CHAPTER 5

APPLICATIONS AND EXAMPLES

5.1 INTRODUCTION

Originally, the MTC was not conceived for isolated or independent applications. It was to be only an algorithm of time and fuel and was actually utilized to generate speed and fuel equations for the ICR model, as discussed in Volume 8. After conclusion, it was decided that, should the MTC not be very demanding in terms of computer time, it would be made part of a system of models or routines which, with innumerable advantages, would substitute the ICR model. This system would be designated *Brazilian Models for the Evaluation of Highway Investments* (MOBAIR).

This possibility in fact occurred, since the MTC program can be rapidly executed in any large or medium-size computer. Consequently, it is now considered possible that the MTC will be incorporated into the future MOBAIR system, whose conception is to be outlined by the *ICR Research* team in 1982.

As regards direct and isolated applications, one should consider the fact that the MTC shows a good degree of precision for different levels of planning. However, it has the disadvantage of demanding highly-detailed inputs that are sometimes incompatible with the objectives and with the aggregate-scale prism adopted in some of the highway-planning studies. Inversely, this same degree of detail that is characteristic of its inputs (every grade, every curve, etc.) makes it possible to use the MTC in the comparison of design alternatives or even in the comparison of complete projects, provided that the comparison criteria based solely on fuel economy (and travel time) can be explicitly justified.

Under these conditions, the future MOBAIR system would have to have sufficient flexibility to use the MTC directly, when the inputs it requires at the engineering project level are available, or as an auxiliary model aimed at generating aggregate equations, of the type required by the present ICR model.

Consequently, one should discuss the validity of the MTC applications on two levels: for direct use as a model, isolatedly and independently; or as an auxiliary model of the present ICR Model or the future MOBAIR system.

5.2 ISOLATED AND DIRECT MTC APPLICATIONS

In isolated applications, the MTC predicts travel time and fuel consumption, simultaneously taking into account all of the important characteristics of a road, in the same manner as they are indicated in a project. In this sense, as far as is known, there exists no alternative, either in Brazil or abroad, which permits comparisons with the MTC, at least in terms of the vast experimental foundation on which the development of the MTC was based.

The decision as to the use for the isolated predictions of the MTC are to be put, this is a decision which should be taken by the user. Based on knowledge of the experiments which form the basis of the MTC, the logic and conceptions inherent in the program, and the more critical limitations of the present version - as extensively discussed in Volume 6 and in previous chapters of this Report - the user will be perfectly able to form his own judgement in taking this decision.

Naturally, there are other factors which will make it possible for the user to extend or restrict the use of the MTC in his arsenal of planning models, programs and parameters. Aside from the inexistence of fuel-consumption prediction methods similar to those of the MTC, one should also take into consideration all of the implications attending the current shortage and costs of oil derivatives. In other words, based on the concept of fuel economy, these two factors could well justify the comparison of design alternatives during the engineering-project stage, or of design alternatives during the phase of feasibility studies, with the condition that it be clearly understood and justified that the exclusion of other operational cost items will not invalidate or weaken or even distort the conclusion which one desires to obtain. In the latter case, given the present economic conditions of the country,considerations regarding the *shadow price* of fuel could be used to strengthen the justification of isolated applications of the MTC.

Obviously, there always exists the possibility of utilizing the MTC together with other methods and parameters, in separate operations. In other words, the MTC could be used in an isolated and independent fashion to calculate speed and fuel consumption, while other models or methods would be used separately to calculate the other items of road maintenance or operating costs of vehicles.

An example of an isolated application of the MTC is presented in the *MTC User's Manual* (bound separately).

5.3 MTC APPLICATIONS AS AN AUXILIARY MODEL

As regards the utilization of the MTC as an auxiliary model in the elaboration of other models, it would seem valid to present its application in relation to the ICR Model, by way of example.

The MTC was used to generate equations for predicting speed and fuel consumption on different road sections corresponding to the factorial cells presented in Table 5.1. Varying in length from 3 km to 40 km, these sections were obtained from the route files of the *User Cost Survey Team*, of the *ICR Research*. More than one section were chosen for each factorial cell, so that one would be able to estimate the error variation in speed and fuel consumption. All of the classes and types of vehicle defined in the MTC were simulated on each type of surface and at two levels of roughness:

- Paved: 50 and 100 QI; and
- Unpaved: 70 and 200.

The initial speed in both traffic directions was set at 80 km/h, for all classes of vehicles.

Speed predictions for the following classes of vehicles were then generated with the use of the MTC:

1. Automobile;
2. Bus;
3. Empty Utility;
4. Loaded Utility;
5. Empty Truck; and
6. Loaded Truck.

In the regression analysis which established the aggregate speed equations, the dependent variable V was utilized and defined as:

$$V = \sum_{i=1}^{2} \left[\frac{2L}{\left(\sum_{j=1}^{n_i} t_{ij} \right) \Big/ 3600} \right]$$

TABLE 5.1 - FACTORIAL MATRIX OF SECTIONS CHOSEN FOR GENERATION OF AGGREGATE EQUATIONS WITH THE USE OF THE MTC

	AVERAGE CENTRAL ANGLE (°/km)		
RISE PLUS FALL (m/km)	LOWER THAN 100	100 to 180	ABOVE 180
0 to 15	164165 534663 766749	463331 478477 698485	331455 447448 449653
15 to 35	532556 765752	476830 207208A 207208B	158879B 456838B 684685 339863
>35	305303 392399 396395 887886	467468 501500 158879A	452655 456838A 687692

NOTE: The alphanumerals within the cells represent the codes which identify the sections chosen from the route file of the User Cost Survey Team.

Where:

V = average speed (km/h) of a given class of vehicles in both directions of a given section;

L = length of the section (km);

t_{ij} = time spent (in seconds) for the vehicle class to cross the j-th link in direction i of the section under consideration;

i = 1 primary direction;
2 secondary direction;

n_1 = number of links in direction i of the section under consideration.

In the case of fuel consumption, MTC predictions were generated for the following types[1] of vehicles:

1. Automobiles;
2. Bus;
3. Empty Utility;
4. Loaded Utility;
5. Light Gasoline-Powered Truck with or without load;
6. Light Diesel-Powered Truck with or without load;
7. Heavy Truck with or without load; and
8. Semi-Trailer with or without load.

In the regression analysis which established the aggregate equations of fuel yield[2], the dependent variable C was used and defined as:

$$C = \sum_{i=1}^{2} \left[\frac{2L}{\left(\sum_{i=1}^{n_i} f_{ij} \right) / 1000} \right]$$

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[1] Observe that a class of vehicles as defined by the MTC can include one or more types (see User's Manual).

[2] Observe that in the greater part of the text, the expression *fuel consumption* has been used in the generic sense, without reference to the unit used. In the case of aggregate equations, however, the need to make this cost item compatible with the other cost items led to the use of the expression *fuel yield* to designate the unit km/ℓ, thus differentiating it from the expression *fuel consumption*, which designates the unit mℓ/sec., which is used principally in the analysis of the experiments.

Where:

C = fuel yield (km/ℓ) of a given vehicle class trafficking in both directions of a given section;

L = length of the section (km);

f_{ij} = fuel consumed (milliliters) by the vehicle class till the point of crossing the j-th link in direction i of the section under consideration;

i = 1 primary direction;
2 secondary direction;

n_1 = number of links in direction i of section under consideration.

In the regression analysis, the following independent variables - representing the geometric characteristics of the sections in aggregate form - were considered:

o Profile - SD = sum in absolute value of rise plus fall (m/km);

o Alignment - ACM = average central angle (degree/km) - (sometimes termed *average degree of curvature* in technical literature).

Table 5.2 presents the values of these variables in relation to the sections chosen and utilized in speed and fuel-yield predictions.

For the aggregate equations of fuel yield, another independent variable was defined:

$$PW = \frac{\text{Power (HP)}}{\text{Gross Weight (t)}}$$

The vehicle specifications utilized in the generation of the aggregate equations for cargo vehicles (classes 5 and 6, types 1, 2, 3 and 4) are presented below:

TYPES OF VEHICLES	POWER (Hp)	GROSS WEIGHT (t)		POWER/WEIGHT RATIO	
		Empty	Loaded	Empty	Loaded
Light Truck (g)	169	2.60	5.90	65.0	24.9
Light Truck (d)	102	2.60	5.90	39.2	17.3
Heavy Truck	147	9.80	21.00	15.0	7.0
Semi-Trailer	285	14.00	40.70	20.4	7.0

TABLE 5.2 - GEOMETRIC CHARACTERISTICS OF SECTIONS CHOSEN FOR GENERATION OF AGGREGATE EQUATIONS WITH THE USE OF THE MTC

SECTION CODE	BEGINNING OF SECTION(km)	END OF SECTION(km)	SUM OF RISES AND FALLS(m/km)	ACM AVERAGE CENTRAL ANGLE(%km)
164165	0.00	14.17	11.5	5.2
305303	0.00	7.94	40.8	47.3
331455	0.00	6.34	13.9	240.6
392399	0.00	13.59	40.2	34.2
396395	0.00	10.26	40.9	30.7
463331	0.00	4.57	9.8	104.0
467468	0.00	11.66	40.5	130.8
476830	0.00	14.53	26.0	138.6
478477	0.00	2.55	6.8	104.9
501500	0.00	13.34	40.9	112.1
532556	0.00	28.32	27.2	16.5
534663	0.00	17.36	11.4	5.3
698485	0.00	8.93	10.0	100.9
765752	0.00	39.99	26.7	17.8
766749	0.00	10.29	11.2	0.0
887886	0.00	5.93	40.9	11.5
158879A	0.00	11.07	40.6	131.4
158879B	17.85	27.04	26.4	191.1
207208A	19.69	27.67	30.4	153.1
207208B	9.84	19.69	25.9	132.3
447448	0.00	12.11	13.7	206.2
449635	27.79	36.43	14.4	240.4
452655	16.05	26.97	39.3	202.0
456838A	8.04	16.33	39.4	412.1
456838B	16.33	22.75	32.3	329.3
684685	10.86	19.45	26.7	198.8
687692	0.00	3.66	38.3	326.3
339863	0.00	8.27	32.1	319.8

Tables 5.3 and 5.4, respectively, present the aggregate equations of speed and fuel yield which were generated by the MTC for the different classes and types of vehicles, utilizing the process described above.

By way of example, the results of the application of the aggregate equations in the prediction of speed for the class of loaded trucks,along with the fuel yield of heavy trucks, are presented in Tables 5.5 and 5.6, respectively, in relation to highway sections with different geometric characteristics and different surface conditions.

5.4 *OBSERVATIONS*

When applied to sections with extreme geometric values (SD and ACM) and roughness (QI*), the equations presented in Tables 5.3 and 5.4 produce excessively-low predictions, including negative values. Even though sections with such extreme combinations are very rare, it is recommended, in order to avoid serious distortions, that one utilizes the following minimum values of fuel yield, when these situations occur:

		In km/ℓ
1.	Automobile	7.05
2.	Bus	2.65
3.	Empty Utility	5.10
4.	Loaded Utility	4.00
5.	Light Truck (gasoline)	1.10
6.	Light Truck (diesel)	2.20
7.	Heavy Truck	1.60
8.	Semi-Trailer	1.00

In determining the aggregate equations of fuel consumption, these values were the smallest predicted by the MTC. It should be noted that the minimum determined for the class *automobile* corresponds to the consumption of the Volkswagen 1300 Sedan. Naturally, the question arises as to whether this automobile and other vehicles in the Project's test fleet are representative of the vehicle population of the country. This question was discussed in Chapter 4.

A further shortcoming in relation to the aggregate equations of speed and fuel is that of the unsuitability of the SD and ACM vari-

TABLE 5.3 - AGGREGATE SPEED EQUATIONS

PAVED SURFACE	
Automobile	$V=95.6-0.237\times SD-0.266\times ACM-0.122\times QI+K$
Bus	$V=90.0-0.356\times SD-0.246\times ACM-0.141\times QI+K$
Empty Utility	$V=89.4-0.241\times SD-0.261\times ACM-0.115\times QI+K$
Loaded Utility	$V=87.9-0.290\times SD-0.262\times ACM-0.117\times QI+K$
Empty Truck	$V=86.5-0.276\times SD-0.253\times ACM-0.127\times QI+K$
Loaded Truck	$V=79.8-0.340\times SD-0.254\times ACM-0.140\times QI+K$
UNPAVED SURFACE	
Automobile	$V=81.8-0.163\times SD-0.236\times ACM-0.062\times QI+K$
Bus	$V=71.0-0.282\times SD-0.216\times ACM-0.081\times QI+K$
Empty Utility	$V=79.8-0.167\times SD-0.232\times ACM-0.055\times QI+K$
Loaded Utility	$V=75.1-0.216\times SD-0.233\times ACM-0.057\times QI+K$
Empty Truck	$V=74.2-0.202\times SD-0.223\times ACM-0.067\times QI+K$
Loaded Truck	$V=70.2-0.266\times SD-0.224\times ACM-0.080\times QI+K$
$K=(0.00058-0.0000137\times SD)\times ACM^2+0.0043\times SD\times ACM-0.00123\times SD\times QI$	

Coefficient of Determination: 0.91

Mean Square Error : 2.89 $(km/h)^2$

Number of Observations : 672

TABLE 5.4 - AGGREGATE FUEL-YIELD EQUATIONS

PAVED SURFACE	
Automobile	$C=C1+12.31-0.030xSD+0.01494xACM-0.02401xQI$
Bus	$C=C1+5.46-0.0301xSD+0.00954xACM-0.00705xQI$
Empty Utility	$C=C1+7.98-0.0193xSD+0.01424xACM-0.01497xQI$
Loaded Utility	$C=C1+7.68-0.0293xSD+0.01122xACM-0.01475xQI$
Light Truck (g)	$C=C1+2.65-0.0079xSD+0.00493xACM-0.00107xQI+0.000059xACMxPW$
Light Truck (d)	$C=C1+5.49-0.0382xSD+0.00355xACM-0.00705xQI+(0.000059xACM+0.0294+0.0005xSD)xPW$
Heavy Truck	$C=C1+2.50-0.0364xSD+0.00546xACM+0.00582xQI+(0.000272xACM+0.0728+0.0011xSD-0.00053XQI)xPW$
Semi-Trailer	$C=C1+1.79-0.0109xSD+0.00156xACM+0.00276xQI+(0.000274xACM+0.0255-0.00034xQI)xPW$
UNPAVED SURFACE	
Automobile	$C=C2+13.11-0.0199xSD+0.01336xACM-0.02401xQI$
Bus	$C=C2+6.10-0.0197xSD+0.00796xACM-0.00705xQI$
Empty Utility	$C=C2+9.09-0.0089xSD+0.01266xACM-0.01497xQI$
Loaded Utility	$C=C2+8.37-0.0189xSD+0.00964xACM-0.01475xQI$
Light Truck (g)	$C=C2+3.06+0.0025xSD+0.00335xACM-0.00107xQI+0.000059xACMxPW$
Light Truck (d)	$C=C2+6.88-0.0278xSD+0.00197xACM-0.00705xQI+(0.000059xACM+0.0206+0.0005xSD)xPW$
Heavy Truck	$C=C2+2.36-0.0260xSD+0.00388xACM+0.00582xQI+(0.000272xACM+0.1046+0.0011xSD-0.00053xQI)PW$
Semi-Trailer	$C=C2+1.83-0.0005xSD-0.00002xACM+0.00276xQI+(0.000274xACM+0.0459-0.00034xQI)xPW$

$C1= -0.00001225xACM^2+K$

$C2= -0.00001085xACM^2+K$

$K= (0.00000011xQIxACM-0.00005xQI-0.000113xSD)xACM$

Coefficient of Determination	:	0.96
Mean Square Error	:	0.31
Number of Observations	:	1344

TABLE 5.5 - SPEED PREDICTIONS (km/h) FOR LOADED TRUCKS OBTAINED THROUGH THE AGGREGATE EQUATIONS

SURFACE		PAVED		UNPAVED	
ROUGHNESS(QI*)		30	100	50	200
AVERAGE CENTRAL ANGLE(°/km)	RISE AND FALL(m/km)				
50	10	62.4	51.7	55.0	41.1
	25	59.4	47.5	52.8	36.1
	45	55.5	41.8	49.9	29.5
150	10	50.2	39.5	45.8	32.0
	25	49.6	37.6	45.9	29.3
	45	48.8	35.1	46.1	25.8
250	10	46.8	36.1	45.4	31.5
	25	44.4	32.5	43.8	27.1
	45	41.3	27.6	41.6	21.3

TABLE 5.6 - FUEL-YIELD PREDICTIONS (km/ℓ) FOR HEAVY TRUCKS WITH POWER/WEIGHT RATIO = 11 Hp/t

SURFACE		PAVED		UNPAVED	
ROUGHNESS (QI*)		30	100	50	200
AVERAGE CENTRAL ANGLE (°/km)	RISE AND FALL (m/km)				
50	10	3.33	3.17	3.52	3.18
	25	2.88	2.72	3.23	2.89
	45	2.28	2.12	2.84	2.50
150	10	3.73	3.38	3.74	2.98
	25	3.11	2.76	3.27	2.52
	45	2.29	1.93	2.66	1.90
250	10	3.95	3.56	3.85	3.00
	25	3.17	2.77	3.21	2.37
	45	2.11	1.72	2.37	1.60

ables, utilized to describe the vertical and horizontal geometry of the road, instead of grades and individualized, sequential curves of the MTC.

These variables (SD and ACM) were utilized by the *Transportation and Road Research Laboratory* (TRRL) and by the *Massachusetts Institute of Technology* (MIT) in the Models RTIM and HDM, which, in terms of level of aggregation, are similar to the ICR. However, there is a consensus of opinion that these are rather unsatisfactory and that it is possible to define other variables or indexes that, though possessing the same level of aggregation as the SD and ACM variables, explain and better discriminate the vertical and horizontal geometry of the roads. Work in this area has already been initiated by the ICR RESEARCH team.

Finally, a word of caution to those who have contemplated using the equations of the MTC program to obtain predictions of speed and fuel consumption without running the program of the Model. This simply cannot be done. The equations of the MTC were designed for use within the context and inference space of the Model. As was demonstrated in Chapter 2, at each node the Model forms a complete survey of the situation (characteristics of the road, value and mode of previous speed, etc.) before selecting the speed equations and, subsequently, associating the corresponding consumption equations to them. It is entirely incorrect to isolate the phases of this intricate process.

Therefore, should the user, for any reason whatsoever, not be able to run the MTC on a computer, it is recommended that he uses the aggregate equations in Tables 5.3 and 5.4, instead of the MTC equations, independent of the relative unsuitability of the aggregate variables of the geometry presently under consideration.

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