Thus, the vehicle-related parameters k_1 and k_2 as well as the trip duration (t) and the trip length (x) of a ride form a sufficient basis for determination of the fuel cost of a taxicab engaged in a trip x mi long and t min in duration; namely,

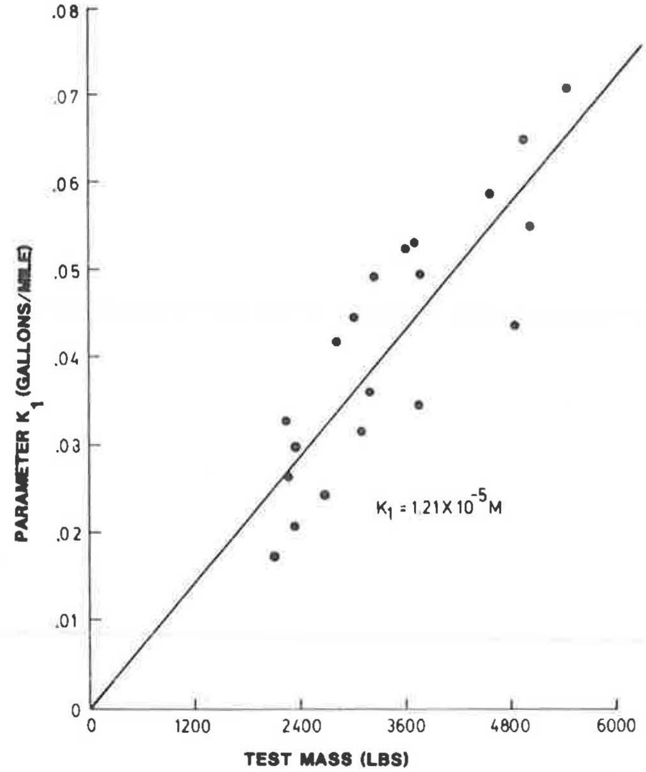

FIGURE 2 Fuel parameter k_1 versus vehicle test mass M for various vehicles in Table 2.

$$C_F = xg(k_1 + k_2T) \tag{7}$$

where g is the gasoline cost per gallon and C_F is the total fuel cost for a trip x mi long with an average trip time of T min/mi. Knowing that T = t/x, Equation 7 may be simplified as

$$C_F = g(k_1x + k_2t) \tag{8}$$

The total operational cost (C_T) of a vehicle includes the fuel cost as well as other major operational expenses such as oil, maintenance and repair, tire wear, and depreciation costs. The ratio C_T/C_F may be denoted by R where R > 1. Results reported by Claffey et al. in 1971 *(15)* yield R = 1.75 for a composite passenger car operating at 30 mph average speed (including turns and speed change effects) for a relatively flat topography. A composite car was defined *(15)* for a vehicle mix of 20 percent large, 65 percent standard size, 10 percent compact, and 5 percent small cars. Data compiled by Zaniewski et al. in 1982 *(16)* imply that R = 1.9 for a medium-sized automobile operating at 20 mph average speed on a relatively flat terrain. The total cost may then be formulated as

$$C_T = Rg(k_1x + k_2t) \tag{9}$$

To formulate a fare-setting algorithm based on the total cost C_T of Equation 9, it is necessary that variables representing the profit and overhead costs of the taxicab agency as well as the driver's wage be included. The driver's unit wage per minute is

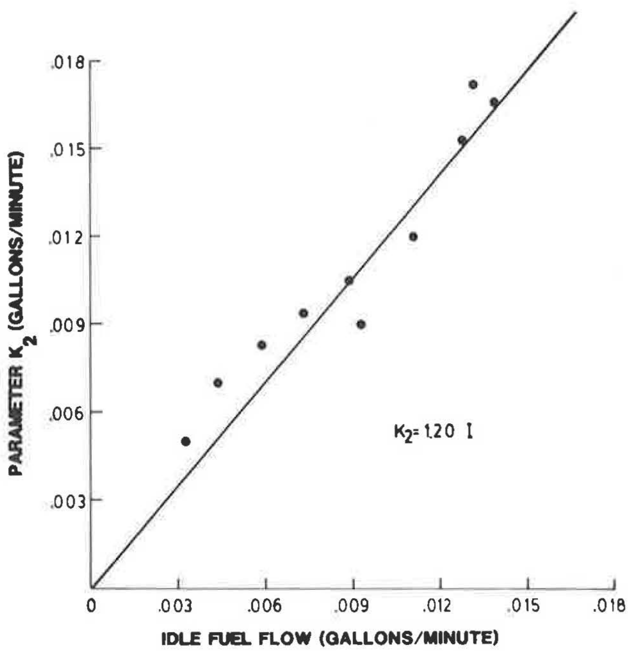

FIGURE 3 Fuel parameter k_2 versus vehicle idle fuel flow I for various test vehicles in Table 2.

denoted by w and the expected company profit and overhead costs per mile of operation per taxicab by p. Then during an x-mi, t-min ride, the accumulated fare (F) may be computed as

$$F = F_0 + (x - \delta_0)(Rgk_1 + p) + (t - \tau_0)(Rgk_2 + w) \quad (10)$$

where F_0 is as before the flag-drop charge, which also covers the fare for the initial δ_0 mi or τ_0 min of the ride, whichever is reached first. The variables in Equation 10 are x and t.

The initial fare F_0 is usually set at a higher value than may be computed by considering unit operating costs, profit, company overhead, and driver wage for δ_0 mi and τ_0 min of operation. A higher value of F_0 is generally used in order to discourage customers from engaging taxicabs for very short trips. Responding to calls for short trips is undesirable from an operational standpoint, because in a competitive environment this could result in losing customers in need of considerably longer and more profitable rides. In addition, the cost incurred by responding to such calls (for driving to the customer's location and making the actual trip to the destination) may indeed exceed the fare collected unless a sufficiently high value of F_0 is charged.

The foregoing considerations suggest that the computation of F_0 as a minimum must include the cost of a trip $(x_0 + \delta_0)$ mi long and $(t_0 + \tau_0)$ min in duration, where x_0 and t_0 are the slack distance and time, respectively (i.e., the mean distance and time that a taxicab without passengers travels before arriving at the origin of a call). The values of slack distance x_0 and slack time t_0 must, of course, be determined by performing a statistical analysis on the relevant data available or to be collected. These values primarily would be a function of the size of the metropolitan area, the taxi fleet size, and the spatial distribution of taxicabs. Having set the values of δ_0 and τ_0 by policy and knowing the values of x_0 and t_0, the initial fare F_0 may then be estimated to be

$$F_0 = (x_0 + \delta_0)(Rgk_1 + p) + (t_0 + \tau_0)(Rgk_2 + w) \quad (11)$$

Combining Equations 10 and 11 would then yield an analytical algorithm based on fuel consumption to determine the fare for a taxi ride x mi long and t min in duration.

A NUMERICAL EXAMPLE

The following numerical example is presented to provide a better understanding of the magnitude of the various parameters in the proposed fare-setting formula (Equation 10) as well as the sensitivity of the fare to these parameters. In addition, the fare associated with a specific trip as determined by Equation 10 is compared with an estimate of the currently charged fare obtained through Equation 4.

For example, consider a New York City taxicab agency operating a fleet of medium-sized cars ($k_1 = 0.032$ gal/mi, $k_2 = 0.009$ gal/min). Let us also assume a driver's hourly wage of \$9.00 (w = \$0.15/min) and a profit and overhead rate of \$0.25 per mile per taxicab (p = \$0.25). An average cost for unleaded gasoline of \$1.35/gal (g = \$1.35) and R = 2 will also be used in the computations. Note from Table 1 that in New York the flag-drop charge currently in effect covers an initial distance of 1/9 mi ($\delta_0 = 1/9$) or an initial duration of 0.5 min ($\tau_0 = 0.5$ min). An assumption must also be made regarding the values of x_0 and t_0 in New York City. In this example $x_0 = 1$ mi and $t_0 = 4$ min are used. Hence,

x_0 = 1 mi,
t_0 = 4 min,
R = 2,
g = \$1.35/gal,
k_1 = 0.032 gal/mi,
k_2 = 0.009 gal/min,
δ_0 = 1/9 mi,
τ_0 = 0.5 min,
p = \$0.25/mi, and
w = \$0.15/mi.

With these parametric values, Equation 11 yields a flag-drop charge of F_0 = \$1.16 compared with the current New York City flag-drop charge of \$1.10. Substituting a value of \$1.16 for F_0 in Equation 10 and using the foregoing parameter values results in the following fare-setting relation for New York:

$$F = 116 + 33.64\,[x - (1/9)] + 17.43\,(t - 0.5) \quad (12)$$

Therefore, a peak period 6-mi ride of 30 min duration in New York City corresponds, according to Equation 12, to a fare F = \$8.28.

For comparison purposes, the current charge for a 6-mi 30-min ride in New York can be estimated by means of Equation 4 *(6)* by using the current taxicab fare structure in New York outlined in Table 1, namely,

F_0 = \$1.10,
ΔF = \$0.10,
δ = 1/9 mi, and
τ = 0.5 min.

Note that in using Equation 4, the average running speed (v_r) for this 6-mi, 30-min trip must first be estimated. Observations in the New York–Newark area *(17, 18)* have shown that, on the average, a vehicle is stopped 36.8 percent of the time during the peak period. Therefore, during the 6-mi, 30-min ride, on the average, the taxicab can be assumed to have been stopped for 11.3 min and in motion for the remaining 18.7 min of the trip, yielding an average running speed v_r = 19.2 mph or 0.32 mi/min. Hence, Equation 4 is calibrated as

$$F = 110 + 27.5x + 20t \tag{13}$$

Consequently, by using Equation 13, an estimate of the fare currently charged in New York City for a 6-mi, 30-min ride is $8.75. This is to be compared with a fare of $8.28 for the same trip computed by using the fuel-consumption-based relation of Equation 12.

Although these fares ($8.75 versus $8.28) are remarkably close, it must be noted that in the current fare determination practice (Equation 13) the traveled time is weighted slightly more ($0.20/min) as compared with the proposed fuel-based formula (Equation 12), in which time is weighted as $17.43/min. Unlike travel time, the influence of the travel distance is slightly underestimated in practice (Equation 13), particularly at higher levels of congestion. This is so because the coefficient of x in Equation 4 is directly proportional to the average running speed (v_r). As v_r decreases with an increase in the level of concentration, the value of the coefficient of x would become smaller. In order to avoid a negative coefficient for x, v_r must be greater than δ/τ. Thus, the fare approximation relation of Equation 5 is only valid for $v_r > \delta/\tau$. For this numerical example that threshold is 13.4 mph. As a result, in uncongested traffic conditions (short trip times per mile), from the perspective of the cost of operating a taxicab, customers are slightly undercharged. On the contrary, in very congested traffic (long trip times per mile) the customers would be overcharged. It must, however, be noted that the time and distance coefficients in Equations 12 and 13, although insensitive to x_0 and t_0, are rather sensitive to these assumptions regarding p and w. Consequently, the foregoing conclusions are only warranted if realistic values of p and w are assumed. In light of which, the proposed fuel-consumption-based algorithm may be particularly useful to regulatory agencies in estimating a taxicab company's unit profit and overhead costs based on its practiced fare-setting formula.

SUMMARY AND DISCUSSION

Any taxicab fare-setting formula must consider both travel time and travel distance. Although the taxicab in-vehicle public information bulletins may imply that the fare is only a function of the travel distance, in reality a taximeter operates as a function of distance and time. This is self-evident when a meter advances while the taxi is standing still.

The conventional taximeter increases the initial flag-drop charge by a fixed fare increment for every fixed distance or time interval, whichever is reached first. The flag-drop charge itself covers the fare for an initial specified travel distance or time, whichever is reached first.

The results of an urban fuel consumption study are presented on the basis of which a new taxicab fare-setting algorithm is formulated. The formulation considers the total operating cost of the vehicle, the driver's wage, the company's profit and overhead costs, and the cost of taxicab slack times as well as slack distances.

In the use of the developed algorithm, it must be noted that it is based on a fuel consumption relation that is valid only for urban speed regimes less than about 35 mph. This is the case because at speeds greater than 35 mph fuel consumption increases with speed due to aerodynamic drag, as shown in Figure 4. However, as may be seen in Figure 4, these increases are small up to speeds of about 50 mph. Thus the proposed algorithm would not be significantly in error if used for rides a

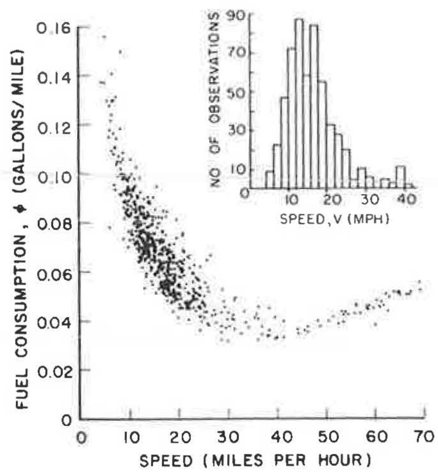

FIGURE 4 Fuel consumption versus speed in central business districts of Austin, Dallas, Lubbock, and Matamoros and highway data from several 3- to 5-mi, relatively flat sections of Texas freeways collected with 1983 Ford Fairmont.

portion of which takes place in nonurban speed regimes. Another limitation of this formulation is that the underlying fuel consumption model does not account for considerable changes in grade. Adjustments are needed if the relation is to be used in other than moderately rolling or flat terrain. Pelensky et al. *(11)* have suggested an urban fuel consumption relation similar to Equation 5 that includes a grade-adjustment term as well. However, the use of such a relation in the determination of taxicab fares would require significant changes in the taximeter operational mechanism to measure longitudinal roadway grades in the course of a ride.

The proposed fuel-consumption-based formulation has been calibrated for New York City. The resulting outcome is compared with that of the current fare-setting practice as determined from a 1985 survey of fare policies in some of the major U.S. cities. The comparison indicates that although the fare based on current practice for an average ride is reasonable, the current fare-pricing structure may be overcharging the peak-period customers and slightly undercharging the off-peak-period customers. The proposed algorithm may also be useful to the regulatory agencies in studying a taxicab agency's fare policy and establishing fare guidelines in conjunction with taxicab operating costs.

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