# Vehicle Operating Costs in Brazil: Results of Road User Survey

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**The development of equations to predict vehicle operating costs was a major objective of recently concluded research into the interrelationships among road construction, maintenance, and utilization in Brazil. A selection of user cost equations determined from survey data analyses is reported. Cost data were collected on 1675 vehicles, which were operated by 147 companies, 75 of which were owner-drivers. Highway characteristics of the routes used by these vehicles were measured by two specially instrumented cars. The equations obtained in Brazil allow costs to be predicted for the full range of vehicles currently operating on Brazilian low-volume highways. Attention is restricted to cars, buses, and medium and heavy trucks to facilitate comparisons with other studies of vehicle operating costs. Predictions for maintenance parts and labor costs, tire consumption, and the change in a vehicle's value over time are addressed. A novel feature of the analysis reported here is that estimation was carried out in the context of an error components model for vehicle operating costs. The effect of road geometry, surface condition, and vehicle age on operating costs receives comment. Estimates of total costs provided by the survey equations for buses and trucks are compared with the prevailing rates and tariffs for these vehicles. The Brazilian results are comprehensive and complement the research carried out in Kenya, the Caribbean, and India.**

A research project into the interrelationships among costs of highway construction, maintenance, and utilization [pesquisa do interrelacionamento de custos rodoviários (PICR)] has been conducted in Brazil over the past seven years. It was funded through an agreement signed in 1975 by the Brazilian Government and the United Nations Development Programme (UNDP). The Brazilian Ministry of Transport, acting through their transport planning agency, Empresa Brasileira de Planejamento de Transportes (GEIPOT), assumed the responsibility for managing the project on behalf of the Government of Brazil and the World Bank acted as the executing agency for the UNDP.

The research was carried out by GEIPOT and the National Highway Department [Departamento Nacional de Estradas de Rodagem (DNER)] through its Road Research Institute [Instituto de Pesquisas Rodoviárias (IPR)]. The World Bank contracted with the Texas Research and Development Foundation (TRDF) to organize the international technical staff and to select and purchase the imported equipment required for the project. The participation of TRDF continued until the end of the primary data-collection and preliminary analysis phases in December 1979.

A major objective of PICR was to establish relationships among road user costs, road geometric standards, and surface conditions for low-volume roads in Brazil. The project had three study areas, one to evaluate pavement performance and the other two to determine vehicle operating costs. Two different procedures were adopted to develop predictions of Brazilian vehicle operating costs, following the experience of the Kenya study by the United Kingdom Transport and Road Research Laboratory (TRRL) (1). One defined a series of experiments designed to generate data from which to obtain predictions of vehicle speed and fuel consumption. The second procedure entailed a survey of road users to determine the remaining major cost items, including maintenance and tire costs and depreciation. At the 1979 Low Volume Roads Conference, a paper by R.J. Wyatt and others (2) reported the survey design and gave some preliminary results. This paper reports some activities from the second phase of the project in which survey data were subjected to more detailed analyses and a final report was presented on the findings (3). This work complements the surveys of vehicle operating costs conducted in Kenya, the Caribbean (4), and India (5).

## INTRODUCTION

The PICR survey was conducted in central, western, and southern Brazil with the objective of collecting and analyzing data on maintenance parts and labor costs, tire consumption, depreciation, and interest charges and drivers' salaries. Whenever possible, information on fuel and speed was also collected so that consistency checks could be made with the experimentally determined predictions. The survey team was also responsible for collecting data on surface roughness, as well as vertical and horizontal geometry characteristics of the routes of those users that provided data.

The primary data-collection phase ran from 1976 to 1979 and considerable time was spent in developing and testing appropriate methodologies, documentation, and data-processing systems for the collection, checking, storage, and analysis of both operating-cost and highway-characteristics data. Contact was made with more than 300 companies and more than 2500 vehicles were registered for survey membership. Operating-cost data were then collected on a regular basis from company records. Many difficulties had to be overcome during this period. A number of users only had records of a few cost components like fuel, and assistance was given whenever possible to provide the necessary documentation and training to collect missing items. Some companies dropped out of the survey and data collection in others was discontinued because the route characteristics of their vehicles were found to be redundant to the needs of the PICR.

Highway characteristics were collected by using two specially instrumented vehicles. Roughness was measured with a Maysmeter and calibration was maintained through a GM profilometer and quarter-car simulator, which generated a series of profiles for a calibration course of highway sections established near Brasilia. Vertical geometry was measured by using a linear accelerometer connected to a panel scale capable of recording grade changes of ±1-12 percent. Horizontal measurements were taken from a standard aircraft directional gyrocompass mounted in the facia of the survey vehicle. More than 85 000 km of roughness and geometry data were collected after more than 36 000 km of user routes had been measured. After editing, these data had to be combined with the vehicle-operating-cost data so that a single file containing both dependent and independent variables could be made available for analysis.

The basic vehicle-operating-cost file was originally designed to record all cost items but ultimately only recorded data suitable for the analysis of fuel, parts costs, maintenance labor costs, and utilization. The maintenance labor costs could not be taken directly off this file for analysis and had to be systematically checked and transferred to a special analysis file separate from the analysis file derived from the basic cost file. This latter file has 54 000 records on 2506 vehicles, although this number of vehicles was considerably reduced for analytical purposes because of the following reasons:

1. Vehicles were not included for analysis if they had less than six months' data assigned to them on the basic file,
2. Vehicles were excluded if they engaged in operations not reflecting normal highway use, and
3. Vehicles were excluded if it was found that their operation included a high proportion of urban use since this would not accord with the PICR terms of reference.

These exclusions reduced the number of vehicles passed to analysis file to 1675 collected from 147 companies (including 75 owner-drivers). Tire consumption was recorded on a special file, which eventually contained 20 820 tire changes that represented 6886 tire lives. In addition to the file on maintenance labor costs, other special files included car speed from timetable data, bus speed from tachograph records, and private car utilization derived from a supplementary survey of 5280 car owners.

The specific number of vehicle records used in the estimation of each cost component was also dependent on the restrictions placed on the data by the analyst. One example is file length and whether the analyst accepts records with less than 12 months' data assigned to them. This, combined with the difficulty in finding users with records covering the full range of cost items, means that the various cost component analysis files vary in size. Very detailed technical reports, including correlation matrices and other tables, for all cost-component analyses are available in the PICR series of final reports (6).

Vehicles were grouped into the five classes in Table 1, which also gives a brief technical description of representative vehicles in each class. Fortunately, there was a degree of homogeneity in all but the utility class, which encompassed a diverse group of vehicles. Despite the difficulty of analyzing this class, attempts were made and results reported. All five vehicle classes were used in all the analyses except the speed analysis, which was restricted to cars and buses. Tires for all vehicle classes were analyzed by tire size. In the recommended equations the effects on user costs of roughness, geometry, vehicle age, and vehicle characteristics were estimated as appropriate and where possible. Substantial effort was devoted to estimating the effect of geometry on the various operating-cost items, but it was difficult to identify a coherent pattern that met prior expectations. Finally, total operating-cost predictions derived from the recommended equations were compared with prevailing market rates and tariffs for transport services. This was considered to be an important consistency check on the results.

## ESTIMATION PROCEDURES

If user cost data are regressed on highway characteristics alone, relatively large residual variation is found whatever statistical procedure is used. Highway characteristics have only a partial effect on user costs, which are also affected by the technical design of the vehicle types and the managerial competence of their owners. A significant company effect is therefore expected to influence any cost data collected through a survey of vehicle owners.

Ideally the sampling frame would have contained few companies, each with a wide representation of vehicles plying routes of different combinations of highway characteristics. Unfortunately, no such companies were found in Brazil. The sampling frame actually contains many users whose vehicles exhibit limited ranges of route characteristics. The structure of the resulting data sets is like that of a cluster sample; the users form the clusters and their vehicles are the observations within each cluster. It was not obvious how best to address the issue of vehicle characteristics and company effects, and a number of econometric problems had to be considered (7).

Four basic statistical methods have been applied to operating-cost data in the PICR project. These are described below.

### Least Squares Applied to Individual Vehicle Data (OLS)

The OLS method is appropriate when the company-specific error is small in magnitude relative to the vehicle-specific error. It was widely used during preliminary analyses and produced some useful results. It does not address any aspect of the company-effects issue and was therefore not suitable for the majority of PICR data sets.

### Least Squares Applied to Company Cell Means (CM)

All the within-company variations in costs are averaged out so that the statistical estimation relies

**Table 1. Representative vehicles in PICR survey.**

| User Survey | | Representative Vehicle Characteristic | | | |
|---|---|---|---|---|---|
| Vehicle Type | Class | GVW (tonnes) | Load (tonnes) | Engine Size (hp)[a] | Description |
| Automobile | 1 | 1 | - | 46 | Gasoline, four-cylinder, rear mounted |
| Utility pickup | 2 | 2.7-3.3 | 1.2-2.2 | 58-133 | Gasoline, four-cylinder, smaller engine rear mounted |
| Utility light truck | 2 | 6 | 4 | 85 | Diesel, four-cylinder |
| Bus | 3 | 11-13 | 4-5 | 130 | Diesel, six-cylinder; monocoque on paved routes; chassis on unpaved routes; monocoque engine options, 192 or 210 hp |
| Medium truck[b] | 4 | 15 | 6-10 | 130 | Six-cylinder diesel |
| Heavy truck | 5 | 40-45 | 24-29 | 285 | Diesel six-cylinder, turbocharged; tractor, two axles; semitrailer, three axles |

[a] British horsepower. [b] If three-axle, GVW is 18-22 tonnes, load is 12-15 tonnes.

entirely on between-company variations. This method was adopted in the Kenya study and for selected cost components in the early stages of the PICR. It is a useful procedure when there is little variation within companies in user costs, perhaps because of companies' identical treatment of the vehicles in their fleets. As with the first method, this procedure does not address the company-effects issue.

In the early analysis of PICR data, the OLS and CM methods were used extensively and generally produced similar results (8, p. 167). Subsequent analysis concentrated on two methods, both developed to address the company effect, which was considered to exert a significant influence within the majority of the data sets presented for analysis. These approaches are described next.

### Least Squares Applied to Individual Vehicle Data with Company Effects Estimated (OLSCE)

In the stochastic relationships between user costs and highway characteristics, the unobservable random error will contain both company and vehicle effects. To allow for company-specific variation in costs, this error term is regarded as the sum of a company-specific error and a vehicle-specific error. The OLSCE technique estimates each company's error term, thus providing a separate intercept for each company. This is equivalent to estimation after expressing all data as deviations about company means. Thus only within-company variation is exploited to estimate the effects of the explanatory variables on costs. To obtain equations that predict levels of costs for companies other than those sampled, as well as the differences in costs associated with different highway designs, it is necessary to combine the estimated company intercepts. Where equations estimated by this procedure are reported in this paper, weighted averages of the estimated company intercepts have been calculated by using the number of vehicles per company as weights. The OLSCE method was subsequently adopted by the Indian study as a major analytical procedure, but in the Indian study the separate company intercepts were not combined. The OLSCE procedure is appropriate when correlations between company effects and route characteristics are likely and when there exists within-company variation in the data.

### Generalized Least-Squares Estimation of Error-Components (EC) Model

The company-specific error is regarded as a random error the variance of which is to be estimated. The generalized least-squares procedure described by Fuller and Battese (9) is applied. The procedure is appropriate when the company-specific error is negligibly correlated with the explanatory variables. When the company error is zero, the procedure gives the same estimates as ordinary least squares applied to individual vehicle data. When the vehicle-specific error is zero, it produces the same estimates as weighted least squares applied to company means. A goodness-of-fit statistic G is reported with EC estimates. The statistic G is analogous to the $R^2$-statistic usually reported with ordinary least-squares estimates.

The EC model has played a useful role in the analysis in the later phases of the PICR; it replaces the CM method. The other three methods have all been used, with and without vehicle age and a selection of vehicle characteristics. In this paper, the acronyms defined above will identify which method was used to estimate the reported equations. Equations were chosen from a large number reported in the technical memoranda accompanying the PICR results (7). These also give tables of results obtained with and without vehicle characteristics as explanatory variables, which identify in detail the effects of such characteristics. The results reported here include equations with vehicle characteristics where these were found to be significant and improved the prediction of the dependent variables. However, it should be noted that the PICR survey was not designed to estimate the effects of vehicle characteristics on operating costs. User-cost equations can be expected to have generally low values for measures of goodness of fit like $R^2$, and equations were chosen for their ability to give good predictions. Data manipulation and analyses were performed by using the SAS statistical analysis package (10). Natural logarithms (base e) are used throughout and are designated by ln. Prices are in December 1981 cruzeiros, when the cruzeiro was valued at 127 to $1 U.S.

## ESTIMATES OF VEHICLE OPERATING-COST RELATIONSHIPS

In this section some of the results obtained from the Brazil study data are described. Attention is directed to maintenance parts and labor costs, tire consumption, and change in market valuation. The vehicle classes examined are cars, buses, and medium and heavy trucks. The equations for these cost components and vehicle classes are those most easily compared with the equations obtained from the other major surveys. Predictions and prediction intervals are available in the PICR final report (3).

### Maintenance Parts Consumption

The PICR maintenance parts data set totals 742 vehicles, which includes 93 cars, 449 buses, and 200 trucks. In the various analyses of these data, linear, piecewise linear, log-linear, and piecewise log-linear functional forms of the methods previously described have been tried. In the equations, roughness, measures of geometry, and vehicle age together with other vehicle and company characteristics have been used. When the four functional forms were compared, there was rarely any convincing statistical evidence in favor of any one particular form. The parts data are quite scattered and, within the ranges of highway characteristics observed, the various forms fitted almost equally well. Standard statistical procedures for testing hypotheses concerning appropriate functional forms did not give any clear indications as to the form to select. However, the functional forms extrapolate rather differently, and this is an important consideration if the equations are to be used for planning purposes.

After some explanatory analysis, it was decided to report the log-linear form over the range of observed data and to recommend that linear extensions be used when the equation was extrapolated. A major advantage of log-linear form is that it allows the effect of vehicle age to be incorporated in a tractable and intuitively sensible way.

### Car-Parts Consumption

This data set shows limited ranges for highway characteristics. The roughness parts equation can be reported with some confidence. When the log-linear form was used, similar roughness coefficients were estimated whether or not vehicle age was included. The car-parts data set comprised 93 vehicles with at least 12 months' of data on file.

The recommended car-parts equation estimated by the EC method (t-statistics in parentheses) is as follows:

$$\begin{aligned}\ln(\text{parts cost}) &= 5.055 + 0.0128QI^* + 0.303\ln(K) \\ &\quad\ (3.67)\quad\ (4.40)\qquad\ (3.38)\end{aligned} \tag{1}$$

where

$QI^*$ = unit of road roughness (11,12),
$K$ = vehicle age (km 000s),
$G$ = goodness-of-fit statistic (= 0.122 here),
$S_u$ = SD of company-specific error (= 0.571), and
$S_w$ = SD of vehicle-specific error (= 0.452).

Recommended equations for prediction are calculated as follows:

$QI^* < 40$: parts cost = $K^{0.303}$ (206.17 + 1.392QI*),

$40 \leq QI^* < 120$: parts cost = $K^{0.303}$ exp(5.055 + 0.0128QI*),

$120 \leq QI^*$: parts costs = $K^{0.303}$ (-390.69 + 9.325QI*).

Parts costs are in December 1981 prices. To give some impression of the QI*-unit, the average value was 40 for paved route sections in Brazil and 140 for unpaved sections.

### Bus Parts Consumption

The bus-parts data set is one of the largest in the survey and the one where correlations among highway characteristics are lowest and ranges of characteristics greatest. A wide range of bus types can be purchased in Brazil, and operators can buy a chassis, platform, or full monocoque vehicle. The first two types can have bodies made from fiberglass, steel, or aluminum. A front or rear engine location is available for the chassis vehicle and a large or smaller diesel engine for platform or monocoque types. Different highway characteristics provide incentives for selecting vehicles with specific characteristics. However, these vehicle characteristics can partly cancel the highway factors and this can cause problems in analysis. The recommended bus-parts equation, estimated by the EC method (t-statistics in parentheses) is

$$\begin{aligned}\ln(\text{parts cost}) &= 5.880 + 0.003\,23QI^* + 0.483\ln(K) \\ &\quad\ (12.97)\quad (4.09)\qquad\ (16.00)\end{aligned} \tag{2}$$

where

$G$ = 0.506,
$S_u$ = 0.407, and
$S_w$ = 0.434.

Recommended equations for prediction are

$QI^* < 40$: parts cost = $K^{0.483}$ (382.01 + 0.627QI*),

$40 \leq QI^*$ 190: parts cost = $K^{0.483}$ exp(5.880 + 0.003 23QI*),

$190 \leq QI^*$: parts cost = $K^{0.483}$ (255.23 + 2.135QI*).

It was noted that vehicles with tachographs and/or high power-to-weight ratios typically have lower costs than those predicted by Equation 2. However, both these effects are difficult to disentangle from the roughness effect because their adoption by operators is more common on higher-quality road surfaces.

### Truck Parts Consumption

Equations without vehicle characteristics are reported although the roughness coefficient changes little as these and vehicle age are included in the regression analyses. First, the log-linear with age equation is given, estimated by the EC method:

$$\begin{aligned}\ln(\text{parts cost}) &= 6.189 - 0.251TIP + 0.365ST \\ &\quad\ (9.38)\quad (-1.4)\qquad (2.21) \\ &\quad - 0.072Ax2 + 0.016QI^* + 0.374\ln(K) \\ &\quad\ (-0.34)\qquad (7.68)\qquad (6.74)\end{aligned} \tag{3}$$

where

$TIP$ = 1 if vehicle is a tipper, 0 otherwise;
$ST$ = 1 if vehicle is the tractor of a heavy articulated vehicle, 0 otherwise;
$Ax2$ = 1 if vehicle is a two-axle, rigid, nontipping vehicle, 0 otherwise;
$G$ = 0.572;
$S_u$ = 0.302; and
$S_w$ = 0.349.

The intercept gives a prediction for three-axle rigid vehicles.

This equation performs satisfactorily over the range of roughness observed for the majority of trucks in the survey. It is reported to show the estimated age coefficient. This is well determined and lies above utilities but below buses, as expected. However, this equation does not extrapolate well and it is recommended that predictions be limited to less than 120 QI*.

Truck parts predictions need to be derived for roughness values significantly higher than this figure, and therefore a piecewise linear form that uses the EC method is recommended as an alternative.

The recommended equation is

$$\begin{aligned}\text{Parts costs} &= 2865 - 2198TIP + 3537ST \\ &\quad\ (1.59)\quad (-1.18)\quad\ (2.27) \\ &\quad - 2560Ax2 + 105.17Q40 \\ &\quad\ (-1.09)\qquad (4.54)\end{aligned} \tag{4}$$

where

$G$ = 0.41;
$S_u$ = 3.022;
$S_w$ = 4.066;
$Q40$ = 40, $QI^* \leq 40$; and
$Q40$ = QI*, $QI^* > 40$.

The intercept is for three-axle rigid vehicles.

Equation 4 is based on an average vehicle age of 204 000 km. To obtain cost estimates for trucks of different ages, the predictions derived from this equation should be multiplied by (actual kilometers in units of 1000 km/204) 0.374.

Heavy tractors pulling large semitrailers are rarely seen on public unpaved roads, and predictions for them (ST) should be limited to 100 QI*. Semitrailer costs have not been analyzed since they move from vehicle to vehicle and route to route in the typical Brazilian company, as efficient management practice would dictate. The average trailer cost for 34 semitrailer units in the survey was 5196 Cr$/1000 km at December 1981 prices, and this should be used to derive the total parts costs for a heavy tractor and semitrailer unit.

### Maintenance Labor Costs

Labor costs were collected in the user survey when the opportunity arose, although with some difficulty since labor recording practices differed widely from company to company. A number of procedures were examined--assigning standard labor hours to maintenance tasks (adopted by the Indian survey), assigning total workshop hours to vehicles in the fleet (reported in the interim PICR results and the 1979 Low Volume Roads Conference), and finally collecting whatever data were available from the records of survey members. It was decided to take the latter data and create a special parts-labor data set. Every effort was made to ensure that this set contained accurate information. Parts costs were checked to ensure that they arose in the same time period as that in which the labor costs were incurred. Since much of the vehicle parts data does not have any corresponding labor costs, a substantial reduction in the sample sizes identified in the maintenance parts analyses resulted. The numbers of vehicles analyzed (numbers of companies in parentheses) in the parts-labor data set are cars, 48 (4); buses, 81 (5); and trucks, 150 (13). These data were used to estimate relationships between labor costs and parts costs so that a relationship between total maintenance costs and highway characteristics could be obtained.

After some preliminary analyses were completed, it was decided to estimate the labor-parts relationship by using the OLSCE method. This seemed appropriate because in this relatively small data set, company-specific variations in costs may be incorrectly attributed to across-company variation in highway characteristics. Further, the small number of companies makes it difficult to estimate the variance of the company effect.

### Car Maintenance Labor Costs

No effect could be found for road roughness in this data set although the coefficient for parts costs is of similar magnitude to that for the other classes. The recommended equation, estimated by the OLSCE method, is

$$\begin{aligned}\ln(\text{labor cost}) = {} & 2.645 + 0.547 \ln(\text{parts cost}) \\ & (2.12) \quad (4.24)\end{aligned} \tag{5}$$

where $R^2$ is 0.29 and $S_w$ is 0.50.

### Bus Maintenance Labor Costs

There are substantial company effects in this data set due to the very different ways companies treated the maintenance of their buses. Some companies exhibit higher-than-average labor costs, often a result of preventive-maintenance programs. Others include bus cleaning when it is done by employees but not if it is done by machine. If within-company variation is used and the logarithm of labor costs is regressed on the logarithm of parts costs, a coefficient of 0.516 is obtained. The introduction of vehicle characteristics barely changes this value, and a significant positive coefficient is found for road roughness. The recommended equation, estimated by the OLSCE method, is

$$\begin{aligned}\ln(\text{labor cost}) = {} & 3.260 + 0.516 \ln(\text{parts cost}) \\ & (5.54) \quad (8.40) \\ & + 0.005\,14 QI^* \\ & (2.23)\end{aligned} \tag{6}$$

where $R^2$ is 0.50 and $S_w$ is 0.241.

### Truck Maintenance Labor Costs

Trucks in this data set are pooled and three zero-one variables are used to identify the truck type. Regressing the logarithm of labor costs on the logarithm of parts costs and estimating company effects produces a coefficient of 0.519, which is similar to the values obtained for the other vehicle classes. This coefficient is little altered by introducing vehicle and company characteristics or roughness. No significant effect for roughness was found. The recommended equation for truck labor costs, estimated by the OLSCE method, is

$$\begin{aligned}\ln(\text{labor cost}) = {} & 3.198 + 0.233Ax2 + 0.348Ax3 \\ & (6.88) \quad (6.74) \quad (8.27) \\ & + 0.781ST + 0.519 \ln(\text{parts cost}) \\ & (8.82) \quad (11.84)\end{aligned} \tag{7}$$

where $R^2$ is 0.50 and $S_w$ is 0.264.

The intercept gives a prediction for a tipping vehicle.

This $R^2$ gives the proportion of within-company variation in the logarithm of labor costs explainable in terms of within-company variation in the logarithm of parts costs. In application, users will find that the truck type coefficients and intercepts provide additional explanatory power. The operating costs of semitrailers of the type hauled by heavy tractors were not collected in sufficient numbers for regression analyses. Since an average figure is reported for semitrailer parts, these data were examined and it was found that trailer labor costs constitute around a third of parts costs. It is suggested that this figure be used to calculate the total maintenance cost for heavy vehicles operating on paved roads.

## Tire Consumption

An operator with a vehicle fleet in Brazil typically switches tires from one wheel position to another and from vehicle to vehicle. It is not efficient to keep tires on one vehicle for all of their life and operators generally use a tire pool into which repaired and recapped tires are placed before being assigned to vehicles. Company policies regarding the timing of recapping and scrapping, vehicle loads, speed of operation, and driver bonuses may be expected to affect tire lives and to vary between companies. Tire lives themselves are very variable, even within companies. In the PICR survey, two different collection procedures were evaluated; one involved the determination of tread wear on a selection of vehicles (13), the other a more conventional survey of company tire records. Despite promising pilot results, the tread-loss approach had to be dropped due to staff shortages, and the PICR data source was therefore company records. Since few companies had good tire records, 90 percent of the bus and truck data comes from 11 companies.

For each tire on the analysis file, the total number of kilometers traveled through the different stages of its life was calculated. This value appears as TK in Equation 8 and was measured in units of 10 000 km. The number of recaps on each tire during its life was also calculated and this appears as RC. The dependent variable used in the reported tire equations is KPT and can be regarded as measuring kilometers per equivalent new tire. The estimated equation is

$$KPT = TK/[1 + (RC/6.6)] \tag{8}$$

The denominator gives the total tire cost when multiplied by the price of a new tire since the cost of recapping on average is 1/6.6 times the new tire cost in the PICR data. Therefore, KPT divided by tire price gives distance traveled per cruzeiro.

### Car Tire Consumption

This data set comprised 245 tires from one company that operated on relatively narrow ranges of roughness, rise plus fall, and curvature. The intercorrelations among the highway characteristics make reliable estimates of the effects of geometry on car tire costs impossible to obtain. A linear equation, estimated by OLS, was fitted:

$$\underset{(12.90)}{\mathrm{KPT} = 6.508} - \underset{(-3.92)}{0.0389\mathrm{QI}^*} \tag{9}$$

where $R^2$ is 0.83 and $S_w$ is 2.125.

The roughness effect is quite substantial and it is possible that roughness is picking up some effects due to rise plus fall, which is positively correlated with roughness in this data set. The maximum QI*-value for the car tire data set was 87, and the equation does not extrapolate well beyond 120 QI*. Therefore, it is recommended that this equation not be used to predict tire consumption for roads in excess of 120 QI* or, if such an estimate is required, that consumption be held at around the estimate derived for 120 QI*.

### Bus and Truck Tire Consumption

The difficulties of assigning highway and vehicle characteristics to periods of a tire's life make this data set the most complex presented for analysis in the PICR survey. The basic tire file was reduced to 3536 tire lives for analysis as a result of assignment difficulties and tire record lengths. These data were analyzed in a variety of ways. Linear and log-linear relationships were estimated between KPT and roughness, rise plus fall, and average degrees of curvature; first no distinctions were made between companies, vehicle classes, vehicle loads, or tire sizes and then variables that capture these distinctions were introduced one by one. To counter the potential statistical distortions from differences in tire costs at the company level and the disposition of the companies over route types, the OLSCE estimation procedure was used. This exploits only within-company variations to obtain estimates of the effect of highway characteristics. Increases in roughness, rise plus fall, or curvature are found to increase tire costs, though the effect of curvature is small. The linear equation for bus and truck tire lives, estimated by the OLSCE method, is

$$\begin{aligned}\mathrm{KPT} = {} & \underset{(15.59)}{5.756A} + \underset{(10.30)}{6.004B} + \underset{(24.23)}{9.450C} - \underset{(-3.44)}{0.009\,51\mathrm{QI}^*} \\ & - \underset{(-3.82)}{0.0424\mathrm{RF}} - \underset{(-0.58)}{0.001\,27\mathrm{ADC}}\end{aligned} \tag{10}$$

where

$R^2$ = 0.87;
$S_w$ = 1.82;
RF = rise plus fall (m/km), equivalent to average gradient of road times 10;
ADC = sum of central angles of all horizontal curves on route divided by route length (degrees/km);
A = 1 if tire size is 900 x 20, 0 otherwise;
B = 1 if tire size is 1000 x 20, 0 otherwise; and
C = 1 if tire size is 1100 x 22, 0 otherwise.

Since buses operate with A and B sizes and trucks with all three sizes, it seemed more appropriate to estimate life for these different sizes than for vehicle types. It should be noted that all tires were of conventional design and that radials had yet to make an impact on Brazilian bus and truck operations when the survey was conducted. The intercepts for each tire size are influenced by company effects but seem to give good predictions of tire life; the larger size, C, has a much longer life, though it costs more to purchase. The curvature coefficient is not so well determined as the roughness and the rise-plus-fall coefficients. The lack of significance of the curvature coefficient is largely due to its small magnitude, which may be a result of speed reductions that arise when route curvature is increased.

**Table 2. Relationship between average market value and age in years by vehicle class.**

| Class | Equation | $R^2$ | Sample Size |
|---|---|---|---|
| Commercial car | V = 0.859 - 0.143A | 0.98 | 75 |
| Private car | V = exp (0.063 - 0.173A) | 0.98 | 162 |
| Bus | V = exp (-0.053 - 0.169A) | 0.99 | 240 |
| Medium truck | V = exp (-0.185 - 0.175A) | 0.92 | 180 |
| Heavy truck | V = exp (-0.174 - 0.160A) | 0.94 | 120 |

### Average Market Valuations

Vehicle depreciation and interest charges are a major component of total vehicle operating costs, and it was therefore essential to derive good estimates of these items for Brazilian conditions. Two complementary approaches were developed to provide these, one to examine the change in market values over time for the different vehicle classes and the other to estimate vehicle use. The first provides annual vehicle depreciation and the latter, annual kilometerage traveled. The two are combined to determine the average depreciation and hence interest cost per kilometer.

This approach is similar to those reported in the Kenya and Caribbean surveys, except for one important feature. No use equations were estimated in those studies and use had to be modeled in other ways. The Brazil and India studies have reported use predictions for various vehicle classes and the information derived from these equations can be used to assess other methods adopted by modelers for predicting use (e.g., multiplying predicted speeds by average hours driven per year). Since the estimation of vehicle use received special emphasis in the previous PICR Low Volume Roads Conference paper, only the predictions of change in market values will be reported here. Because all recent vehicle-operating-cost surveys have reported these predictions, their presentation here allows interesting intercountry comparisons to be made.

Lifetime depreciation is defined as the change in the market's valuation of the flow of services provided by the vehicle over its life. For a certain period in a vehicle's life it is necessary to predict the change in value over that period. It was therefore necessary to estimate the change in value throughout a vehicle's life, and surveys to collect the necessary data were conducted in 1978 and 1981. In each vehicle class, sufficient data were collected to give average market values for each year of the vehicle's life. They were then expressed as a percentage of the new-vehicle price less tires and exponential curves fitted, since the data were strongly nonlinear. The exception to this rule was commercial cars, whose short life made a linear form more appropriate. The results appear in Table 2, in which V is the value of the vehicle aged A years on the second-hand market, expressed as a proportion of the new-vehicle price. It is recommended that cutoff points be used for these equations to allow for the vehicle's scrap values. These are as follows:

| Class | Age (years) | V |
|---|---|---|
| Commercial car | 5 | 0.14 |
| Private car | 12 | 0.13 |
| Bus | 12 | 0.12 |
| Medium truck | 12 | 0.10 |
| Heavy truck | 12 | 0.12 |

## EVALUATION OF FINDINGS

In this section, four major issues are examined. The first is the effect of road geometry on vehicle operating costs in Brazil, an issue of some importance to highway planners. The second concerns the effect of surface roughness on operating costs. The third concerns the inclusion of vehicle characteristics in the estimation procedures and more specifically the effect of vehicle age on operating costs. Finally, the most important attribute of vehicle-operating-cost equations is how well they predict. To test the results, comparisons were made between prevailing rates and tariffs in the market for transport services and the total operating costs derived from the PICR equations.

### Effect of Geometry on Operating Costs

In the PICR results, geometry affects fuel consumption and vehicle speed (both determined experimentally) as well as tire consumption, as previously reported. Each 10-m/km reduction in rise plus fall is predicted to increase kilometers per equivalent new tire by 4240 km and each 20°/km reduction in average degrees of curvature is predicted to increase kilometers per equivalent new tire by 254 km. It will be interesting to compare these results with the Indian findings, where a negative coefficient for rise plus fall has also been determined.

Several attempts were made to estimate the effect of highway geometry on costs by using the parts and use data sets. Many equations were estimated, incorporating geometry, with and without vehicle and company characteristics and by using a number of statistical procedures. Some progress has been made and significant geometry effects estimated for some vehicle cost components like maintenance parts. However, an important feature of the results to date is the lack of any consistent pattern in the significance, sign, and size of the geometry coefficients between vehicle classes. There are a number of explanations for this. First, correlations between measures of vertical and horizontal geometry present in many data sets make it difficult for the analyst to disentangle the effects of vertical and horizontal geometry on costs. Second, the geometry effects may be so small over the ranges encountered in the survey that by using operator's records and crude average measures of vertical and horizontal geometry, it is not possible to capture these effects. Geometry effects may be small because speed reductions that occur on routes with extreme geometry tend to reduce costs measured per kilometer. Third, the effects may be vehicle-class-specific, so that geometry may affect the consumption of a particular cost item in different ways, depending on the vehicle type. Then we would expect signs and magnitudes of geometry coefficients to vary from one vehicle class to another.

The effect of road geometry on vehicle operating costs is a complex issue and there is little vehicle engineering evidence available to help form hypotheses. Furthermore, other operating-cost studies shed little light on the problem and the results from Kenya and the Caribbean with respect to geometry effects are broadly similar to the PICR findings. More work needs to be carried out before a decision can be made on the appropriateness of the geometry effects so far estimated with the Brazil data but not reported here. These geometry effects are fully described in the relevant technical literature of the PICR final report series. The results from India may be useful in assessing the estimated geometry effects obtained so far. In this paper attention has been directed to the relatively well understood effects on costs of road roughness and vehicle characteristics.

**Table 3. Financial costs per kilometer for three-year-old bus.**

| | Paved Road | | Unpaved Road | |
|---|---|---|---|---|
| Cost Item | Cruzeiros | Percentage | Cruzeiros | Percentage |
| Fuel | 11.94 | 30 | 12.69 | 26 |
| Oil + grease | 1.43 | 4 | 1.63 | 3 |
| Parts | 5.46 | 14 | 7.52 | 15 |
| Labor | 2.20 | 5 | 4.35 | 9 |
| Tires | 3.55 | 9 | 4.60 | 9 |
| Depreciation | 4.84 | 12 | 5.47 | 11 |
| Interest | 3.45 | 9 | 3.89 | 8 |
| Salary | 7.25 | 17 | 9.52 | 19 |
| Total | 40.12 | | 49.67 | |

Notes: Roughness: 38 QI* paved, 138 QI* unpaved; rise plus fall: 28 m/km; average degrees of curvature: 30 degrees/km. Prices in cruzeiros, August 1981. Use (km/month) is 9036, paved; 6879, unpaved. Interest rate is 12 percent. Age is 348 000 km. Route length: 340 km, paved; 250 km, unpaved. Monocoque operates on paved road, chassis type on unpaved road. Salary is driver's and conductor's wages plus all social taxes in August 1981.

**Table 4. Financial costs per kilometer for three-year-old, three-axle flat truck.**

| | Paved Road | | Unpaved Road | |
|---|---|---|---|---|
| Cost Item | Cruzeiros | Percentage | Cruzeiros | Percentage |
| Fuel | 13.54 | 38 | 15.09 | 28 |
| Oil + grease | 0.83 | 2 | 0.96 | 2 |
| Parts | 5.39 | 15 | 13.26 | 24 |
| Labor | 2.54 | 7 | 4.05 | 8 |
| Tires | 6.57 | 18 | 8.52 | 16 |
| Depreciation | 2.27 | 7 | 3.83 | 7 |
| Interest | 1.95 | 5 | 3.26 | 6 |
| Salary | 2.94 | 8 | 4.77 | 9 |
| Total | 36.03 | | 53.74 | |

Notes: Roughness: 38 QI* paved, 138 QI* unpaved; rise plus fall: 28 m/km; average degrees of curvature: 30 degrees/km. Prices in cruzeiros, August 1981. Use (km/month) is 9415, paved; 5601, unpaved. Interest rate is 15 percent. Age is 375 000 km. Route length: 500 km, paved; 300 km, unpaved. This vehicle type is chosen because it is the most numerous in the medium-truck class. Chassis is Mercedes-Benz L2013. Salary is driver's wage plus all social taxes in August 1981.

### Effect of Roughness on Operating Costs

Road surface condition is captured in user surveys by measuring surface roughness, and a variety of measurement systems can be used. However, in previous studies, irrespective of the system used, the statistic derived from roughness measurements has been found to be strongly related to operating costs. In the Brazil study, too, surface roughness is a major determinant of vehicle operating costs. Tables 3 and 4 are indicative of the roughness effects found in Brazil. These show the effect of roughness both on individual components and on total operating costs for buses (Table 3) and medium trucks (Table 4). Levels of roughness are chosen that correspond to typical paved and unpaved roads so that differentials in moving from one type to the other can be examined. Predictions for all the components are derived from survey equations or data and details of the assumptions made appear in the notes to each table. Costs are in financial terms and are calculated on a per-kilometer basis. Since highway planning is generally concerned with the consequences of improvement, the differentials obtained on moving from unpaved to paved highways are considered for the two vehicle classes. Fuel is affected rather little by changes in roughness; there is a reduction of 6 percent for buses and 10 percent for trucks following paving. The buses, with their regulated speeds and driver familiarity with the highway features, are expected to operate within a narrower range than trucks. Trucks are also more likely to be overloaded on unpaved roads, and overloading affects fuel consumption. Overloading also contributes to high truck-parts consumption on unpaved roads, where maintenance of transmission and suspension is expensive. The reduction in truck-parts costs after paving (60 percent) contrasts with that obtained for buses (27 percent). Bus design is different for paved and unpaved operations, and this results in a maintenance parts and labor expenditure pattern unlike that for trucks. Unpaved-road bus design requires relatively high labor expenditures, but this results in reduced parts consumption so that total maintenance parts and labor costs are kept low. This trade-off can be seen in Table 3 and in the two bus differential cost reductions, 49 percent for labor and 27 percent for parts.

Tires for both vehicle classes have identical differentials, 23 percent. Depreciation, interest, and salaries for trucks are almost wholly affected by differentials in use, and this results in an approximate 40 percent reduction for these items on moving from unpaved to paved operations. This is not repeated for buses because the capital investment for unpaved and paved designs is quite different and the utilization differential is narrower for buses than for trucks. The total depreciation and interest differential cost reduction is 12 percent for buses. Total operating-cost reductions on switching to paved operations are approximately one-fifth for buses and one-third for trucks.

## Vehicle Characteristics

In the early stages of the PICR analysis, selected vehicle characteristics were used as explanatory variables. These vehicle characteristics included number of carburetors (for cars), tachograph (for buses), engine size, and location of engine.

Including vehicle characteristics in user cost equations generally improves the fit of the equations, provides insight into how vehicle characteristics affect operating costs, and can allow the equations to be transferred to other countries more easily. But including vehicle characteristics also creates problems. The effect of vehicle characteristics on user cost may be nonlinear and vehicle characteristics may interact with highway characteristics. Further, the effect of vehicle characteristics on operating costs may alter over time with technical developments. Also, owners may choose vehicles with characteristics suited to the routes over which vehicles are expected to travel.

One of the most important vehicle characteristics is age. In Kenya it was found that the inclusion of vehicle age in kilometers had a substantial effect on maintenance costs. Specifically the Kenya study reported that, as vehicle age doubles for cars and trucks up to a limit of 160 000 and 400 000 km, respectively, so do maintenance expenditures per kilometer. For buses, the estimates from the Kenya study suggest that doubling vehicle age causes maintenance costs to rise by more than 40 percent up to a limit of 1 100 000 km. These increases in maintenance costs apply to each successive doubling of vehicle age. It was important to estimate the age effect in the PICR maintenance data to see whether Brazil age effects differ significantly from those found in Kenya.

As noted earlier, adopting the log-linear form allows the effect of age to be estimated in a tractable way. The form reported in this paper is

$$\ln(\text{parts costs}) = a + bQI^* + c\ln(k) \qquad (11)$$

or

$$\ln(\text{parts costs}) = \exp(a + bQI^* k^c) \qquad (12)$$

As age approaches zero with c positive, parts costs also approach zero. The coefficient c indicates the time path of parts costs as a vehicle ages, and with c positive, parts costs increase with age. If c is less than 1, then the increase in parts costs occurs at a decreasing rate as the vehicle ages. The evidence from Kenya is that for cars and trucks c is about 1 (implying linearity) and for buses about 0.5.

The values for c derived from the PICR analyses to date are as follows (utilities are not discussed in this paper):

| Class | c-Value |
|---|---|
| Car | 0.303 |
| Utility | 0.302 |
| Truck (medium and heavy) | 0.374 |
| Bus | 0.483 |

The Brazil coefficients fall within a relatively narrow range. Given the technologies shared by the vehicle types, this is not surprising. It is also noted that the Brazil and Kenya bus age effects are very similar, which is encouraging. A major difference in the age effects is that although bus maintenance costs are most influenced by age in Brazil among all reported vehicle types, they are least affected by age in Kenya. In Brazil, maintenance of a bus so that it continues to offer the flow of services required by owners and desired by users is increasingly expensive as the vehicle ages, so the ranking found in Brazil is consistent with expectations for that country.

The Brazil study results suggest that each doubling of vehicle age (in kilometers) leads to approximately a 23 percent increase in costs per kilometer for cars and utilities and a 30 percent increase in costs per kilometer for trucks. These effects are substantially smaller than those found in Kenya.

## Rates and Tariffs Comparison

In any competitive economy, aggregate vehicle operating costs should be related to the average rates charged by vehicle operators. Owners may accept rates that fall below average costs from time to time, but, on average, rates must exceed costs or bankruptcy will follow. Therefore, an important consistency check in any operating-cost survey is to see how the estimated average costs compare with the prevailing rates in the industry. In Brazil, freight haulage is competitive, so a rates study is useful in assessing predictions of operating costs. However, the passenger sector is regulated and care must be exercised when comparisons are made there, since some distortions may be expected. Nevertheless, it was considered that such an exercise was worthwhile if the PICR equations were used, and a small rates and tariffs survey was carried out after all analyses had been completed.

The estimated PICR costs do not include any contribution to fixed costs (overhead) or profits, so the PICR total cost for any vehicle class should be less than the prevailing equilibrium average rate or tariff. The comparisons are given in Table 5. Each truck company gave the rates structure for its route and the route most regularly used was selected. The

**Table 5. Comparison of PICR estimates of per-kilometer costs with company tariff and rate data.**

| | | | Company Data (Cr$/km) | |
|---|---|---|---|---|
| Company | Vehicle Type | PICR Estimate (Cr$/km) | Own Vehicle | Hired Vehicle |
| 1 | Two-axle tipper | 28.94 | 35.40 | 27.63 |
| 2 | Two-axle tipper | 54.48 | | 57.79 |
| 3 | Two-axle tipper | 44.24 | | 48.60 |
| 4 | Two-axle tipper | 40.06 | | 51.48 |
| | Two-axle flat | 37.24 | | 41.15 |
| 5 | Three-axle flat | 36.60 | | 41.67 |
| | Articulated heavy truck | 75.48 | 85.03 | |
| 6 | Tractor for articulated heavy truck | 51.11 | | 52.00 |
| 7 | Bus (chassis type) | 48.80 | 65.85 | |
| 8 | Bus (monocoque) | 41.29 | 47.68 | |

Note: Costs and rates at August 1981 prices.

characteristics of the route and the vehicle (principally age) were then used to calculate a PICR estimate of total costs, less overhead or profit, for the type of vehicle employed by the company over that route. The full range of PICR survey results, including fuel, oil, use, and crew costs not reported in this paper, was used to derive total costs. Except for company 1, the earnings per kilometer exceed the PICR estimates of costs per kilometer. Company 1 uses hired vehicles operated by owner-drivers who may be particularly efficient or who underestimated certain cost components (like parts and labor cost). Averaging all truck data gives a 13 percent gross margin for two axles, 14 percent for three axles, and 10 percent for articulated vehicles. Despite the difficulties in comparing costs with rates in a year influenced by a recession (1981), it would seem that PICR aggregate costs are not far from the competitive rates, which provides some confidence in the recommended equations.

In the bus sector, two companies were examined in the rates survey, one operating on unpaved roads, the other on paved roads. It was not considered useful to collect more bus data because of the regulated nature of the industry. One would expect that the difference between earnings and costs on an individual-vehicle basis would be greater for buses than for trucks. Bus operations require more office staff, financial controls, routine maintenance, and cleaning. The gross margin was 15 percent paved and 35 percent unpaved, a very large margin for the unpaved highway. The tariffs are fixed at periodic intervals following the submission of detailed operating-cost figures for different operations. These data were compared item by item and discrepancies were discovered. Tariffs were based on information that suggests that parts consumption on unpaved roads is three times that on paved roads but that maintenance labor costs are 27 percent greater on unpaved roads. Examples like this give cause for concern. PICR estimates suggest that the tariffs are about right for paved roads but are incorrect for unpaved roads. Since competitive rates on unpaved roads are critical to mobility and hence rural development, this highlights the danger of a strongly regulated uninformed system of pricing.

The PICR final report and associated reports contain a much more detailed discussion of the tariff and rates comparison, including differentials at the tonne-kilometer and passenger-kilometer levels. This report summarizes part of that work. The recommended equations are consistent with rates charged by owners. This gives increased confidence in the Brazil study's results.

## CONCLUSIONS

The PICR survey data are a major contribution to research into the relationships between vehicle operating costs and highway characteristics. They complement the Kenya, Caribbean, and Indian studies and are especially important in Latin America. The full results include estimates of various operating costs for the five major classes of vehicle encountered in that region. This wide coverage of vehicle types is an important feature of the survey.

The results broadly confirm the findings in Kenya and the Caribbean with respect to road roughness, which is found to exert the biggest influence on most individual cost components and therefore on total vehicle operating costs. The unit of roughness used in Brazil is currently being evaluated as part of a large experiment to determine a generalized unit of measurement. After the findings of this experiment have been made available, more reliable comparisons between the PICR results and those of other studies will be possible.

The effect of vehicle age in kilometers on operating costs, particularly maintenance parts expenditures, has received close attention. It was found to exert a significant effect on parts, and therefore labor costs, but not so large an effect as in Kenya. Maintenance labor costs have been estimated as a function of parts costs and, for some vehicle classes, road roughness and type of fuel. It is now possible to predict labor cost for all major vehicle classes without resorting to prorating, a technique frequently used in Brazil. Equations predicting vehicle use, not reported here, have been estimated by vehicle class and although highly dependent on type of operation and levels of activity in the economy remain a guide to appropriate differentials in use required by many highway planning models.

A series of final reports and working documents containing the relevant technical memoranda on the Brazil study will be made available. Inquiries should be directed to the PICR Project Coordinator, GEIPOT, SAN Q3 LA, Brasilia D.F., 70040, Brazil.

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# Local Rural Roads and Bridges: Current and Future Problems and Alternatives

C. PHILLIP BAUMEL AND ELDO SCHORNHORST

**The existing county road and bridge system was basically designed and developed during the 1930s and 1940s to accommodate the small motor vehicles of that era. Today, the traffic moving on this system is substantially larger, wider, and heavier than the traffic for which the system was designed. The condition of the county road and bridge system is deteriorating rapidly in all sections of the United States with the possible exception of the Western states. The most serious problems are in Texas, Missouri, Iowa, Nebraska, New York, and West Virginia. This paper identifies several alternative policies to deal with the problem of inadequate funds to rebuild and maintain all the existing county roads and bridges to handle the levels and types of traffic moving on the system.**

A major characteristic of the local rural road system in the United States is the large number of roads. There are about 2.3 million miles in the local rural road system (which refers to those rural roads and bridges that are not in the federal-aid system). This is 71 percent of the 3.2 million miles of rural roads in the United States. A second characteristic of the local rural road system in the Midwest and West is the rectangular road grid. The grid usually conforms to a 1-mile spacing. The density and regularity of the county road system date back to the Ordinance of 1785. This act established townships and the 1-mile survey grids. The objective of Congress was to open the land for settlement.

Many of today's local rural roads and bridges were built in the late 1800s and early 1900s, when overland transportation for both passengers and freight was limited to horse and wagon or the recently built railroad lines. Farms were small, and farmers needed road access to homes, schools, churches, and markets. Technological change soon took its toll on the rural roads and bridges. First came the steam engine and the 4- to 5-ton threshing machine. Some of the bridges collapsed under the weight of these machines. The discovery of large petroleum reserves in Texas and Oklahoma spurred the development of the automobile and small-truck industries during the 1920s and 1930s. This created a need to get rural America "out of the mud." Roads were surfaced, and some bridges were replaced to accommodate the trucks with gross weights of 6-7 tons. About 70 percent of today's rural bridges were built before 1935. Most of the bridges constructed in the 1940s were designed for 15-ton loads. By 1950, about 50 percent of the local rural roads were improved with all-weather surfaces. Thus, the widths, grades, bases, surface designs, and capacities of many local rural roads and bridges are based on the traffic needs during the 1940s and 1950s.

Agricultural technology also changed the type of local rural roads and bridges needed in rural America today. Agricultural output has become export oriented and increasing amounts of grain move over the local road system. There are no weight limits on "implements of husbandry" (farm equipment) in many states. Today, it is common for farmers to use a tractor and two wagons to haul 600-900 bushels of grain with a gross weight of 28-36 tons to the local elevator. Many bridges are 55 ft long or longer, so the entire load is on the bridge simultaneously. Some single-axle wagons hold more than 800 bushels of grain. If we deduct about 6000 lb of hitch weight, the loaded weight ranges up to 50 000 lb/axle.

Farm equipment manufacturers have been forced by farm consolidation and farmer demand to create larger, more efficient machinery. Present-day disks and row-crop cultivators are up to 54 ft wide. These types of equipment can be folded to 18-20 ft wide. But even the folded equipment will not pass through the 16- to 18-ft widths of many local rural bridges. One county engineer in Iowa reported that the entire railing and the posts from two wooden bridges located about 1000 ft apart were missing. There was no doubt in the engineer's mind that some frustrated