Critique of Texas Research and Development Foundation Vehicle Operating Cost Model

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Between 1979 and 1981 the Texas Research and Development Foundation (TRDF) investigated the effects of highway design and pavement condition on vehicle operating costs (VOC) for FHWA. TRDF VOC data have been included in many highway planning and project evaluation models, including the Canadian Highway User Benefit Assessment Model, and two recent models, Highway Economic Requirements System and MicroBENCOST. The estimation methodology adopted and current applicability of VOC data developed by TRDF are critically examined. In addition, the structure and major assumptions underlying the TRDF model are described, and the TRDF data are compared with actual consumption of the VOC components and with fuel consumption predictions by ARFCOM. The TRDF model encodes highway, vehicle technology, operation, and economic conditions typical of the 1970s. Judgmental manipulation of the data base by TRDF has introduced further problems. Typical vehicles are fixed to those reflecting the fleet in 1978, and the model lacks a representative modern heavy truck. All VOC components, especially fuel consumption, have been proven to be erroneous to some degree. The model cannot adequately serve present highway investment appraisal needs. A mechanistically based substitute for the TRDF model should be developed from the components of state-of-the-art models: HDM-III, VETO, ARFCOM, and South African VOC methodology.

Between 1979 and 1981 the Texas Research and Development Foundation (TRDF) investigated the effects of highway design and pavement condition on vehicle operating costs (VOC) (*1*). The TRDF VOC data have been used in the Highway Performance Monitoring System (HPMS), and some highway departments have included the relationships into computerized models. The effects of pavement condition from the TRDF data has been included by Elkins et al. (*2*), whose aggregated equations, with only minor modifications and price indexing, have been included into the Highway Economic Requirements System (HERS). The TRDF relationships form the VOC prediction module of the Canadian Highway User Benefit Assessment Model (HUBAM).

The most current application of the TRDF data is in the MicroBENCOST software being developed under NCHRP Project 7-12. MicroBENCOST features multiple regression equations fitted to VOC tables developed by Zaniewski et al. (*1*) but modified for fuel consumption of trucks at zero grade in accordance with data collected by France (*3*). The component unit prices from 1980 have been updated using price indexes.

This paper critically examines the estimation methodology adopted, and the transferability of VOC data developed by TRDF. The TRDF data are compared with actual consumptions of the VOC components and with fuel consumption predictions by ARFCOM. The disaggregate VOC relationships, as used in MicroBENCOST in November 1991, are considered to represent the TRDF data for the present critique.

OUTLINE AND GENERAL CRITIQUE OF TRDF MODEL

Major Assumptions

The TRDF study made a number of assumptions to obtain a workable model of VOC from available statistical and experimental data, but inaccuracies resulted in the VOC. Independent verifications in Canada and Australia confirmed the inaccuracy of fuel, tire, maintenance and repair, and depreciation predictions of VOC models on the basis of TRDF data.

Elemental Vehicle Operations

The TRDF model assumes that the following four classes of vehicle operation adequately describe all traffic operations relative to road variables in highway investment analyses: (a) running at constant speed under uniform road and traffic conditions on level tangents and on grades, with an adjustment for the effect of pavement condition; (b) changing speed between road sections with different physical road and traffic characteristics; (c) negotiating a horizontal curve; and (d) idling the engine while the vehicle is stopped.

Disaggregation

Aggregate data on vehicle resource consumption can be disaggregated to yield data on representative vehicle types. This information can be further disaggregated by road characteristics and vehicle operating conditions, using proxy methods as described below. Except for fuel consumption, the functional dependencies between consumption of vehicle operating resources and road conditions were judgmental.

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Vehicle Type

Seven vehicle classes represent the highway fleet. Each vehicle is representative of its class, and all members of a vehicle population relevant to highway investment appraisal are covered. In reality, there is a variation of vehicle characteristics within each vehicle type, and the borderlines between types may be arbitrary. Actual vehicles in a traffic stream differ in characteristics and utilization and thus in the amount of resources consumed under identical road conditions.

Data Base

The collection of data in the United States was limited to truck operating costs and fuel consumption experiments for the seven vehicle classes. Operating costs for 12,489 trucks were provided by 15 intercity line-haul carriers operating primarily on Interstate highways. Truck ages and mileages were obtained from the Bureau of Census 1977 inventory, which was supplemented with historical vehicle registrations. The operating costs of light vehicles were estimated from pre-1980 data whose vehicle technology, utilization, and cost factors are now obsolete. Fuel consumption was measured on eight vehicles during idle, acceleration, deceleration, and constant-speed driving. Tests for various speeds, grades, and road surfaces were conducted at constant speeds.

The TRDF researchers had the benefit of access to data collected for the study in Brazil from which eventually the World Bank's HDM-III model resulted. Preliminary results of the Brazil project were used to estimate the effect of road roughness on VOC for FHWA.

Model Structure

MicroBENCOST calculates VOC for representative vehicles as a function of road parameters and traffic operating conditions. The operating cost components include fuel, oil, tire, maintenance and repair (MRP), and mileage-related vehicle depreciation. The highway vehicle representatives are three light vehicles, two straight trucks, and two truck combinations. Road conditions are represented by grade, curvature, and pavement surface condition.

Elemental VOC

MicroBENCOST disaggregates the VOC components by the class of vehicle operation: (a) uniform speed costs, (b) pavement condition excess costs, (c) horizontal curve excess costs, (d) speed change cycle excess costs, and (e) idling costs. Table 1 shows which VOC components are calculated for each vehicle operation class. Logically, no tires are consumed in the idling mode, but TRDF did not consider that there is additional oil consumption and depreciation on curves or added fuel consumption on pavement surfaces in poor condition.

Total VOC

For a vehicle type, each VOC component is the product of the resource consumed and the unit resource price. These component costs sum up to a vehicle operation class subtotal cost for that type of vehicle. The subtotal is then multiplied by the amount of elemental operations, which is the segment length for uniform speed, pavement condition, and horizontal curve; the number of cycles for speed change; and the number of idling hours for idling. All elemental subtotals relevant to the planning case add up to the total VOC for that vehicle type. A product of the total VOC and the annual volume of the vehicle type represents the vehicle's total VOC per year. A sum of these VOC per year over all vehicle types is the grand total VOC per year of the highway planning case.

Major Variables

Traffic Speeds

Vehicle speed is the speed of a vehicle running along a section with uniform physical and traffic characteristics. All uniform-speed VOC components are dependent on the speed of vehicle on positive, zero, and negative grades, except that depreciation cost has no models for grades other than zero. Horizontal curve excess costs of fuel, tires, and MRP also depend on vehicle speed in MicroBENCOST.

Whenever a vehicle changes its traveling speed to stop or slowdown or to resume its initial speed, it incurs additional costs. "Begin cycle speed" is the constant travel speed of a vehicle before the change in speed takes place. After the change, the new constant speed is the "end cycle speed." After the speed reduction to the slower end cycle speed, which includes a stop, the vehicle is assumed to return to the begin cycle speed. The full speed change cycle thus goes from the begin speed to the lower end speed and back to the begin speed. These variables appear only in the speed change cycle VOC submodels.

Many speed change profiles cannot be adequately represented with the begin and end cycle speeds. Returning to a

TABLE 1 VOC Components by Vehicle Operation Class

	Uniform Speed	Horizontal Curve	Speed Change	Idling	Pavement Condition
Fuel	yes	yes	yes	yes	no
Oil	yes	no	yes	yes	yes
Tires	yes	yes	yes	no	yes
MRP	yes	yes	yes	yes	yes
Depreciation	yes	no	yes	yes	yes

speed different from the begin cycle speed is usual in congested traffic and urban driving, but this type of speed profile is not covered by the TRDF method.

Road Conditions

Road conditions are represented by Grade -8 to $+8$ percent, horizontal curvature 1 to 30 degrees, and pavement service index (PSI)—a measure of longitudinal roughness and the independent variable in all pavement condition excess VOC submodels. Such submodel does not exist for fuel consumption in MicroBENCOST.

The TRDF relationships do not contain pavement surface variables other than PSI. A large contribution to vehicle rolling resistance arises from the road surface texture, and the effect of pavement deflection bowl that forms under a heavy wheel could also be substantial on gravel roads, surface treatments, and thin pavements (*4*). The TRDF relationships for heavy vehicles are most likely not appropriate for appraising low-volume roads.

Gross Vehicle Weight

Gross vehicle weight (GVW) includes the mass of the vehicle and its payload. MicroBENCOST uses GVW only for vehicles larger than pickup trucks and vans. For a road investment proposal involving significant changes to grades, actual average GVW on the forehaul and backhaul legs of a trip should be considered. When a higher level of aggregation is required, average round-trip GVW of trucks can be assumed. Average GVW on each leg of a trip, average round-trip GVW, and variations from the averages are not well surveyed. Time and regional and road class variability can be expected. Future predictions depend on factors such as possible changes to truck axle and GVW limits, economic conditions in the country, and truck fleet operations management.

In MicroBENCOST, truck GVW affects fuel consumption on all grades at uniform speeds, excess MRP caused by pavement surface condition, and excess fuel and depreciation caused by idling. In the latter relationships GVW is obviously used as a proxy of a more detailed description of vehicle parameters such as engine size. GVW should also affect tire consumption, but TRDF data do not show this.

Unit Resource Prices

The resources consumed by a vehicle on a road are fuel, oil, tires, maintenance and repair parts and labor, and depreciable value of vehicle. The unit prices of these resources differ between vehicle types.

Uncertainty

TRDF data do not address uncertainty of VOC estimates. Highway investment appraisals would benefit from analysis of uncertainty of the economic indicators calculated from the uncertain cost components. Road condition variables are considered deterministic in the analysis of planning cases using MicroBENCOST. This is not strictly true for aggregated analyses, such as corridor studies, in which gradients and curvatures are estimated. However, these estimates bear much less uncertainty than traffic or operating cost assumptions and can thus be regarded as deterministic. Pavement condition is a random variable, depending on pavement quality, traffic and environmental loading, maintenance effort, and rehabilitation policy, all of which change over time.

The most uncertain inputs into VOC calculations are traffic volumes and mix, typical vehicles, and characteristics of these vehicles. The MicroBENCOST VOC model does not provide any procedures for calculating the variance of total VOC. A vital piece of information for decision making is thus missing.

Transferability

User costs depend on a region's economy, vehicle technology, driver behavior, regulations, and fleet operating decisions (*5*). Since the TRDF VOC data embody the effects of the various conditions in the 1970s, updating these data—as well as transfer to regions with local conditions that are different from the average considered by the TRDF—is problematic. The TRDF fuel consumption values are based on eight vehicles chosen to be typical in 1980. Other VOC components are based on data collected in the 1960s. The TRDF VOC data are not suitable at all to examine road investment policy, program, and project analysis questions arising from current and expected developments affecting operations and VOC of light and heavy vehicles. The transferability limits are discussed by Bein (*4*).

Vehicle types in MicroBENCOST are based on 1970s vehicle fleets analyzed by Zaniewski et al. (*1*) and France (*3*). The vehicle characteristics and utilization encoded into the vehicle types and VOC relationships are thus largely obsolete. Truck combinations larger than 3-S2 are not represented.

MicroBENCOST updated the 1980 unit resource prices (*1*). However, price indexes cannot reflect relative price changes within a VOC component, such as parts and labor in the MRP. It is unreasonable to keep updating an old price over a long period, particularly if drastic changes have taken place in the economic environment.

CRITIQUE OF FUEL CONSUMPTION

The fuel consumption values are deficient and unsuitable for use in VOC models. Fuel consumption tests were carried out by TRDF for idling, acceleration, deceleration, and constant-speed driving. The latter mode received most of the experimental effort, and it tested the effects of speed, grade, surface type, and pavement condition. Measured values were transferred into sets of fuel consumption tables. No tests were carried out for large truck combinations, and results for a 3-S2 unit were assumed. The effect of curves was derived by comparing horsepower needed to traverse a curve at a constant speed with the horsepower required to climb a grade at the same speed, for which fuel consumption was measured.

Reliability of Measured Values

The fuel consumption values are based on only one test vehicle in each class, except that two identical vehicles were used for a medium car. If any of the single test vehicles had unusual fuel consumption characteristics, all future estimates for that class would be affected. For example, the two large TRDF trucks cut off fuel during engine motoring on steep grades and hard decelerations, and all trucks in those classes are assumed to behave this way.

The measured values were smoothed, but some inconsistencies remain. For example, the five-axle diesel truck traveling at 80.5 km/hr consumes less fuel on a 5.6 percent grade than on a 2.6 percent grade, and the constant speed fuel consumption rate of a four-axle truck is less at 113 km/hr than at 72 km/hr on zero grade.

The measured values tended to be lower than expected when fuel flow rates were high. Fuel consumption is difficult to measure for diesel engines because of a fuel return loop that takes unused fuel from the engine back to the fuel tank. It appears that this problem had not been overcome, but it should have been identified when the data were collected. This problem raises the question of how well other factors, such as wind, tire pressure, and engine temperature, were controlled during the tests.

Inconsistencies

Clayton (*6*) gives expressions for calculating on-road fuel consumption rates for a given GVW for each season on the basis of a large amount of data collected for trucks across Canada. The data apply to nonurban travel at about 90 km/hr on high-class, paved rural and intercity highways. The fuel rates would be slightly lower in the United States because of the milder winters. Table 2 compares TRDF fuel consumption values with average summer values for those trucks calculated using Clayton's expression. The TRDF estimates include the effect of speed fluctuation, but not the effect of the number of stops, which are few in intercity travel and will have little effect on fuel consumption. TRDF values are given for two running speeds and are 40 to 60 percent greater than typical on-road values for Canadian trucks.

For uniform speeds, observed Canadian vehicle fuel consumption is only about half of that predicted with the TRDF relationships in the HUBAM model for four vehicle types examined (*7*).

Excess Fuel Consumption per Stop or Slowdown

The method used in the TRDF study to calculate acceleration and deceleration fuel consumption and excess fuel per stop gives very poor estimates. The test vehicle was accelerated (decelerated) from rest (maximum cruise speed) to maximum cruise speed (rest), and the fuel flow was measured every 2 sec. A very simple linear function was fitted to the cumulative fuel flow during the maneuver. The fuel consumption for accelerating (decelerating) from any Speed v1 to a Speed v2 was found by subtracting the cumulative fuel flow at Speed v1 from the cumulative fuel flow at v2. Excess fuel consumption per slowdown or stop was then found in the usual way from the acceleration, deceleration, and cruise fuel consumption. The estimates are poor for two reasons:

1. The acceleration and deceleration profile and rate depend on the initial and final speeds. For example, for small decelerations at high speed the brake is often not used and thus there is little fuel penalty. During a deceleration from 110 km/hr to rest, the brake will certainly be applied and the estimated fuel penalty for that slowdown using the TRDF approach will be much greater.
2. The fuel that flows through a flow meter in a 2-sec period when the vehicle is accelerating or decelerating is not a good indication of the actual fuel being burnt in the engine, especially for diesel engines. For an accurate measurement, the vehicle must be in a stable operating condition, preferably idling, for at least 5 sec before and after a maneuver.

TABLE 2 Comparison of TRDF Truck Fuel Consumption Estimates with On-Road Values for Trucks in Canada

Variable	4 axle truck		5 axle truck	
Total vehicle mass	18100	kg	28300	kg
Observed on-road fuel rate	401	ml/km	451	ml/km
From TRDF model *:				
1. Running speed 88.5 km/h				
Constant speed fuel	395	ml/km	475	ml/km
Average speed change	16	km/h	16	km/h
Number of speed changes	1.4	cycle/km	1.4	cycle/km
Excess fuel per change	149	ml/cycle	178	ml/cycle
Overall fuel rate	604	ml/km	724	ml/km
1. Running speed 80.5 km/h				
Constant speed fuel	398	ml/km	468	ml/km
Average speed change	17	km/h	17	km/h
Number of speed changes	1.3	cycle/km	1.3	cycle/km
Excess fuel per change	136	ml/cycle	170	ml/cycle
Overall fuel rate	574	ml/km	689	ml/km

* *Assuming multi-lane road (fuel values are greater assuming a two-lane road and slightly less assuming a freeway). Ambient temperature 26°C (Celsius).*

Effect of Road Roughness

Estimates of the effect of road roughness on vehicle fuel consumption range from 0 to 30 percent (*1,8*). TRDF could find no significant relationship between fuel consumption and road roughness and has assumed zero effect. Road roughness increases rolling resistance and must therefore increase fuel consumption. Vehicle oscillations from a rough ride produce a more turbulent flow of air, and consequently a higher aerodynamic drag, compared with a smooth ride on a smooth road. The road user costs study in Brazil (*9*), from which all nonfuel costs related to roughness were adopted in the TRDF model, found a significant relationship between rolling resistance and roughness [see the work by Biggs (*10*) also for analysis of these data]. The TRDF data were analyzed to determine the proportional increase in rolling resistance caused by roughness, and by combining data into a smaller number of classes, a significant relationship was found (*10*).

Only about a third of fuel consumption at cruise speeds is caused by rolling resistance. Because fuel consumption is difficult to measure accurately, only large changes in rolling resistance can be identified by measuring fuel consumption. On the basis of the available data, the estimated effect of an increase in roughness is given in Table 3. The effect is small, but significant, and should not be ignored. Curiously, TRDF has not studied the smaller effect of road curvature but has included it into the model.

TABLE 3 Effect of Roughness on Rolling Resistance and Fuel Consumption

PSI		Change in	
Initial	Final	Resistance (%)	Fuel Consumption (%)
4	3	5	2
4	2	16	5

Comparison of TRDF and ARFCOM Fuel Estimates

Such problems with the TRDF fuel values are examined using ARFCOM, a detailed mechanistic model of vehicle fuel consumption, developed by the Australian Road Research Board (*11,12*). ARFCOM vehicle parameters can be easily changed to allow for technological improvements and various vehicle classes, fleet composition, and operating conditions. ARFCOM estimates have been checked over a wide range of vehicles to ensure that the effect of changes in vehicle parameters is reflected correctly. ARFCOM has been extensively tested on a wide range of fuel consumption data for cars and trucks in the United States (*13,14*), Australia (*15–17*), the United Kingdom (*18–20*), Canada (*6*), and the World Bank Study in Brazil (*9*). ARFCOM estimates compared well with measured values from these studies. Biggs (*21*) compared observed heavy vehicle fuel consumption in Canada with ARFCOM estimates. ARFCOM produced 2 percent error overall compared with a 50 percent error for TRDF estimates. ARFCOM also reliably estimated the effect of seasonal temperature variations on fuel consumption and the effectiveness of fuel conservation measures.

In ARFCOM acceleration and deceleration profiles and rates depend on both the initial and final speeds, as does the contribution of the change in kinetic energy to fuel consumption. The calculation of acceleration fuel consumption is based on sound theoretical principles, and estimates have been calibrated and validated using data collected over complete acceleration and deceleration maneuvers.

Table 4 compares TRDF and ARFCOM estimates for a range of constant speeds. ARFCOM estimates were made for the vehicles used in the TRDF study (Set 1) and for typical vehicle classes in the United States today (Set 2). The TRDF constant-speed fuel consumption rates are reasonably good for cars but not good for all the truck classes. In particular, fuel consumption does not increase fast enough as speed increases. The TRDF estimates for the three- and five-axle trucks show very little change with speed increases from 72 to 97 km/hr.

TRDF data grossly overestimate the effect of speed changes (Table 5). Low values of excess fuel consumption caused by a slowdown can occur because aerodynamic drag is significantly reduced and much of the change in kinetic energy during a slowdown is used to overcome rolling and aerodynamic drag. This is often the case for minor slowdowns and for vehicles with a high proportion of fuel consumption caused by aerodynamic drag (e.g., two-axle truck at high speeds).

TABLE 4 Comparison of Constant Speed Fuel Consumption Estimates

Vehicle	Source *	Constant Speed (km/h)					
		56.3	64.4	72.4	80.5	88.5	96.6
Medium car	TRDF	88	89	95	101	113	124
	ARFCOM-1	85	91	98	106	115	137
	ARFCOM-2	81	85	91	99	107	128
3-axle truck	TRDF	360	350	351	351	360	367
	ARFCOM-1	218	238	260	285	312	376
	ARFCOM-2	195	214	236	260	287	349
5-axle truck	TRDF	475	473	468	468	475	487
	ARFCOM-1	426	450	415	454	498	602
	ARFCOM-2	381	404	372	411	453	554

**ARFCOM-1: estimates for vehicles used in TRDF study.*
ARFCOM-2: estimates for current typical vehicles in the U.S.
Values given in milliliters per kilometer.

TABLE 5 Effect of Speed Change From 88.5 km/hr to a Minimum Speed on Fuel Consumption

Vehicle	Source	Minimum Speed (km/h)					
		0.0	16.1	32.2	48.3	64.4	72.4
Medium car	TRDF	68	60	52	42	27	18
	ARFCOM-1	33	28	23	19	15	12
	ARFCOM-2	27	23	19	16	13	11
3-axle truck	TRDF	469	435	390	326	224	156
	ARFCOM-1	188	138	86	43	19	18
	ARFCOM-2	201	153	99	52	22	16
5-axle truck	TRDF	636	571	492	386	258	178
	ARFCOM-1	351	254	154	71	31	59
	ARFCOM-2	376	289	185	95	39	35

**ARFCOM-1: estimates for vehicles used in TRDF study.*
ARFCOM-2: estimates for current typical vehicles in the U.S.
Values given in milliliters per kilometer.

The large errors in the TRDF estimates of the effect of speed changes could significantly overestimate the benefits of some types of road improvements and could unjustifiably favor road improvements involving reductions in speed changes.

CRITIQUE OF OTHER COMPONENTS

Figure 1, which is based on previous work (*7*), compares observed VOC with predictions by HUBAM, which uses TRDF VOC data. The observations refer to a new, urban-driven car selected by the Canadian Automobile Association (CAA). The equivalent vehicle in HUBAM is operating in free-flow traffic; consequently one would expect that it has lower fuel consumption and lower total VOC than the CAA car. The Canadian trucking industry operating cost data from Trimac Consulting Services Ltd. for a five-axle truck confirm the gross inaccuracy of TRDF fuel consumption predictions in HUBAM. It is also clear that the other VOC components are inaccurate. HUBAM maintenance cost is too low because newer cars, such as that of CAA, have lower maintenance costs than a fleet average. The industry data presented include total depreciation costs as a result of both use and passage of time, whereas HUBAM accounts only for depreciation from use. The following are some of the reasons for the discrepancies in the other cost components.

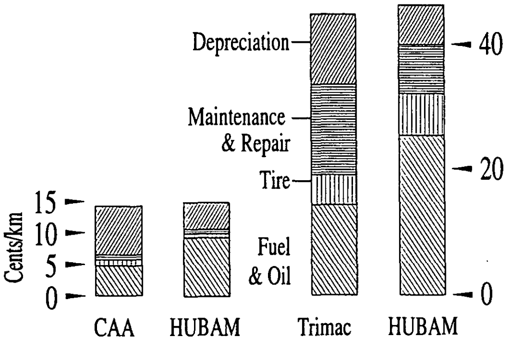

FIGURE 1 Comparison of observed VOC and HUBAM predictions. *Left*, medium car; *right*, five-axle truck.

Oil Consumption

Oil consumption is a minor VOC item and elaborate models are not warranted. Oil consumption on grades was adjusted by the ratio of the horsepower required on the grade to the horsepower required for the same speed on a level tangent section. No correction was made for oil consumption on curves. Effects of pavement roughness were adopted from the study in Brazil for lack of U.S. data. It is not clear whether the TRDF data and MicroBENCOST account for the cost of labor necessary to change engine oil.

Tire Consumption

Tire consumption is a small VOC item. MicroBENCOST expresses the consumption of a set of tires installed on all wheels of a vehicle as an equivalent percent of wear of a single tire. Tire wear was estimated by TRDF with a model (*22*), for which coefficients were selected by comparison of results with Winfrey's values corrected for greater tire cost and longer tread life. Brazilian relationships were used to determine tire cost adjustment factors for surface roughness. The U.S. and Brazilian data used reflect bias-ply tire technology, now obsolete for all vehicle types. Coefficients for the tire wear model were based on highly variable data and representative of asphalt concrete surfaces only.

Maintenance and Repair

The consumption of materials and labor necessary to maintain and repair a vehicle type is expressed as a percentage of an average MRP cost of that vehicle type. Percentage MRP costs were estimated by category (general maintenance, brakes, drive train) for light vehicles. The MRP cost categories were allocated to other trucks using trucker survey data for 3-S2. The distributed costs were then employed to calculate correction factors to net costs of brakes at constant speed on level tangents. For acceleration, grades, and curves, excess costs were calculated from a regression between horsepower and constant-speed costs. Adjustment of MRP costs for surface roughness was made using the Brazilian data. To distribute the brake cost between deceleration and holding constant speed on negative grades, it was converted to a cost per unit of work using rather limited data to calculate the cost/work coefficient. This coefficient was then multiplied by the brake work per distance in deceleration and on negative grades to obtain the excess maintenance cost of brakes.

The questions arising from the MRP component are as numerous as those from the fuel consumption component. Is the distribution of MRP cost categories in the 1970s fleet data still valid? Can MRP data for 3-S2 trucks be extrapolated to other types of trucks? Are correction factors to MRP costs and regression between horsepower and constant-speed MRP costs defendable approaches? Is the approach to brake cost analysis acceptable? Because the cost of MRP covered under factory warranty is included in the new vehicle price, is it accounted for properly? Are trailer MRP costs handled properly? The Brazilian data on surface roughness effects on MRP are likely not applicable to North America because operators adjust vehicle technology and utilization policies in response to economic and road conditions. A mechanistic approach, such as that seen previously (*23*), relating consumption and wear rates to road and traffic conditions through the dynamic forces acting on a vehicle, would be more suitable.

Mileage-Related Depreciation

Mileage-related vehicle depreciation cost is expressed as a percent of a depreciable value. The mileage-related depreciation was estimated with a survivor curve method. The use of the highest 3-percentile class of annual mileage in conjunction with the survivor curve for the entire vehicle type to determine average extreme annual mileage seems arbitrary. Given that North American trucks go through a number of life stages with different uses, the survivor curve of the entire fleet cannot possibly be a good base to estimate mileage-related depreciation. A simpler method would probably yield as good or better results.

The age and accumulated mileage of vehicles were compiled from the 1977 census, and the number of registrations corresponding to the census data was obtained from 1945–1977 statistics. These data are not representative of newer technology and use of vehicles. The estimates were updated using relative adjustment factors for the range of operating speeds produced, but are the assumed distributions of vehicle depreciation costs to speeds, speed changes, and idling reasonable? Depreciation expenses were not distributed to grades and horizontal curves, but the excess time consumed in speed changes relative to constant speed was considered in the updating.

Brazil data were used to adjust the updated estimates of depreciation for different roughness conditions. The data cannot possibly reflect accurately the effect of pavement roughness on depreciation of vehicles. Operators adjust vehicle maintenance and scrapping policies in response to economic and road conditions, which are quite different between the two countries.

Strictly speaking, the depreciable value of a vehicle should be reduced by that portion of new vehicle price that is added by manufacturers to cover the cost of factory warranties. Trailers undergo uses that are different from those for truck tractors or straight truck units, but this fact is not accounted for in depreciation cost estimations. Given that vehicle depreciation and MRP costs are interdependent, the estimation methods for the two components of operating costs are deficient in MicroBENCOST. A better approach, the optimal life method, was recently implemented in South Africa (*24*).

CONCLUSIONS

The TRDF model of VOC and any aggregated relationships derived from the data, such as those in HERS, as well as updates incorporated into MicroBENCOST—although the models of choice in the U.S. highway policy, planning, and project evaluation—all have a number of deficiencies. The deficiencies arise mainly because the model has a statistical rather than mechanistic or other causal foundation. The data encode highway, vehicle technology, and operating, and economic conditions typical of the 1970s, which are not adequate to examine questions arising today in highway transportation planning. The judgmental manipulation of the data base by TRDF has introduced further problems.

A representative of a modern heavy truck is missing in the TRDF model. The typical vehicles are fixed and cannot be altered by the user by changing vehicle characteristics and utilization parameters—in contrast to the mechanistic models.

Without exception, all VOC components are inaccurate at least for one vehicle operating class: running at uniform speed. Fuel consumption has been proven erroneous for all operating classes. The speed change VOC estimation method does not address the real conditions of impeded traffic flows in congestion and urban driving. A similar conclusion was reached independently by the HERS study (*25*).

Of the vital highway decision variables, longitudinal roughness is excluded from fuel consumption relationships, whereas pavement type and surface texture do not appear at all in the TRDF model. Surface texture alone has at least as great an effect on VOC as does roughness.

VOC are the major user cost in maintenance, rehabilitation and upgrading evaluations. A large part of the transportation improvement budgets in the United States is directed toward solving urban traffic and highway congestion problems. The lack of a better VOC model in the United States to serve these needs must be remedied. The HERS study reached a similar conclusion.

A mechanistically based substitute for the TRDF model should be developed as soon as possible. The development work should draw on the best elements from HDM-III (*9*), VETO (*23*), and ARFCOM (*11*). It should also implement the optimal life method for calculating vehicle depreciation.

ACKNOWLEDGMENTS

Analysis presented in this paper comes from the author's research sponsored by the Saskatchewan Highways and Transportation (1987–1988), the former Roads and Transportation Association of Canada (1988–1989), the Canadian National Highway Policy Study Committee (1989), and the British Columbia Ministry of Transportation and Highways (1990 to the present).

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The authors are solely responsible for the opinions expressed in the paper.

Publication of this paper sponsored by Committee on Transportation Economics.