CENTER FOR ENVIRONMENT
OFFICE OF ENERGY, ENVIRONMENT, AND TECHNOLOGY

FINAL REPORT

THAILAND TUK-TUK ELECTRIC VEHICLE DEMONSTRATION PROJECT

Prepared for:

Royal Thai Government
Ministry of Science, Technology and Environment
Pollution Control Department

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SUMMARY

Thailand has undergone a rapid transformation from a predominately agricultural-based economy to an industrialized economy with a strong private sector. Two of the negative consequences of this dramatic growth are the increasing deterioration of ambient air quality and noise pollution in the Bangkok Metropolitan Area. Brought on largely by the transport sector, vehicle registration in the Bangkok Metropolitan Area has soared from 600,000 in 1980 to 2.76 million in 1993. The emissions of two-cycle internal combustion engines and diesel engines are the primary contributors to these environmental challenges. A three-wheeled, two-cycle vehicle used primarily in taxi and light cargo applications and affectionately known as the tuk-tuk, is notorious for its belching noxious fumes and disconcerting noise.

The United States Agency for International Development's Mission in Bangkok and the Royal Thai Government's Ministry of Science, Technology, and Environment (MOSTE), recognizing the need to address these issues, requested assistance from the Center for Environment's Office of Energy, Environment, and Technology (EET) to develop and implement an electric vehicle demonstration program. This program had the multiple objectives of enhancing the environment, leveraging government funds, and increasing U.S. exports. An adjunct to the demonstration program included technical assistance to a Thai-U.S. joint venture involved in the development and production of electric vehicles.

While a collaborative program comprised of distant participants presented challenges, it has been recognized as a key element in the successful execution of this demonstration effort. Differing views, strengths, and contributions were channeled into providing the timely, effective resolution for issues that are inevitable in such an undertaking. One of the more remarkable contributions was the cost sharing provided by all participants. Every dollar provided by USAID was met with at least one dollar from the other participants.

EET's Energy Technology Innovation Project (ETIP), in collaboration with MOSTE, designed a demonstration program to determine the feasibility of replacing conventional tuk-tuks in the Bangkok Metropolitan Area with electric tuk-tuks. Tuk-tuks were selected as the target market because: 1) the market is controlled by fleet operators; 2) the design of the vehicle is relatively simple; 3) the urban drive profile lends itself toward electric drive technology; and, 4) the vehicles emit significant air and noise pollution.

Demonstration Program elements included:

Industry Assessment:	How the industry is organized and operates.
Safety Tests:	Braking tests for the conventional and electric tuk-tuks.
Performance Tests:	Acceleration tests for the conventional and electric tuk-tuks.

Urban Drive Cycle Tests:	Use data for conventional tuk-tuks that identify driving habits.
Electric Vehicle Prototypes:	Three electric tuk-tuks with slightly different design characteristics provided.
Electric Vehicle Performance Model:	Model provided to analyze data collected from urban drive tests.
Environmental Assessment:	Evaluate environmental consequences of replacing conventional tuk-tuks with electric powered vehicles.
Infrastructure Assessment:	Determine the infrastructure needed to support an electric tuk-tuk industry.
Economic/Financial Assessment:	Determine the financial commitment requested by the Royal Thai Government to market electric vehicles.

The initial phase of this program called for designing and testing three electric tuk-tuk prototypes. The lessons learned would be applied to the second phase - a small fleet of pre-production electric tuk-tuks tested over an extended time.

This report covers the activities to-date on the initial phase of the demonstration program.

Electric vehicles provide a quiet, pollution free (at the source point) transportation option. The primary problems facing this technology are vehicle range and initial cost. While advances in battery research are promising and mass production offers cost reductions, it appears that a government subsidy is needed to initially promote the purchase of electric vehicles in the Bangkok Metropolitan Area.

INTRODUCTION

1.1 BACKGROUND

Thailand is a vibrant country, averaging over 10% annual GDP growth from 1988 to 1993. Rapid economic growth, however, can also develop the seeds for constraint. The robust growth in Thailand has been slowing from the fast gait of the late 1980's. Infrastructure bottlenecks and environmental degradation have worsened in recent years. In the Bangkok Metropolitan Area, for example, traffic congestion and the resulting effects on ambient air quality are major concerns of the Royal Thai Government.

Vehicle registration in the Bangkok Metropolitan Area soared from 600,000 in 1980 to 2.76 million in 1993. Airborne emission estimates from the transport sector have averaged a 12% growth rate between 1986 and 1991. Internal combustion two-cycle engines and diesel engines are significant contributors to carbon dioxide and hydrocarbon emissions in Bangkok. The tuk-tuk, a three-wheeled, two-cycle vehicle used primarily as a taxi and to haul light cargo, emits significant fumes and is very noisy. Estimates, for example, indicate that the annual 1995 emissions from tuk-tuks in Thailand were 456,000 tons of Carbon Dioxide, 23,00 tons of Carbon Monoxide, 13,400 tons of Hydrocarbons, 100 tons of Nitrous Dioxide, and, 30 tons of Sulfur Dioxide.

Precipitated by a Memorandum of Understanding between Vice President Al Gore and then Deputy Prime Minister Amnuay Virawan in 1993, MOSTE, USAID/Bangkok, and USAID/Washington's Office of Energy, Environment, and Technology in the Global Center for Environment entered into a collaborative demonstration program to determine the feasibility of replacing conventional tuk-tuks with electric powered tuk-tuks.

Two phases were designed into the demonstration program. The initial phase required three electric tuk-tuk prototypes to be designed, assembled and tested. The lessons learned from the first phase are to be applied to a small fleet of electric tuk-tuk pre-production units. The second phase is for extended testing of this fleet to determine vehicle reliability and to make improvements in the overall design.

This report covers the activities performed to-date on the initial phase of the demonstration program.

1.2 PROGRAM PARTICIPANTS

A Steering Committee was established to provide overall direction for the demonstration program. Members of the Steering Committee are identified in *Figure 1*.

The primary project participants included:

MOSTE (project sponsor)
USAID/Bangkok (project sponsor)

USAID/EET (project sponsor)
Chulalongkorn University (managed demonstration program in Thailand for MOSTE)
Electric Power and Research Institute (provided technical advice)
Advanced Electric Car Technology (US partner in joint venture)
Pholasith Motors (Thai partner in joint venture)
Electrosource (supplier of batteries)
Keenan Institute (manager of US-Thai Partnership Program)
Bechtel Corporation (manager of ETIP)

While a collaborative program comprised of distant participants presented challenges, the differing views and strengths of the team were key elements in the successful execution of this demonstration effort. The combined contributions of the team provided timely, effective resolution for issues that are inevitable in such an undertaking. Moreover, cost sharing for the demonstration program was provided by all participants.

1.3 DEMONSTRATION PROGRAM

The demonstration program, in addition to addressing the objectives, was developed to provide support for other, future demonstration programs MOSTE may initiate. The environmental and infrastructure assessments and the economic model, for example, offer utility for an electric bus demonstration program being contemplated by MOSTE.

The demonstration program components include:

Industry Assessment:	An assessment of the current tuk-tuk industry; organization, capital and operating costs, regulations, fare structure, and, use patterns.
Safety Tests:	Braking and general handling tests were performed on conventional tuk-tuks as a baseline for the design and operation of electric tuk-tuks; these same tests were performed on the electric tuk-tuks for comparison.
Performance Tests:	Acceleration tests were performed on conventional tuk-tuks as a baseline for the design and operation of electric tuk-tuks; these same tests were performed on the electric tuk-tuks for comparison.
Drive Cycle Tests:	Daily use data was obtained on the conventional tuk-tuks to determine: driving habits, range, fuel consumption, typical fare revenue, and an urban driving profile for subsequent emissions tests and the design and operation of electric tuk-tuks. The

	electric tuk-tuks included data acquisition systems to allow for the collection and evaluation of actual drive use
Electric Tuk-Tuk Prototypes:	Three prototypes were designed, built and provided to MOSTE; design criteria was based upon data collected from the previous demonstration program components and the joint venture's view of the intended marketplace.
Electric Vehicle Performance Model:	A performance model was provided by ETIP to allow for analysis of data collected from the urban tests on the electric tuk-tuks; it is hoped that with this data model validation could occur and eliminate or reduce the need for actual urban tests.
Environmental Assessment:	A two step approach: 1) a methodology was developed by ETIP as a baseline; and 2) the assessment by MOSTE is to determine the environmental benefits of switching from an internal combustion engine to electric motors.
Infrastructure Assessment:	A two step approach: 1) a terms of reference was developed by ETIP; and 2) the assessment by MOSTE is to determine the infrastructure requirements to support and sustain an electric tuk-tuk industry.
Economic/Financial Assessment:	A model was developed by ETIP to allow for flexibility in determining the costs and returns from four perspectives: 1) vehicle owner; 2) vehicle driver; 3) charging station owner/operator; and 4) the Royal Thai Government. Flexibility was a primary consideration since the final inputs were expected to be provided by MOSTE.

A flow chart, *Figure 2*, depicts the relationship of the demonstration program elements.

1.4 DEMONSTRATION PROGRAM SCHEDULE

Activity	Completion Date
Industry Assessment	July 1994
Initial Safety and Performance Tests for Conventional Tuk-Tuks	August thru September 1994

Urban Drive Data Acquired from Conventional Tuk-Tuks	September 1994
Terms of Reference Developed for Thai Contractors	November 1994
Placement of Order for Electric Tuk-Tuk Prototypes	December 1994
Urban Drive Cycle Developed	March 1995
Economic/Financial Model Developed	April 1995
Environmental Methodology Developed	June 1995
Initial Safety and Performance Tests for Electric Vehicles	July 1995
Delivery of Two Electric Tuk-Tuks to Thailand	August 1995
Final Safety and Performance Tests for the Third Electric Tuk-Tuk	March 1996
Final Delivery of Third Electric Tuk-Tuk	May 1996

1.5 REPORT STRUCTURE

This report is organized into the following sections:

Section 2 - Industry Assessment

Section 3 - Safety and Performance Tests, Conventional Tuk-Tuks

Section 4 - Urban Drive Profile, Conventional Tuk-Tuks

Section 5 - Electric Tuk-Tuk Prototypes

Section 6 - Safety and Performance Tests, Electric Tuk-Tuks

Section 7 - Performance Model

Section 8 - Environmental Assessment

Section 9 - Infrastructure Assessment

Section 10 - Economic/Financial Assessment

Section 11 - Conclusion

Section 12 - Appendices

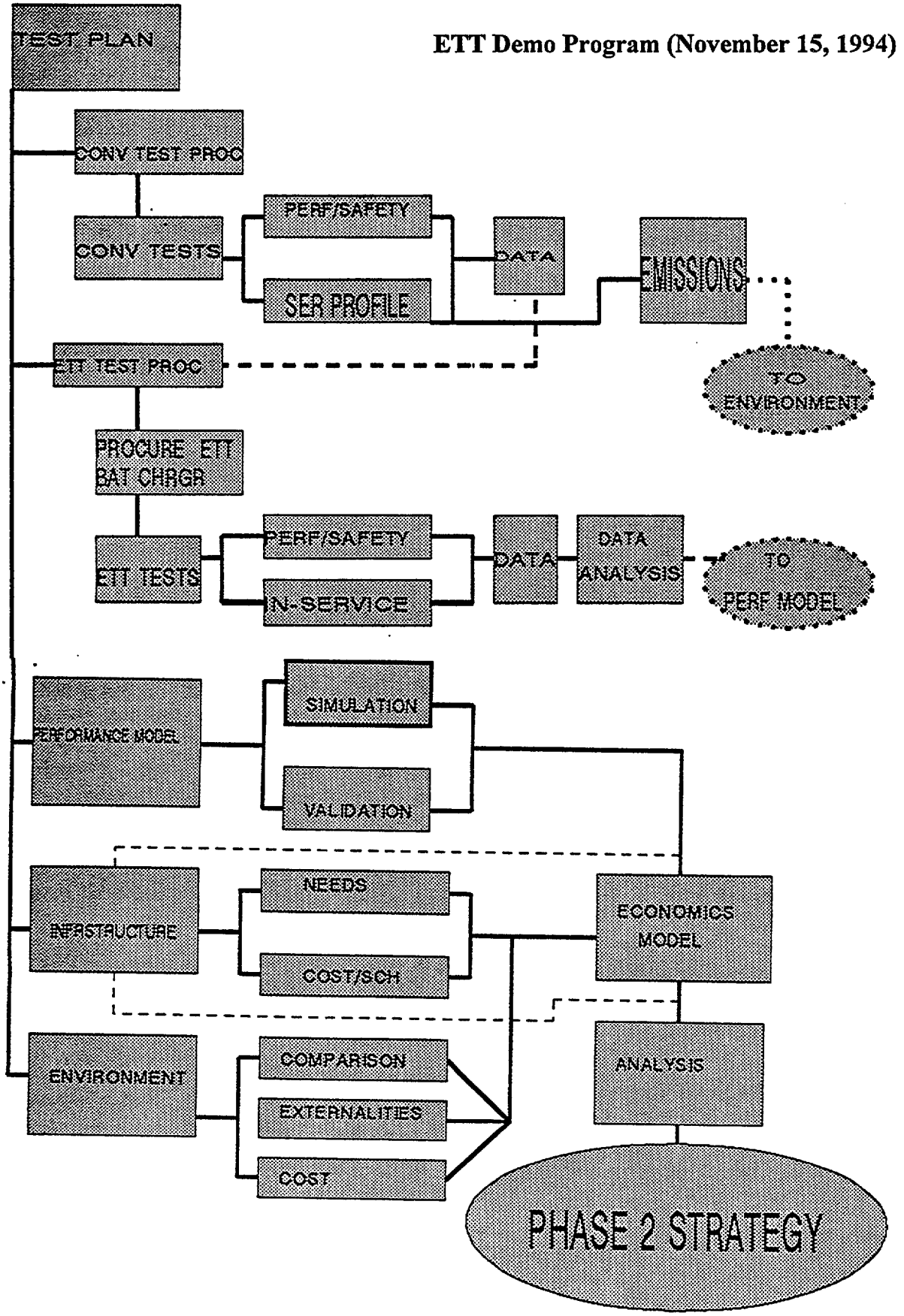
Figure 1

Joint Steering Committee Membership

- √ USAID/Bangkok
- √ USAID/G/ENV/EET
- √ Ministry of Science, Technology, and Environment (MOSTE)
- √ Metropolitan Electricity Authority (MEA)
- √ Electricity Generating Authority of Thailand (EGAT)
- √ Bangkok Ministry of Transport
- √ Bangkok-Thon Buri Metropolitan City Office of the Governor

Figure 2

ETT Demo Program (November 15, 1994)



INDUSTRY ASSESSMENT

2.1 OBJECTIVE

The objective was to obtain a better understanding of the tuk-tuk industry. This information was used to assist in the refinement of the demonstration program components and to serve as inputs for the design of the electric tuk-tuks, infrastructure assessment, environmental assessment, and, economics model.

2.2 GENERAL DESCRIPTION

Little documented information existed on the organization, costs, and use characteristics of the tuk-tuk industry in the Bangkok Metropolitan Area. It was determined that an industry assessment, jointly performed by MOSTE and ETIP, needed to be undertaken.

Tuk-tuks provide two services in the Bangkok Metropolitan Area: taxi and cargo. Primary fuel source is liquefied petroleum gas. The internal combustion engine is mostly a two-stroke design. There are approximately 8,300 tuk-tuks registered in the Bangkok Metropolitan Area. Approximately 90% of these vehicles operate as taxis.

In addition to offering an inexpensive transportation option, the tuk-tuk can often outmaneuver most other motorized vehicles by traveling less congested, but extremely narrow, routes. The fare structure is usually a negotiated fixed rate, providing incentive for the driver to arrive at the destination as quickly as possible.

The Royal Thai Government has established a quota for conventional tuk-tuks operating within the Bangkok Metropolitan Area. Most of the taxi tuk-tuks are owned by fleet operators and are members of the Tricycle Association of Thailand. The market price for a medallion to operate a conventional tuk-tuk in the Bangkok Metropolitan Area is estimated at $20,000.

The commercial aspects of taxi service involve a fleet operator responsible for providing and maintaining the tuk-tuk and the driver whom is responsible for rent and fuel costs. The taxi tuk-tuks generally operate on 12 hour shifts.

Appendix A contains more detailed information on the tuk-tuk industry in the Bangkok Metropolitan Area.

SAFETY AND PERFORMANCE TESTS - CONVENTIONAL TUK-TUKS

3.1 OBJECTIVE

The objective was to perform tests to acquire baseline performance, braking, and operational data. This data would be used:

1) To provide design criteria for the electric tuk-tuks;

2) To provide a comparison with the performance of the electric tuk-tuks; and,

3) To develop a drive cycle for emissions tests.

3.2 CONVENTIONAL TUK-TUK TESTS

Little documented information existed on safety, accelerating and use characteristics of the conventional tuk-tuks. MOSTE advised that there is no suitable urban drive cycle for the tuk-tuk. Verification of information received from the industry assessment was also needed.

Braking and acceleration tests were performed on a conventional taxi and cargo tuk-tuk in accordance with Society of Automotive Engineers (SAE) and U.S. Federal Motor Vehicle standards. These standards were selected over others by ETIP and MOSTE because they were more applicable to the vehicles being tested.

Test results are summarized in *Figures 3, 4 and 5* for the taxi and *Figures 6, 7 and 8* for the cargo.

Operating data was collected for a continuous seven day period, twenty-four hours per day to develop an urban drive profile. A data acquisition system was installed on a conventional taxi and cargo tuk-tuk. Typical driving and operating practices were simulated by following taxi and cargo tuk-tuks at work. A map identifying the areas of Bangkok included in the taxi test is shown in *Figure 9*. A written checklist was also maintained that identified: day, time, weather conditions, degree of traffic congestion, location, and other remarks. The results of this test indicated that more than 50% of a shift is spent between 0 - 10 kph. Maximum range per shift was 130 kilometers. Average range per shift was 110 kilometers.

Figure 10 is a photo of a conventional tuk-tuk with an installed data acquisition system used during these tests.

Appendix B contains the complete results of these tests and the procedures used.

Figure 3

Taxi Tuk-Tuk Braking Test Summary

VEH: Taxi Tuk-Tuk TEST DATE: 8/27-30/94

PROCEDURE	SPEED (kph)	DECEL (mpsps) Avg.	STOP DIST. (m)	MAX. BRAKE PEDAL FORCE (N)	NUMBER OF TESTS
Effectiveness Test - 50 kph (Unloaded Test Weight)	51.7	-4.55	22.6	156.5	6
Effectiveness Test - 50 kph (Loaded Test Weight)	49.3	-4.60	20.4	190.4	6
Fade and Recovery (Baseline)	48.9	-3.07	30.1	87.2	3
Fade and Recovery (Fade Test)	58.3	-3.45	38.0	153.9	10
Fade and Recovery (Recovery)	50.9	-3.11	32.1	149.9	5
2nd Burnish Procedure	--	--	--	--	--
Final Effectiveness Test - 50 kph (Unloaded Test Weight)	50.7	-4.62	21.5	71.2	3
Final Effectiveness Test - 65 kph (Unloaded Test Weight)	64.2	-4.78	33.3	93.0	3
Final Effectiveness Test - 50 kph (Loaded Test Weight)	48.9	-4.82	19.1	127.2	3
Final Effectiveness Test - 65 kph (Loaded Test Weight)	65.8	-4.42	37.8	114.8	3
Water Recovery (Baseline)	49.1	-3.00	31.0	107.6	3
Water Recovery (Recovery)	42.3	-2.19	31.5	73.0	5

Figure 4

Passing Acceleration Tests - 40-60 kph - Taxi Tuk-Tuk

RUN NUMBER	LOADING CONDITION	HEADING	3rd GEAR		4th GEAR	
			Elapsed Time (sec)	Distance (meters)	Elapsed Time (sec)	Distance (meters)
TACC07	Loaded	East	9.8	139	--	--
TACC08	Loaded	West	9.9	143	--	--
*TACC09	Loaded	East	7.7	114	--	--
TACC10	Loaded	West	9.6	138	--	--
TACC11	Loaded	East	9.9	141	--	--
TACC12	Loaded	West	10.2	146	--	--
TACC13	Loaded	East	--	--	12.5	177
TACC14	Loaded	West	--	--	15.8	221
**TACC15	Loaded	East	--	--	19.2	260
TACC16	Loaded	West	--	--	12.9	180
TACC17	Loaded	East	--	--	19.0	268
TACC18	Loaded	West	--	--	12.2	170
TACCU25	Unloaded	East	8.2	114	--	--
TACCU25	Unloaded	West	8.1	114	--	--
TACCU25	Unloaded	East	8.0	113	--	--
TACCU25	Unloaded	West	8.1	116	--	--
TACCU25	Unloaded	East	8.0	115	--	--
TACCU25	Unloaded	West	8.1	115	--	--
TACCU25	Unloaded	East	--	--	9.9	139
TACCU25	Unloaded	West	--	--	9.7	138
TACCU25	Unloaded	East	--	--	9.9	138
TACCU25	Unloaded	West	--	--	10.2	143
TACCU25	Unloaded	East	--	--	10.0	141
TACCU25	Unloaded	West	--	--	10.0	139

* Initial Speed = 46 kph

** End Speed = 57.4 kph

Figure 5

Standing Start Acceleration Tests - Taxi Tuk-Tuk

Run Number	Loading Condition	Heading	Elapsed Time (sec)			Terminal Speed (kph)		Distance (meters)
			0 to 50 kph	0 to 65 kph	0 to 0.4 km	0 to 0.4 km	0 to 5 Sec.	0 to 5 Sec.
TACC01	Loaded	East	15.7	29.5	31.7	65.0	26.4	23.2
TACC02	Loaded	West	15.0	30.8	31.7	59.7	25.6	22.6
TACC03	Loaded	East	14.6	28.2	30.9	60.3	27.4	24.0
TACC04	Loaded	West	15.6	30.8	31.6	59.2	25.6	24.1
TACC05	Loaded	East	15.0	28.4	31.3	61.5	26.9	22.3
TACC06	Loaded	West	15.1	30.6	31.4	61.5	27.4	25.3
TACCU19	Unloaded	East	11.6	21.6	29.0	72.9	30.9	26.5
TACCU20	Unloaded	West	11.7	21.6	28.9	72.4	33.1	26.8
TACCU21	Unloaded	East	11.7	21.7	29.0	71.9	30.9	24.7
TACCU22	Unloaded	West	12.0	21.7	29.1	71.9	29.9	24.7
TACCU23	Unloaded	East	11.5	21.1	28.7	72.6	31.1	26.5
TACCU24	Unloaded	West	11.6	21.6	28.9	72.2	31.9	27.1

Figure 6

Cargo Tuk-Tuk Braking Test Summary

VEH: Cargo Tuk-Tuk TEST DATE: 9/02-03/94

PROCEDURE	SPEED (kph)	DECEL (mpsps) Avg.	STOP DIST. (m)	MAX. BRAKE PEDAL FORCE (N)	NUMBER OF TESTS
Effectiveness Test - 50 kph (Unloaded Test Weight)	50.4	-3.93	24.9	282.5	6
Effectiveness Test - 50 kph (Loaded Test Weight)	49.4	-3.36	28.1	375.0	6
Fade and Recovery (Baseline)	49.4	-1.83	51.4	275.8	3
Fade and Recovery (Fade Test)	49.9	-1.64	58.5	218.4	10
Fade and Recovery (Recovery)	50.4	-1.74	56.1	245.1	5
2nd Burnish Procedure	--	--	--	--	--
Final Effectiveness Test - 50 kph (Unloaded Test Weight)	50.2	-3.86	25.2	311.4	3
Final Effectiveness Test - 65 kph (Unloaded Test Weight)	63.6	-3.44	45.3	333.2	3
Final Effectiveness Test - 50 kph (Loaded Test Weight)	49.6	-2.38	39.9	354.5	3
Final Effectiveness Test - 65 kph (Loaded Test Weight)	63.6	-1.81	86.2	262.0	3
Water Recovery (Baseline)	50.2	-1.80	54.1	295.8	3
Water Recovery (Recovery)	41.1	-1.13	57.5	447.0	5

Figure 7

Passing Acceleration Tests - 40-60 kph - Cargo Tuk-Tuk

RUN NUMBER	LOADING CONDITION	HEADING	3rd GEAR		4th GEAR	
			Elapsed Time (sec)	Distance (meters)	Elapsed Time (sec)	Distance (meters)
CACCL07	Loaded	East	10.7	152	--	--
CACCL08	Loaded	West	10.3	145	--	--
CACCL09	Loaded	East	10.4	147	--	--
CACCL10	Loaded	West	10.4	146	--	--
CACCL11	Loaded	East	10.6	149	--	--
CACCL12	Loaded	West	10.8	157	--	--
CACCL13	Loaded	East	--	--	20.6	286
CACCL14	Loaded	West	--	--	18.3	253
CACCL15	Loaded	East	--	--	17.3	245
CACCL16	Loaded	West	--	--	18.7	260
CACCL17	Loaded	East	--	--	16.3	232
*CACCL18	Loaded	West	--	--	13.3	188
CACCU07	Unloaded	East	5.5	78	--	--
CACCU08	Unloaded	West	5.3	74	--	--
CACCU09	Unloaded	East	5.5	77	--	--
CACCU10	Unloaded	West	5.3	74	--	--
CACCU11	Unloaded	East	5.3	76	--	--
CACCU12	Unloaded	West	5.6	79	--	--
CACCU13	Unoaded	East	--	--	6.8	97
CACCU14	Unloaded	West	--	--	8.0	111
CACCU15	Unloaded	East	--	--	7.7	106
CACCU16	Unloaded	West	--	--	6.7	95
CACCU17	Unloaded	East	--	--	6.7	96
CACCU18	Unloaded	West	--	--	6.7	95

* Initial Speed = 43.9 kph End Speed = 58.6 kph

Figure 8

Standing Start Acceleration Tests - Cargo Tuk-Tuk

Run Number	Loading Condition	Heading	Elapsed Time (sec)			Terminal Speed (kph)		Distance (meters)
			0 to 50 kph	0 to 65 kph	0 to 0.4 km	0 to 0.4 km	0 to 5 Sec.	0 to 5 Sec.
CACCL01	Loaded	East	19.2	31.7	32.9	66.1	23.8	19
CACCL02	Loaded	West	18.7	30.4	32.7	65.2	24.9	21
CACCL03	Loaded	East	17.7	28.1	31.8	67.6	25.9	23
CACCL04	Loaded	West	18.2	29.1	32.2	66.6	25.4	21
CACCL05	Loaded	East	17.1	27.3	31.8	68.5	25.4	20
CACCL06	Loaded	West	18.1	29.0	32.2	66.9	25.3	21
*CACCU01	Unloaded	East	--	--	--	--	--	--
CACCU02	Unloaded	West	11.8	17.4	27.7	79.6	30.0	25
CACCU03	Unloaded	East	11.7	17.2	27.7	79.3	30.9	24
CACCU04	Unloaded	West	11.8	17.2	27.6	74.2	28.6	25
CACCU05	Unloaded	East	10.6	15.9	27.0	79.8	31.5	25
CACCU06	Unloaded	West	10.0	15.5	26.7	76.6	33.5	27

* Data Acquisition Error

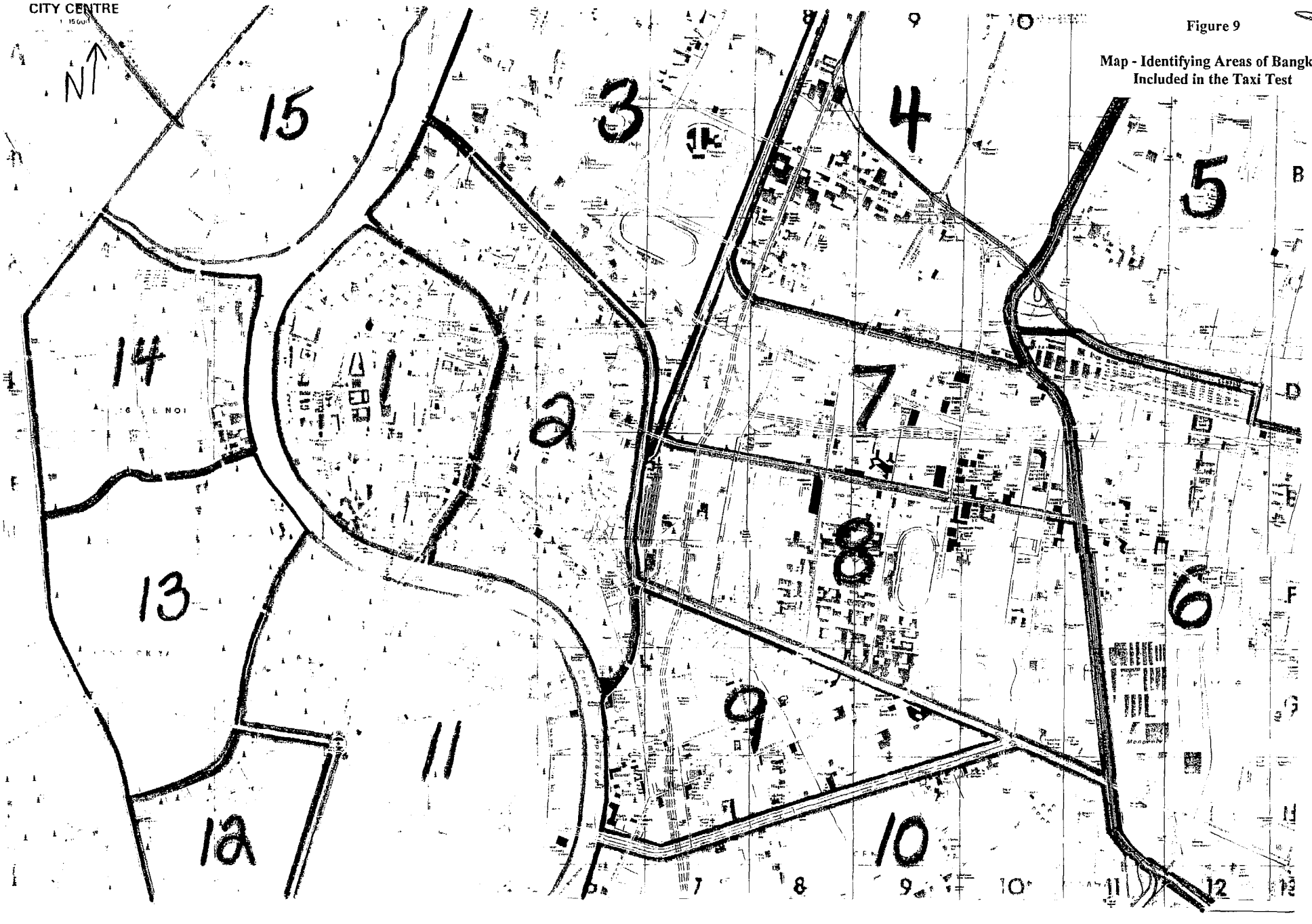


Figure 9

Map - Identifying Areas of Bangkok Included in the Taxi Test

Figure 10

Conventional Tuk-Tuk With Data Acquisition System

URBAN DRIVE PROFILE - CONVENTIONAL TUK-TUKS

4.1 OBJECTIVE

The objective was to obtain actual operating data representative of conventional tuk-tuks in commercial service. This data would be used to develop an urban drive profile, assess operational costs, determine vehicle range, and owner and driver values.

4.2 URBAN DRIVE PROFILE

MOSTE advised that neither the U.S. nor the international urban drive cycles were representative of the driving characteristics for tuk-tuks in the Bangkok Metropolitan Area.

The raw operating data collected on the conventional tuk-tuks was evaluated, reduced, and the distance traveled each day was calculated. Distance traveled per shift for a conventional taxi tuk-tuk did not exceed 130 km. Average range for a taxi tuk-tuk is 110 kilometers. Two urban drive cycles were developed - one for the taxi and one for the cargo tuk-tuk. The development of the urban drive cycles allows MOSTE to more accurately test the emission levels of conventional tuk-tuks on a chassis dynamometer and assists in identifying the service duty.

Appendix C contains the methodology and the two urban drive cycles developed from the data referenced in Section 3.

ELECTRIC TUK-TUK PROTOTYPES

5.1 OBJECTIVE

The objective was to test three electric tuk-tuk prototypes and apply lessons learned into the pre-production electric powered vehicles for Phase 2 of the demonstration program.

5.2 GENERAL DESCRIPTION

The design of the demonstration program called for two taxi electric tuk-tuks, one enclosed cargo electric tuk-tuk, and a stationary charger system. The vehicle design would consider data collected from the industry survey, safety and performance tests performed on the conventional tuk-tuks, and the decisions of the U.S.-Thai joint venture.

Each vehicle was designed differently so that a variety of components could be tested to assist in determining the initial production design. A data acquisition system was installed on each electric tuk-tuk. By collecting operating data, the various designs could be evaluated and the lessons learned would be applied for the initial production models.

The three electric tuk-tuks and stationary charger system were provided by Advanced Electric Car Technology, the U.S. partner in the joint venture with Thailand's Pholasith Motors. An operating manual was also provided to MOSTE.

MOSTE and their contractor visited the manufacturer's facility during assembly to gain firsthand experience with the technology.

The design and assembly of a transportation vehicle is a complex undertaking. It is not surprising that this effort encountered difficulties. The approach MOSTE and USAID took was to allow the U.S.-Thai Joint Venture the freedom to design an electric vehicle they believed to be suitable for the intended market. Within this approach, the two governments designed a demonstration program that included the testing of the electric tuk-tuk prototypes.

Figure 11 is a photo of one of the electrical taxi tuk-tuk prototypes.

5.3 GENERAL SPECIFICATIONS

Figure 12 provides the specifications for Taxi 1, Taxi 2 and Cargo 3.

Figure 11

Taxi Tuk-Tuk Prototype

Figure 12

Specifications on Taxi 1, Taxi 2 and Cargo 3

	TAXI 1	TAXI 2	CARGO 3
Motor	6.7 inch Series Wound DC Traction Motor, 15 hp avg. Internal cooling fan	6.7 inch Series Wound DC Traction Motor, 15 hp avg.	8 inch Series Wound DC Traction Motor, 35 hp avg.
Differential	High Efficiency 12.25:1 ratio Gear Drive Single Speed - Dana Spicer	High Efficiency 12:1 ratio Gear Drive Single Speed - Dana Spicer	High Efficiency 6.5:1 ratio Gear Drive Single Speed - Daihatsu
Rear Suspension	Coil over shock absorbers	Coil over shock absorbers	Coil over shock absorbers
Brake System	Hydraulically actuated drum on rear -- Disc on front	Hydraulically actuated drum system on 3 wheels	Hydraulically actuated drum system on 3 wheels
Steering	Tricycle type	Tricycle type	Tricycle type
Chassis	Welded high tensile rectangular steel tubing	Welded high tensile rectangular steel tubing	Welded high tensile rectangular steel tubing
Body	High impact self-supporting fiberglass. Taxi style with single rear passenger seat and fabric roof.	High impact self-supporting fiberglass. Taxi style with single rear passenger seat and fabric roof.	High impact self-supporting fiberglass. Pickup style with utility bed and fabric enclosure.
Tires	155R - 13	5.00 - 10	5.00 - 10
Wheelbase	93 inches	93 inches	93 inches
Turning Radius	10.5 feet	10.5 feet	10.5 feet
Overall Length	122 inches	122 inches	122 inches
Overall Width	54 inches	54 inches	54 inches
Ground Clearance	6 inches	5 inches	5 inches
Electrical System	120 Volt - 90 Amp-Hr 450 Amp Controller	120 Volt - 90 Amp-Hr 275 Amp Controller	120 Volt - 90 Amp-Hr 275 Amp Controller
Curb Weight	2000 lbs.	1700 lbs.	1650 lbs.
Payload Used	350 lbs.	350 lbs.	350 lbs.
Batteries	Yuasa Model No. NGP 18-12	Horizon Model No. 12N95	Yuasa Model No. NGP 18-12

SAFETY AND PERFORMANCE TESTS - ELECTRIC TUK-TUKS

6.1 OBJECTIVE

The objective of this program element was to obtain test data for the electric tuk-tuks under similar operating conditions as the conventional tuk-tuks for comparison of the two technologies.

6.2 ELECTRIC TUK-TUK TESTS

This program element was designed to provide a direct comparison of braking and acceleration characteristics between electric and conventional tuk-tuks.

Braking and acceleration tests were performed in the same manner as the conventional tuk-tuks.

The results of these tests indicate the electric tuk-tuks outperform the conventional tuk-tuks. A summary of the results with a comparison of the same test results for the conventional tuk-tuks are detailed in *Figures 13, 14 and 15*.

Operating data is to be compiled by MOSTE. Preliminary data from MOSTE indicates the range per charge with YUASA batteries is approximately 120 kilometers at 80% depth of discharge. Data is not available for the HORIZON batteries. The target established for electric tuk-tuk range is 130 kilometers at 80% depth of discharge.

MOSTE and their contractor witnessed the safety and performance tests of the first two electric tuk-tuks in the U.S.

Appendix D contains the test procedures and results.

Figure 13

Final Braking Effectiveness Summary

Unloaded @ 50 kph

	TAXI 1 (RETT)	TAXI 2	CARGO 3	CTT Taxi	CTT Cargo
Stopping Distance, meters	14.30	14.40	17.86	20.80	25.56
Avg. Deceleration, m/s/s	7.00	6.50	6.91	4.60	3.66
Brake Temp., celsius (LR/RR/F)	59/69/29	66/65/68	67/68/50	65/62	58/64

Loaded @ 50 kph

	TAXI 1 (RETT)	Taxi 2	CARGO 3	CTT Taxi	CTT Cargo
Stopping Distance, meters	13.50	13.60	28.60	21.20	41.33
Avg. Deceleration, m/s/s	7.40	6.00	2.56	4.50	2.21
Brake Temp., celsius	63/66/29	67/68/69	55/71/56	65/61	61/64

Unloaded @ 65 kph

	TAXI 1 (RETT)	TAXI 2	CARGO 3	CTT Taxi	CTT Cargo
Stopping Distance, meters	18.60	16.50	23.53	21.17	46.23
Avg. Deceleration, m/s/s	5.50	8.14	6.33	4.53	3.38
Brake Temp., celsius	69/76/30	61/65/65	46/57/42	64/60	62/65

Loaded @ 65 kph

	TAXI 1 (RETT)	TAXI 2	CARGO 3	CTT Taxi	CTT Cargo
Stopping Distance, meters	15.70	18.56	34.00	37.83	86.60
Avg. Deceleration, m/s/s	6.05	5.48	3.91	4.23	1.76
Brake Temp., celsius	69/77/32	64/69/69	62/71/58	64/58	67/69

Figure 14

Standing Start Acceleration Test Summary

ETT @ 100% SOC vs. CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 0 to 50 kph, unloaded	10.25	10.60	11.60	14.90	16.80	11.20
Elapsed Time, sec. 0 to 65 kph, unloaded	21.60	18.40	21.50	20.00	26.90	16.60
Elapsed Time, sec. 0 to 50 kph, loaded	10.00	9.60	15.20	19.60	17.50	18.20
Elapsed Time, sec. 0 to 65 kph, loaded	18.22	17.50	29.70	26.80	27.30	29.20

ETT @ 60% SOC vs. CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 0 to 50 kph, unloaded	10.20	7.40	11.60	15.90	16.20	11.20
Elapsed Time, sec. 0 to 65 kph, unloaded	19.67	14.60	21.50	21.60	23.40	16.60
Elapsed Time, sec. 0 to 50 kph, loaded	10.27	8.60	15.20	18.70	19.30	18.20
Elapsed Time, sec. 0 to 65 kph, loaded	20.43	14.60	29.70	25.60	26.10	29.20

ETT @ 20% SOC vs.CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 0 to 50 kph, unloaded	12.43	7.50	11.60	13.40	15.60	11.20
Elapsed Time, sec. 0 to 65 kph, unloaded	25.75	11.00	21.50	18.00	23.20	16.60
Elapsed Time, sec. 0 to 50 kph, loaded	13.93	8.10	15.20	15.00	17.90	18.20
Elapsed Time, sec. 0 to 65 kph, loaded	27.97	12.50	29.70	20.70	23.70	29.20

Figure 15

Passing Acceleration Test Summary

ETT @ 100% SOC vs. CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 40 to 65 kph, unloaded	14.21	15.60	9.95	9.30	11.20	7.10
Elapsed Time, sec. 40 to 65 kph, loaded	15.37	16.20	15.20	11.60	12.90	17.40

ETT @ 60% SOC vs. CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 40 to 65 kph, unloaded	14.69	13.60	9.95	11.30	12.10	7.10
Elapsed Time, sec. 40 to 65 kph, loaded	17.56	13.70	15.20	13.00	13.90	17.40

ETT @ 20% SOC vs. CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 40 to 65 kph, unloaded	17.07	13.40	9.95	-	12.60	7.10
Elapsed Time, sec. 40 to 65 kph, loaded	19.05	17.10	15.20	11.90	14.30	17.40

note: data omission due to instrumentation error

PERFORMANCE MODEL

7.1 OBJECTIVE

The objective was to validate the model, enabling the user to simulate a series of conditions with reliable output data, thereby reducing the cost and time needed for field tests.

7.2 GENERAL DESCRIPTION

Obtaining operating data is expensive and time consuming. The data acquisition system installed in each electric tuk-tuk, for example, costs approximately $6,000 per vehicle. A performance model, once validated, can eliminate or significantly reduce the need for field tests, reducing hardware and labor costs.

The computer simulation program is a PC compatible projection model which simulates the effects of various routes and drive profiles. The input files allow the user/programmer to customize the program within the limits of the model.

Another program, Drive Cycle Approximation Program (DCAP), was developed by ETIP to improve the efficiency in handling raw data from urban tests into the simulation model.

Training was provided in the U.S. and Thailand to MOSTE and their contractor. Once the electric tuk-tuks were delivered to Thailand, MOSTE implements and manages the urban tests and model validation.

Appendix E contains the computer simulation model and DCAP.

ENVIRONMENTAL ASSESSMENT

8.1 OBJECTIVE

The objective of this element of the demonstration program was to provide the framework for:

1) Comparing emissions (grams of pollutants), consisting of hydrocarbons, carbon monoxide, sulfur dioxide, nitrogen oxides, and particulate matter; and,

2) Comparing cumulative emission loadings to the environment over varying time periods.

8.2 GENERAL DESCRIPTION

Inherent inefficiencies in the internal combustion engines used for the conventional tuk-tuk result in emitting significant amounts of pollution. Electric tuk-tuks do not have direct air emissions.

An environmental assessment of air quality impacts on replacing conventional tuk-tuks with electric tuk-tuks is to be conducted by MOSTE. This assessment is to assess and quantify the benefits to ambient urban air quality. ETIP developed the methodology for this comparative assessment.

In general, a two step approach was recommended to MOSTE:

Phase 1, a short-term approach, included:

- Estimate conventional tuk-tuk emissions;
- Estimate power plant emissions; and,
- Compare the emissions resulting from the transport options to obtain a net emissions and net impact on the health of the population.

Phase 2, a medium/long-term approach, included:

- Combining existing MOSTE models to allow for the comparison of the reduction in conventional tuk-tuk emissions to the increase from additional electricity production from power plants in the Bangkok Metropolitan Area.

Training was provided to MOSTE and their contractor in the U.S.

Appendix F provides the details of the environmental methodology.

INFRASTRUCTURE ASSESSMENT

9.1 OBJECTIVE

The recommended objective for the infrastructure assessment was to:

1) Determine the changes needed to support this technology in the Bangkok Metropolitan Area;

2) Determine the implementation of the changes; and,

3) Determine the cost and schedule of the changes.

9.2 INFRASTRUCTURE ASSESSMENT

The infrastructure requirements and services to support a new technology in a consumer market need to be assessed. A term of reference was developed by ETIP. MOSTE is to perform the assessment.

Fuel delivery, electricity billing system, repair/maintenance requirements, battery recycling, regulations, training, and policy initiatives are issues that need to be assessed when considering electric vehicle transportation options.

ETIP provided a terms of reference for MOSTE to consider before undertaking this effort. A series of discussions in Thailand were held between MOSTE and ETIP to provide the rationale for the scope, approach, and expected outcome.

Appendix G contains the terms of reference for the infrastructure assessment.

ECONOMIC/FINANCIAL ASSESSMENT

10.1 OBJECTIVE

The objective was to provide a user friendly, flexible tool that would allow MOSTE to determine the economic and financial implications of replacing conventional tuk-tuks with electric driven technology.

10.2 GENERAL DESCRIPTION

A market economy, such as Thailand's, dictates that the private sector will pursue a business opportunity if the expected rewards are commensurate with the anticipated risks.

A PC model was developed by ETIP for MOSTE's use in evaluating several scenarios and cost functions. Based upon discounted cash flow techniques, a PC model was developed. The model evaluates the impact to four key players: 1) driver; 2) vehicle owner; 3) battery charger and station owner; and 4) the Royal Thai Government. Changeable inputs are provided.

Once complete data is available from the environment, performance, and infrastructure assessments, the model can be modified to develop an accurate assessment of the financial commitment required by the Royal Thai Government to facilitate this technology.

Preliminary assessments indicate that a government subsidy would be needed to entice the private sector to invest in electric tuk-tuks.

Training was provided to MOSTE and their contractor in the U.S. and Thailand.

Appendix H provides the economic/financial model and documentation.

CONCLUSION

Phase 1 of the Electric Tuk-Tuk Demonstration Program sought to determine the feasibility of replacing conventional tuk-tuks with electric powered tuk-tuks. Phase 2 of this program is envisioned to apply the lessons learned in the first phase to a small fleet of pre-production electric tuk-tuks and primarily test for product reliability.

USAID's assistance to Thailand is over. This project received a waiver to continue work until September 1996.

ETIP's efforts were completed in July 1996. This report was delayed to allow for documenting the results of MOSTE's final activities which included: environmental assessment, infrastructure assessment, urban tests, and refinement of inputs into the economics model. These activities are currently scheduled to occur in the future.

The feasibility of replacing conventional tuk-tuks with electric powered tuk-tuks is uncertain. Certainly from one standpoint the technology exists. There will undoubtedly be a need to improve upon the design and to strengthen troubleshooting capabilities. It was ETIP's experience that the design of the third and final electric tuk-tuk was an improvement over the first two units. For example, ground clearance was increased to reduce damage to the undercarriage and the motor parameters were changed while incorporating an internal fan to dissipate heat more quickly.

Whether the technology meets the commercial and political needs of the people of Thailand is an open issue. The environmental and infrastructure assessments should provide insight allowing for a more critical economic and financial assessment.

A concerted and sustained effort is also going to be needed to attend to aftermarket services - repairs and maintenance. The need for a trained workforce to understand the technology and to have the appropriate equipment and parts to effectively handle vehicle service is a key consideration.

Given the organization of the tuk-tuk industry, roadways, and ambient air quality in the Bangkok Metropolitan Area, electric powered tuk-tuks can provide an effective transportation option for the people of Thailand. The benefits of reducing harmful airborne emissions should have an impact upon the government's view and treatment of this technology.

It is hoped that Phase 2 of the demonstration program will be undertaken. By applying what has been learned to date to a small fleet of electric tuk-tuks for extended use, answers will be provided to the questions remaining today. This phase will also identify issues that will need to be addressed to make electric tuk-tuks in the Bangkok Metropolitan Area a commercial reality.

APPENDICES

APPENDIX A

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
Bureau for Global Programs, Field Support and Research
Center for Environment
Office of Energy, Environment, and Technology

THAILAND TUK-TUK ELECTRIC VEHICLE DEMONSTRATION PROJECT

BANGKOK, THAILAND

INDUSTRY SURVEY

Final Draft Report

Prepared for:

Royal Thai Government
Ministry of Science, Technology and Environment
Pollution Control Department

August 1994

Prepared By:

Energy Technology Innovation Project
Contract No. DHR-5741-C-00-1061-00
Prime Contractor: Bechtel Corporation

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Introduction

Tuk-Tuks provide two services in Bangkok, taxi and cargo. They primarily are fueled by LPG, although some still use gasoline. The taxi predominates, comprising 7,406 of the 8,329 registered with the City. Although tuk-tuks make up less than 1% of vehicle registration, they contribute a significantly greater amount of air and noise pollution. They are also a potential test case for determining the viability of electric vehicles for use in Bangkok and other Asian cities.

This survey is a compilation of facts and the flavor of the tuk-tuk industry gathered through interviews with industry and government officials. Discussions of the taxi and cargo tuk-tuks are separate because they are operated by different owners and are subject to different regulations.

Taxi Tuk-Tuk

Tuk-Tuks are generally used for short trips. Assuming that a third of the distance travelled in a shift includes paying passengers (fares), the distance traveled per fare is estimated to be 2.5 km (1.68 mi). The remaining distance travelled is devoted to cruising for passengers.

There are several other modes of transport used within Bangkok. At the high end are metered taxis, which are air conditioned and safer. Public buses are inexpensive and reliable, typically costing 10 baht or less. Some are air conditioned, although in many cases they are also overcrowded. On the next level are the tuk-tuks, which are open air but about 40% cheaper than the car taxis. At the bottom of the rung are the motorcycles, which have the advantage of moving between traffic, thus avoiding backups. While this advantage can be critical to arriving at one's destination on time, using motorcycles can be quite dangerous. All of these modes of transport are subject to regulation by the government.

The major player in the taxi tuk-tuk industry in Bangkok is the Tricycle Association of Thailand, which represents most of the tuk-tuk owners operating in the Bangkok Metropolitan Area (see Map 1). It is believed that other associations or private owners comprise the remaining tuk-tuks operating in Bangkok.

There are four Chapters that are part of the Association. Their names have been translated as follows: Bangkok Tricycle, Mass Tricycle, Rattanakosint Tricycle, and Metropolitan Tricycle. These Chapters include approximately 600 members, which own about

100 tuk-tuks each. The role of the Association is not completely known, although it does provide health and accident insurance to its members and acts as their trade association.

The color of the frame indicates the chapter that the tuk-tuk belongs, while the passenger seat color indicates the owner. The following color schemes have been identified through street observations, although the Chapter affiliation is unknown:

Body Color	Windshield Frame Color	Number of Observed
Blue	Yellow	19
Blue	Red	21
Blue	White	01
Green	White	17
Total Observed		68

Two privately owned vehicles with white license plates were also spotted: a red tuk-tuk in front of the Association's headquarters, and a gray metallic tuk-tuk cruising the streets.

During the observation, it was noted that some of the tuk-tuks carried significant cargo along with their passenger. One tuk-tuk was hauling eggs and no passengers.

Another observation from the street shows that the number of fares with more than one person is equivalent to the number of single rider fares, 74 and 86, respectively.

The Association said that they manufacture and repair all of their own tuk-tuks. Their in-depth knowledge of the tuk-tuk and understanding of mechanics was evident during our discussions.

The Association estimates that there are about 20 factories serving the various Chapters. Most of these factories are believed to be located close to the rental area and includes basic repair facilities. Another tuk-tuk manufacturer (Wat Industries) was mentioned.

According to the Association, a tuk-tuk engine is replaced about every 4-5 years. Cleaning the motor and replacing the cylinder, rings, and bearings is carried out every 1.5 years. Generally, after the third cylinder replacement, the engine is discarded. The gear box is rebuilt every four months and the clutch every 40 days. Typically, odometers don't work. When engines are replaced, the serial number must be registered with the government.

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Shifts are decided by the owner. Typically, there are only two per day, with all the tuk-tuks arriving and departing at the same time. For example, one owner has his first shift from 3:00 am to 3:00 pm and the second shift from 3:00 pm to 2:00 am. Based on our discussions with the tuk-tuk drivers, most shifts rotate between early morning (1:00-3:00) and early afternoon (13:00-15:00).

Drivers rent the tuk-tuk by presenting a valid tuk-tuk drivers license. The license is obtained from the Land Transport Department and requires a test.

The economics of tuk-tuk operation for the owner and driver are shown in Economic Analysis attachment. Generally, a tuk-tuk is rented for 250-280 baht, the owner pays for maintenance and the driver pays for fuel. Annualized revenues for the owner are estimated to be 74,152 baht ($3,090), and for the driver 227,213 baht ($9,467).

An issue brought up prior to arriving in Bangkok was the preference by drivers for noisy tuk-tuks. Drivers, it was assumed, equated noise to power and would not accept quiet tuk-tuks. This assumption generated further concern because of the belief that many of the tuk-tuks were owner-operated. Results from our survey indicate that both pollution and noise is considered serious and undesirable. Drivers will turn off their engines in heavy traffic in an effort to reduce air and noise pollution and save energy. Also, only a small fraction of tuk-tuks are privately owned, eliminating the need for marketability of noiseless tuk-tuks among drivers.

Restrictions on Taxi Tuk-Tuk Operation in Bangkok

Regulations have been implemented restricting access by other tuk-tuk owners to the downtown Bangkok market. Only the Association members and a small number of private owners can legally operate tuk-tuks east of the Mae Nam Chao Phraya River. However, the Association can operate its tuk-tuks anywhere.

Due to the limit on tuk-tuks, vehicle licenses can be bought and sold among tuk-tuk owners. The price can reach 375,000-500,000 baht ($15,000-$20,000). Once the sale has been completed, the change of ownership must be registered with the government.

Pay Offs to Police

The Association has an arrangement with the police to operate tuk-tuks illegally within Bangkok. The tuk-tuks are registered in surrounding provinces and brought to Bangkok to get around the limit imposed by the government. The Association said that Pholasith has its own arrangements with Thonburi police to operate illegal tuk-tuks.

owner

The ~~Association~~ must also pay an extra "unofficial" annual tax to the police:

Official Tax	235
Pay Off	315
Total	550

It also is considered normal practice to pay off police when accidents occur to avoid investigations. The purpose of the pay off is unclear, however, it seems to be related to insurance. The pay off is typically 2,500 baht.

Relationship between Pholasith and Association

Pholasith is not a member of the Association. Pholasith tuk-tuks are operated in Thonburi, across the river from central Bangkok and are not allowed in central Bangkok.

The relationship between the Association and Pholasith is adversarial. The Association has accused Pholasith of actively working to abolish the limit on tuk-tuk registration in Bangkok. During our first meeting with the Association, it was necessary to clearly state it is not the project's aim to support or hinder Pholasith's efforts. We stated that we were not in anyway involved in the process. Only when the Association was convinced did they agree to work with us.

During our discussions, there were several instances where Pholasith was criticized for their lack of collaboration with the Association. Apparently, the Association had contacted Pholasith about purchasing some electric tuk-tuks for testing, but received no response. A short time later, it was discovered that Pholasith had presented an electric tuk-tuk to the Prime Minister.

The relationship between the Association and Pholasith could hinder the test engineers ability to complete their work if cooperation between the two is necessary. This point was made clear when the head of the Association stated that we could work with them or Pholasith, but not both.

Government Oversight

Bangkok is served by the Land Transport Department, which issues vehicle and personal licenses, and conducts vehicle inspections. All vehicles must be inspected annually for safety, emissions, and noise. All vehicles, including the tuk-tuk, must pass annual inspection and pay an annual operating tax before they can renew their license.

Emission and noise standards for the tuk-tuk follow:

Hydrocarbons	HC	14,000	ppm
carbon monoxide	CO	6% of total emissions	
noise		100	decibels

Taxes are based on the weight of the vehicle:

Weight (kg)	Annual Tax (baht)
0 - 500	300
501 - 750	450
751 -1000	600
1001 -1250	750

Due to concerns about safety and traffic congestion, the number of passenger tuk-tuks allowed within Central Bangkok has been limited to approximately 8,000. As of December 31, 1993, there were 7,406 passenger tuk-tuks registered.

Drivers must obtain special licenses from the Land Transport Department, which involves passing a test. Taxi tuk-tuk drivers can operate either a taxi or cargo tuk-tuk, where as a cargo tuk-tuk driver is restricted from operating a taxi tuk-tuk.

The number of taxi tuk-tuk licenses is unrestricted. Most drivers come from north east Thailand and drive tuk-tuks as a way of entering the Bangkok economy. It is believed that some of the tuk-tuk drivers eventually become car taxi drivers.

Future Markets for Tuk-Tuks

Pholasith has provided some general information on the current and future market for the tuk-tuk industry. The following table shows current Pholasith sales:

	Bangkok	Thailand	Exports
Taxi	05%	12%	35%
Cargo & Personal	09%	13%	25%
Total Sold	15%	25%	50%

Pholasith is looking to expand markets domestically and overseas. In all areas of the World, including Africa, Asia, Latin America, and Europe, tuk-tuks are being used for passenger and cargo vehicles.

Association Concerns About Project

During a meeting with the Association on the project, there were concerns expressed on their part centering on the cost of the tuk-tuk, both the initial price of parts, and operation and maintenance costs. We said that these were precisely the issues that were being investigated by MOSTE and that they would be given the results.

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Cargo Tuk-Tuks

The cargo tuk-tuks are used by several companies to haul goods around the city and within the manufacturing plant. In recent years the number of registered cargo tuk-tuks in Bangkok has risen dramatically. Current figures show a total of 923 cargo tuk-tuks in Bangkok, an 700 increase from just two years ago. Unlike taxi tuk-tuks, the number of cargo tuk-tuks that can be registered in Bangkok is unlimited.

Tuk–Tuks in Bangkok and Surrounding Provinces

Province	Passenger Number	Passenger % of Total	Service Number
Nonthaburi	2,370	4.8%	
Bangkok Metropolitan Area	7,406	15.1%	923
Samut Prakan	1,603	3.3%	
Nakhon Pathon	152	0.3%	
Pranakom Sri–Ayudhya	1,184	2.4%	
Thailand	48,929	100.0%	2,918

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General Information of Tuk–Tuk Industry

Lifetime of Tuk–Tuk		
Frame	Years	10
Engine	Years	4.5
Gear Box	Years	0.33
Clutch	days	.40
Tuk–Tuk Operation		
# of Shifts	per day	2
Length of Shift	hours	11–13
number of fares	per shift	20–30
Distance Traveled	km/shift	60–140
	km/fare	2.5
Operating Days	%/year	67%
Cost of LPG	b/l	5.83
	$/gal	$0.92
Engine Size	cc	350
Government Pollution and Noise Standards		
NC	ppm	14,000
CO	% of total	6
Noise	decibels	100

Tax Rates for Taxi Tuk–Tuks

Size (kg) from	to	Tuk–Tuk
0	500	300
501	750	450
751	1000	600
1001	1250	750
Origination Tax:	15,000–18,000	
Annual Tax:	355	

Economic Analysis

Tuk–Tuk Owner Revenue/Cost

Item	Unit	Cost	Annual Revenue/Costs (baht)	($)
Costs				
New Tuk–Tuk	per 10 years	60,000	6,000	250
Maintenance	daily	170	41,574	1,732
Taxes	annual	235	235	10
Pay Offs	annual	315	315	13
Total Costs			48,124	2,005
Revenue				
Rent	per shift	250	122,275	5,095
Total Revenue			122,275	5,095
Net Revenue/Costs			74,152	3,090

Notes:
Assumes tuk–tuk operates 67% of year

Tuk–Tuk Driver Revenue/Cost

Item	Unit	Cost	Annual Revenue/Costs (baht)	($)
Costs				
Rent	per shift	250	136,875	5,703
Fuel Costs (LPG)	per shift	85	46,538	1,939
Total Costs		335	183,413	7,642
Revenue				
per Fare	per fare	30		
# of fares	per shift	25		
revenue	per shift	750		
Total Revenues			410,625	17,109
Net Revenue/Cost			227,213	9,467

Notes:
Assumes driver works 75% of year

Questions for Tuk-Tuk Drivers

Question	Driver 1	Driver 2	Driver 3	Driver 4
How many hours do you work each day	15:00-02:00 11 hours	14:30-01:00 10.5 hours	15:00-02:00 11 hours	13:00-02:00 13 hours
When do you take breaks	21:00-21:30 0.5 hours	20:00-20:30 0.5 hours	18:00-18:30 0.5 hours	21:00-21:30 0.5 hours
How much is fuel per shift	85	80	80	85
How far do you travel	N/A	140 km	N/A	60 km
How many fares per shift	20-30	20	30	30
How much do you work in a year	9 months	11 months	8 months	N/A
Do you turn off motor to save fuel while stopped in traffic	Yes	Yes	Yes	Yes
When looking for fares, do you cruise or stay in one location	Cruise	Cruise during the day and stay after 23:00	Cruise	Stay at Department Store
Does the color of the tuk-tuk indicate the owner	Frame = Chapter Seat = Owner	Frame = Chapter Seat = Owner	Frame = Chapter Seat = Owner	Frame = Chapter Seat = Owner

APPENDIX B

USAID/Bangkok

United States Agency for International Development
Center for Environment
Office of Energy, Environment, and Technology

ELECTRIC TUK-TUK DEMONSTRATION PROGRAM PHASE 1 TEST DOCUMENTATION REPORT - Baseline Braking and Acceleration Performance and Drive Cycle Testing of a Conventional Taxi and Cargo Tuk-Tuk Vehicle

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1.0 PURPOSE and SCOPE

The purpose of this test program was to acquire baseline braking and acceleration performance data on LPG and fossil fuel powered Tuk-Tuk vehicles. Testing was also performed to acquire Tuk-Tuk vehicle drive cycle data during operation in the Bangkok, Thailand urban area. Two exemplar Tuk Tuk vehicles were tested, a taxi style and a cargo style. All testing was performed in the Bangkok, Thailand area.

2.0 DEFINITIONS

Initial Speed or Test Speed
The travel speed of the vehicle at the moment the brakes are applied.

Start of Brake Application
The initial movement of the brake system control pedal and/or lever.

Braking Interval
The distance measured from the start of one brake application to the start of the next brake application.

Initial Brake Temperature
The temperature of the hottest service brake at 300 meters (985 ft) before any brake application.

Stopping Distance
The distance traveled by a vehicle from the start of the brake application to the point where the vehicle stops.

Unloaded Vehicle Weight

The weight of the vehicle as built with production parts with maximum capacity of all fluids necessary for operation of the vehicle.

Unloaded Test Weight

The weight of the vehicle as built with production parts with maximum capacity of all fluids necessary for operation of the vehicle plus 90 kg. The 90 kg includes the weight of the driver

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and instrumentation. Ballast shall be secured to the vehicle to prevent weight shift during acceleration/deceleration, etc.

Loaded Test Weight

The weight of the vehicle as built with production parts with maximum capacity of all fluids necessary for operation of the vehicle plus 90 kg. The 90 kg includes the weight of the driver and instrumentation. In addition, ballast shall added to simulate a nominally full passenger/cargo load. Ballast shall be secured to the vehicle to prevent weight shift during acceleration/deceleration, etc.

3.0 TEST VEHICLE DESCRIPTION

3.1 Taxi Tuk Tuk

An in-service taxi Tuk-Tuk test vehicle was provided by the Tricycle Association of Thailand. The Tricycle Association represented the vehicle as being typical of the Taxi Tuk-Tuks in service with regard to condition and performance. No odometer was installed on the vehicle, therefore the mileage on the vehicle was not indicated.

The taxi Tuk-Tuk is a three wheel vehicle in a tricycle configuration, i.e., one steerable, non-driven wheel in front and two driven, non-steerable wheels in the rear. The vehicle is capable of sitting three passengers comfortably in the passenger compartment; space is also provided for additional cargo or luggage. The operator sits astride the engine in the front. The wheel base is 185 cm. Steering is via a motorcycle type handlebar arrangement. The front suspension consists of two coil spring shock absorbers with hydraulic damping. The front wheel is installed motorcycle style between the shock absorbers. The rear suspension consists of automotive type leaf springs and dampers.

The taxi Tuk-Tuk is powered by a Daihatsu 2-stroke engine. The engine is an LPG fueled, liquid cooled, in-line two cylinder engine displacing 350cc and producing approximately 23 PS at 5,000 rpm. The engine drives the rear wheels through a four speed transmission (with reverse) and a driveshaft/differential final drive arrangement. The in-line two cylinder engine is longitudinally mounted in the chassis such that the crankshaft is parallel to the longitudinal axis of the vehicle. The throttle control is a motorcycle style twistgrip located on the right

handlebar. The clutch and brakes are actuated be means of foot pedals, braking on the right and clutch on the left.

The taxi Tuk-Tuk has a hydraulically actuated drum brake system installed on the two rear wheels only. The drum brakes are of standard automotive design.

The tires on the taxi Tuk-Tuk are 145 SR10 on the rear and 5.00 x 9 on the front.

3.2 Cargo Tuk-Tuk

A relatively new cargo Tuk-Tuk test vehicle was provided by the Pholasith Tuk-Tuk Motors Company. The vehicle was a model CPU with 16,000 km on the odometer. The vehicle was in very good condition.

The cargo Tuk-Tuk is a three wheel vehicle in a tricycle configuration, i.e., one steerable, non-driven wheel in front and two driven, non-steerable wheels in the rear. The operator sits in the forward compartment; the rear compartment is equipped for carrying cargo only. The wheel base is 250 cm. Steering is via a motorcycle type handlebar arrangement. The front suspension consists of two coil spring shock absorbers with hydraulic damping. The front wheel is installed motorcycle style between the shock absorbers. The rear suspension consists of automotive type leaf springs and dampers.

The cargo Tuk-Tuk is powered by a Daihatsu 4-stroke engine. The engine is a gasoline fueled, liquid cooled, in-line two cylinder engine displacing 550cc and producing approximately 30 PS at 5,000 rpm. The engine drives the rear wheels through a four speed transmission (with reverse) and a driveshaft/differential final drive arrangement. The in-line two cylinder engine is longitudinally mounted in the chassis such that the crankshaft is parallel to the longitudinal axis of the vehicle. The throttle control is an automotive type pedal located on the right floorboard. The clutch and brakes are actuated be means of foot pedals, braking on the right and clutch on the left (standard automotive layout).

The cargo Tuk-Tuk has a hydraulically actuated drum brake system installed on the two rear wheels only. The drum brakes are of standard automotive design.

The tires on the cargo Tuk-Tuk are 5.00 x 10 on the rear and the front.

4.0 METHOD

The braking test procedures were based on established automotive and motorcycle brake test standards and practices (References 1, 2, 3, 4, 5). The braking tests involved straight line braking from various speeds, brake burnishing, fade and recovery, and wet brake fade and recovery. All tests were performed by experienced test drivers.

The acceleration tests were performed to acquire vehicle acceleration performance data under specified conditions. The acceleration test procedures were based on established automotive standards and practices (Reference 6, 7). The acceleration tests involved standing start and passing acceleration performance. All tests were performed by experienced test drivers.

The urban drive cycle tests were performed to acquire data during operation of the taxi and cargo Tuk-Tuks under the Bangkok, Thailand urban driving conditions. A drive cycle test procedure was established to obtain data that could be compared with established emissions drive cycles (Reference 8). Local Tuk-Tuk operators were utilized for these tests.

4.1 Test Facility

Acceleration and Brake testing was conducted at the Environmental Research and Training Center (ERTC) operated by the Ministry of Science, Technology, and Environment (MOSTE). The ERTC is located near Bangkok. The East/West access road in front of the ERTC building was used for a test track. Approximately 700 meters of concrete surfaced straight-away was available for use during testing. The concrete surface was substantially level, in good condition, and afforded good adhesion.

Drive cycle testing was conducted in the Bangkok, Thailand Central City area. The Tuk-Tuk operators utilized randomly selected routes each day. Testing was conducted in both dry and wet environments.

4.2 Instrumentation

A lightweight, on-board, vehicle instrumentation package was used for data acquisition during this project (Reference 9). The self-contained package included a digital data recorder, multiplexer, power supplies, and sensors. The instrumentation used for each type of testing is described in the following sections. Appendix A contains a complete instrumentation list.

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The digital data recorder weighs 1.1 kilograms and is 203 mm long, 102 mm wide, and 53 mm high. Data inputs include ten single ended analog channels, three frequency or pulse accumulation channels, eight digital inputs (event markers), three digital outputs, and four programmable digital lines for input or output. The maximum throughput is 76.8 Khz for a single analog channel or 6.5 Khz for multi-channel operation. Data is stored in a 448K CMOS static RAM memory. Built into the unit is a 5 volt (125 milliamp) excitation for powering sensors. Stored data is transferred to an personal computer via a built-in RS-232-C port using a proprietary communications and data conversion program. The data recorder is fully programmable and application programs can be written on a personal computer and downloaded to the unit. A sixty-four character display window (four rows by sixteen characters) can be utilized for display of data or custom menus.

A multiplexer was used to provide more analog channel capability than available on the basic data recorder. The basic data recorder has 10 "single-ended" or 5 "double-ended" analog channels, therefore, additional channels were required to run all the analog sensors double-ended. The multiplexer measured 241.3 mm wide, 342.9 mm long, and 76.2 mm high and weighed 2.6 kilograms. It also had built-in power supplies that were used to power the sensors. The data recorder, multiplexer, and sensors were powered by the vehicle battery.

4.2.1 Braking Tests

The following sensors were installed on the vehicles for brake testing:

- A fifth wheel to measure distance.
- A load cell to measure actuation forces on the foot brake pedal.
- Thermocouples to measure brake temperatures.

Software - - A specialized program optimized for vehicle brake testing was used for the brake tests of this project. The data recorder is programmed to display brake temperatures and speed until a handlebar mounted push-button switch is depressed. The brake temperatures displayed at the moment the switch is activated are stored in an initial temperature data file. In addition to storing the initial temperatures, activation of the switch also provides the trigger signal to begin continuous recording of actuation forces and fifth wheel pulses. Speed is continuously calculated and displayed during the data acquisition process. An event marker is recorded in the data file upon application of the brakes to indicate the beginning of the stop. Braking data is then recorded until a logic loop determines that the fifth wheel has stopped. At

the completion of data recording, the unit automatically analyzes the data file and displays the following information to the data recorder screen (or external display, if used):

- Initial speed at brake application.
- Stopping distance.
- Maximum brake pedal actuation force.
- Brake temperatures stored prior to brake application.

After the analysis is viewed and the recorder is incremented to a new data file, the brake temperatures and speed are again displayed until activation of the handlebar mounted push button. Therefore, brake temperatures can be monitored until the initial temperatures are within limits. Typically, the temperatures would be stored at 0.3 kilometer prior to a brake application.

Although it was possible to store data from 50-60 stops in the recorder memory, data was transferred to the personal computer after completion of each test procedure section. Two types of data files could be downloaded from the data recorder, time histories of actuation forces and fifth wheel pulses and a data analysis summary file. Examples of the data summary and time history formats are shown in Tables 1 and 2. The data is recorded in Imperial units and later converted to metric units. The sample rate was set at 10 hz.

Computations - - *Initial speed* or *test speed* is defined as the travel speed of the vehicle at the moment either brake is applied. Since application of either brake is recorded by the data acquisition system, the initial speed data point is clearly marked. The *stopping distance* was determined by summing the pulses generated by the fifth wheel during the interval from *brake application* to the point at which forward speed has decreased to zero. *Average deceleration* during the stop was calculated using initial speed and stopping distance. The following equation was used to calculate average deceleration:

$$a = \frac{V^2}{2d}$$

Where:

a = Average deceleration in $\frac{\text{m}}{\text{sec}^2}$

V = Velocity in $\frac{\text{m}}{\text{sec}}$

d = stopping distance in meters.

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TABLE 1 - TYPICAL BRAKE TEST DATA SUMMARY FILE FORMAT

Speed	Dist.	Force	Decel.	TC1	TC2
29.7	37.5	24.1	-25.30	136.2	137.9
31.1	39.1	18.2	-26.58	136.9	142.1
31.5	45.5	19.3	-23.47	135.6	142.6
30.5	37.5	27.8	-26.69	134.8	138.3
60.6	140.2	19.9	-28.18	134.4	138.4
60.0	148.8	21.2	-26.01	141.8	143.5
60.6	140.2	17.7	-28.18	137.9	140.7
60.9	152.7	12.0	-26.12	130.4	133.9

where:
- Speed = Speed at brake application (miles per hour).
- Dist. = Stopping distance (feet).
- Force = Maximum brake pedal force during stop (lbs).
- Decel. = Average deceleration during stop (feet per second per second).
- TC1 = Left rear brake temperature (°F).
- TC2 = Right rear brake temperature (°F).

TABLE 2 - TYPICAL BRAKE TEST TIME HISTORY FILE FORMAT

TIME	BRKAPP	MPH	TOTAL	REAR
0.1	1	12.2	1423	1.15
0.2	1	12.2	1824	-1.05
0.3	1	12.4	2232	0.15
0.4	1	12.2	2633	0.05
0.5	1	12.1	3032	0.05
0.6	1	12	3428	0.05
0.7	1	12	3824	0.15
0.8	0	11.9	4215	-0.25
0.9	0	11.5	4594	-0.05

where:
- TIME = Timebase (seconds).
- BRKAPP = Event marker for brake application (digital input from brake switch - value changes to zero when brakes are applied).
- MPH = Speed calculated from fifth wheel total pulses and time (miles per hour).
- TOTAL = Cumulative total of fifth wheel pulses since data logging start.
- REAR = Brake pedal actuation force calculated from load cell millivolt output (pounds).

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Vehicle Speed and Stop Distance Sensor - - Distance was measured by a trailing wheel device commonly known as a fifth wheel. The fifth wheel is a custom fabricated assembly that was attached to the rear bumper of the vehicles. A damper installed at the hinge point of the trailing arm controls bouncing. The diameter of the tire is about 43.2 cm when inflated to 70 psi. A 500 pulse per revolution optical encoder is connected to the wheel via a toothed belt at a one to one ratio, thus, one revolution of the wheel produces a 500 pulse output (one pulse equals 0.002720 meter). The pulse output of the fifth wheel is connected to one of the data recorder pulse accumulation channels. Vehicle speed and deceleration were calculated from the distance versus time data. No filtering was applied to the data collected. A typical vehicle speed vs. time plot is shown in Figure 1.

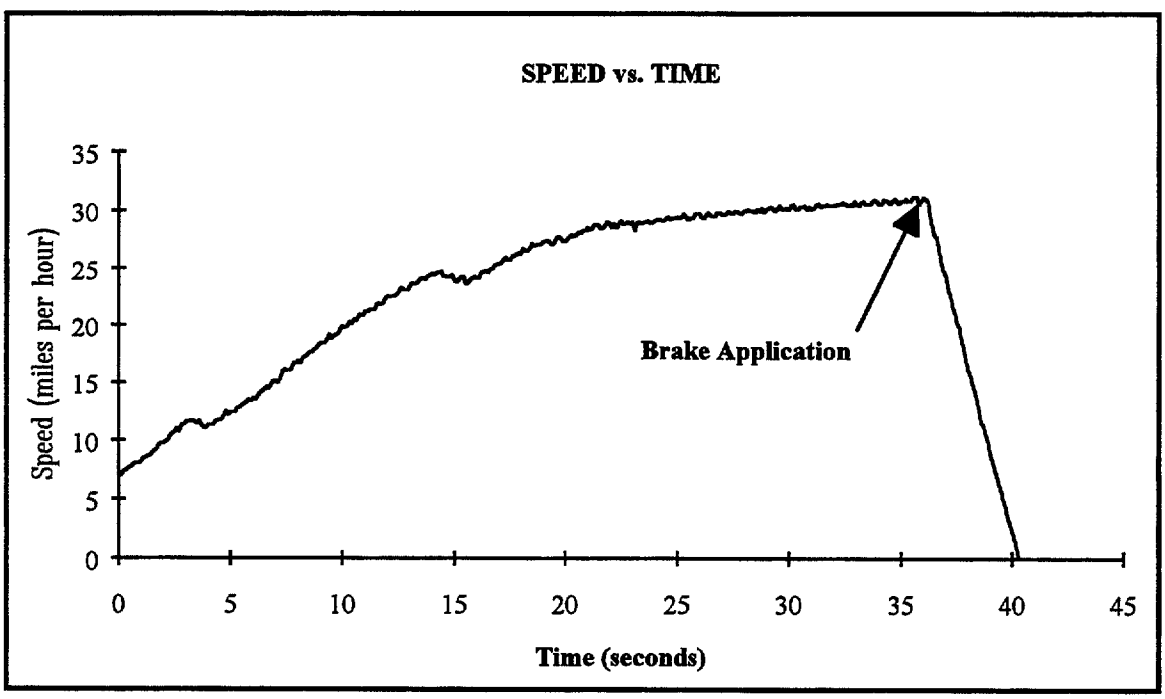

Figure 1. Typical Vehicle Speed vs. Time Plot.

Brake Pedal Force Sensor - - A load cell was installed on the brake pedal to facilitate measurement of brake actuation forces. application. The load cell calibration curve is shown in Figure 2. No filtering was applied to the data collected. A typical brake actuation force vs. time plot is shown in Figure 3. Note in this instance the maximum force is a short duration event as compared to the total actuation time. The Tricycle Association questioned the

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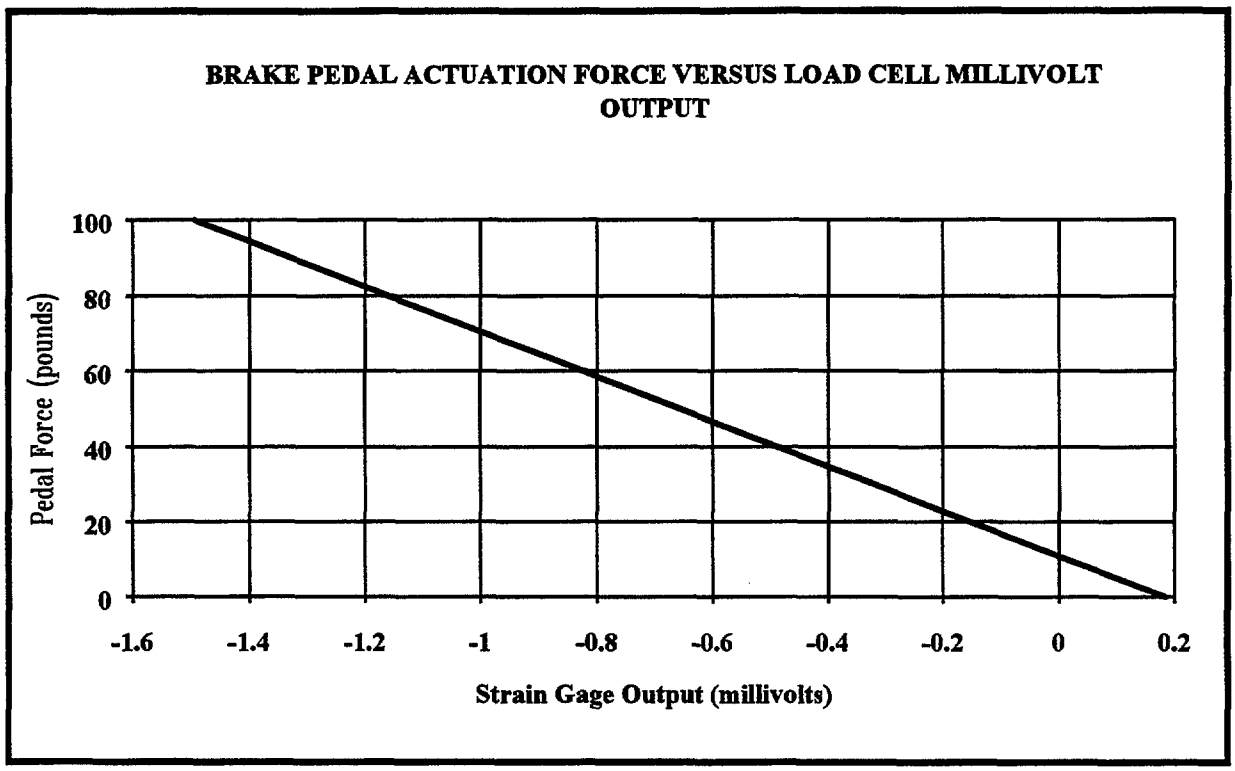

Figure 2. Brake Pedal Load Cell Calibration Curve.

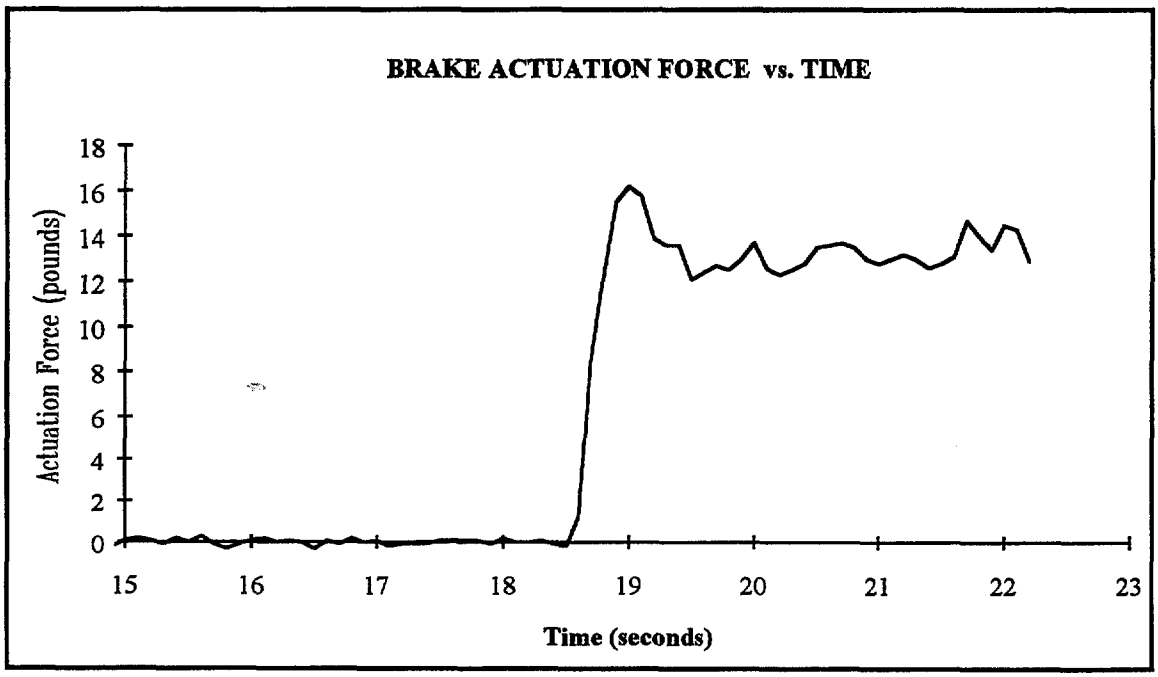

Figure 3. Typical Brake Actuation Force vs. Time Plot.

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installation of the load cell on the pedal pad portion of the brake lever since their drivers generally apply the brakes by pressing on the shaft portion of the lever nearer the pivot. The installation position on the pad portion was retained due to ease of mounting, consistency of results, and ease of comparison during later phase testing with other vehicles. In addition, it is good practice to use the pedal as it was designed rather than as local custom dictates.

Brake temperature Sensors - - Brake temperatures were measured by installing thermocouples in one brake pad or shoe of each brake. The thermocouples were fabricated and installed as specified in Figure 4. Type "K" thermocouples were used for this application. The thermocouples were connected to the data recorder analog inputs as double-ended sensors. A thermister was mounted in the multiplexer to provide temperature compensation. No filtering was applied to the data collected.

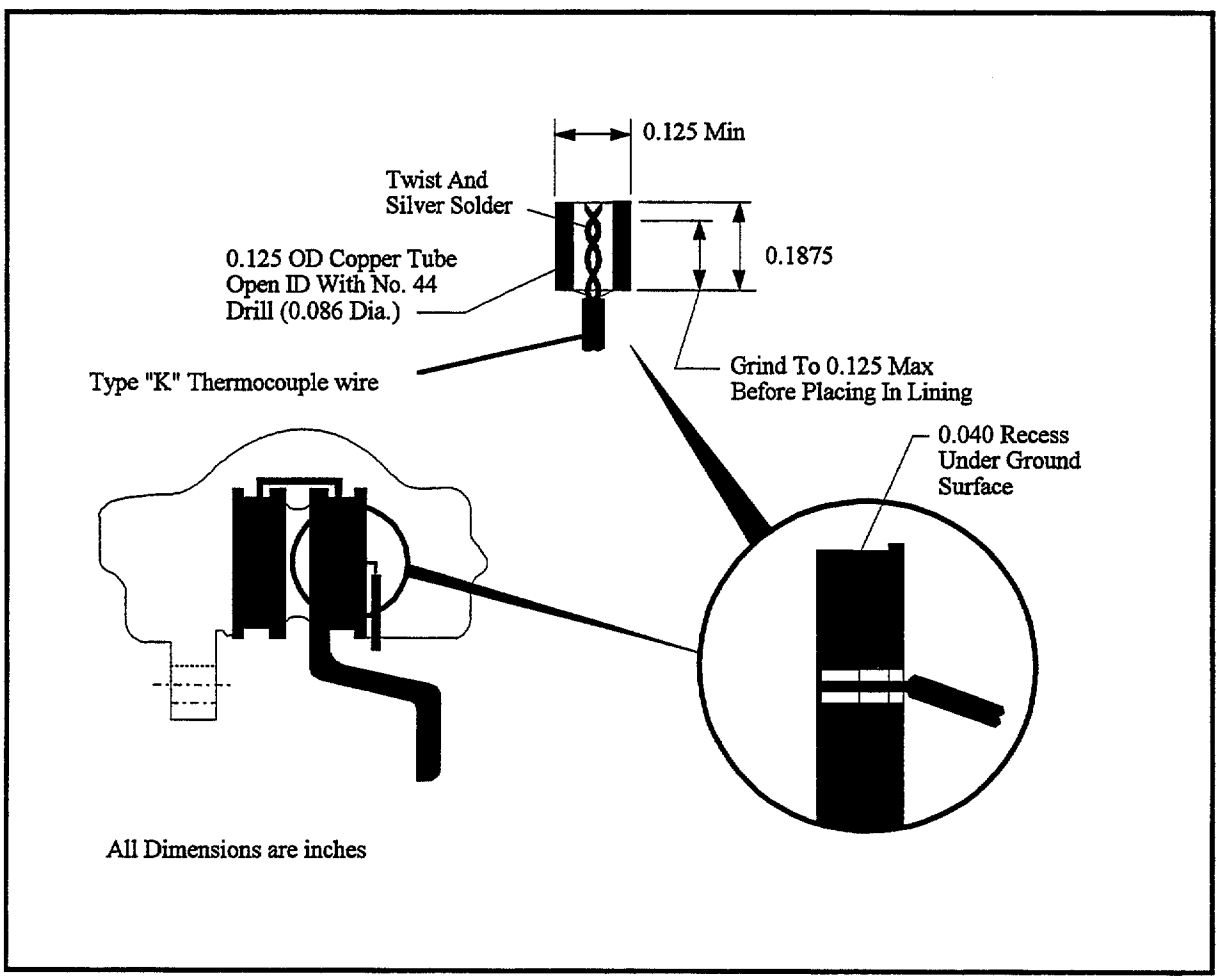

Figure 4. Typical Plug Type Thermocouple Installation

4.2.2 Acceleration Tests

The following sensors were installed on the vehicles for acceleration testing:

- A fifth wheel to measure distance (described above)

The digital data recorder was programmed to record distance versus time. Speed and acceleration were calculated from the distance versus time data. A handlebar mounted push button switch started the data recording prior to each acceleration run. The data recorder acquired data until the *escape* key was pressed on the data recorder keyboard at the conclusion of the test run. The complete data set from each run was transferred to a portable computer for further analysis. The data file formats are of the same form as Table 1. The sample rate was set at 20 Hz.

4.2.3 Urban Drive Cycle Tests

The following sensors were installed on the vehicles for urban drive cycle testing:

- A proximity sensor mounted on the front wheel to measure distance.
- Linear displacement transducers were mounted to the rear suspension to measure suspension displacement (Taxi only).
- An engine rotational speed transducer (Taxi Only).
- An engine manifold vacuum transducer (Cargo Only).

The digital data recorder was programmed to record distance (taxi and cargo), suspension displacement (taxi only), manifold vacuum (cargo only), and engine rotational speed (taxi only) versus time. Speed was calculated from the distance versus time data. The data recorder acquired data continuously during each test segment until the *escape* key was pressed on the data recorder keyboard at the conclusion of the test segment. The complete data set from each run was transferred to a portable computer for further analysis. The data file formats are of the same form as Table 1. The sample rate was set at 1 Hz.

The linear displacement transducers (commonly referred to as "string pots") were calibration to indicate load in the passenger compartment. This was accomplished by placing weights in the passenger compartment while recording the transducer outputs. Calibration curves for the left and right transducers are shown in Figures 5 and 6. The manifold vacuum sensor was

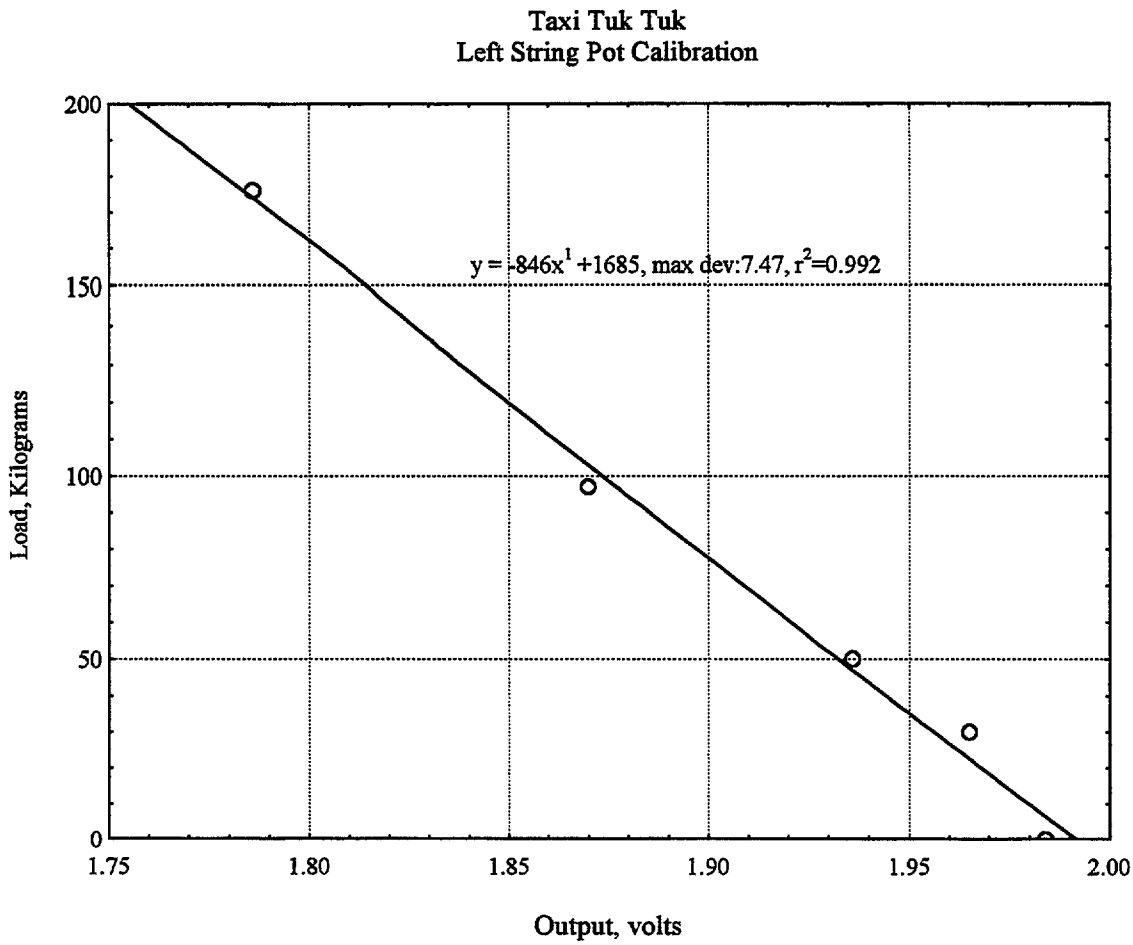

Figure 5. Left Linear Displacement Transducer Calibration Curve.

calibrated by applying a known vacuum to the sensor while recording the sensor output. The calibration curve for the manifold vacuum sensor is shown in Figure 7.

4.2.4 Instrumentation Problems

Both the taxi and cargo Tuk-Tuks broadcasted a severe field of electrical interference from the engine compartment. Difficulties were experienced with getting clean signals from several sensors. The interference was overcome for the most part with all sensors except the engine rotational speed sensor (rpm). The rpm data was, for the most part, unusable.

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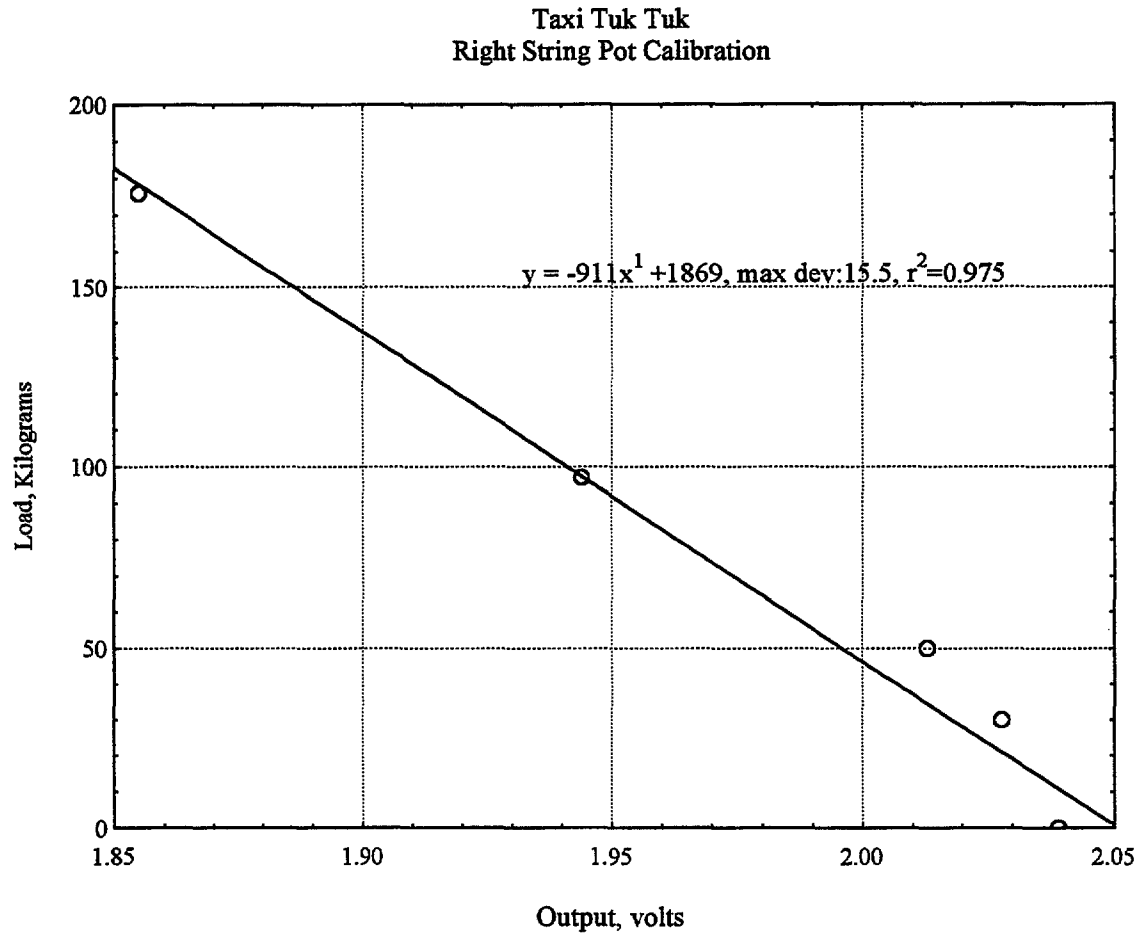

Figure 6. Right Linear Displacement Transducer Calibration Curve.

4.3 Preparation of the Test Vehicles

4.3.1 Brake Tests

Preparation of the vehicles for testing is outlined in the following sections:

4.3.1.1 Inspect and adjust the vehicle as necessary to meet manufacturer's specifications. Tune and time engine, and make all other adjustments, as necessary, in accordance with manufacturer's published procedures. Verify that the tires must have at least 75% of the tread remaining and tread is in good condition. Verify the braking system has been refurbished to "as new" condition. Verify brake adjustments and function.

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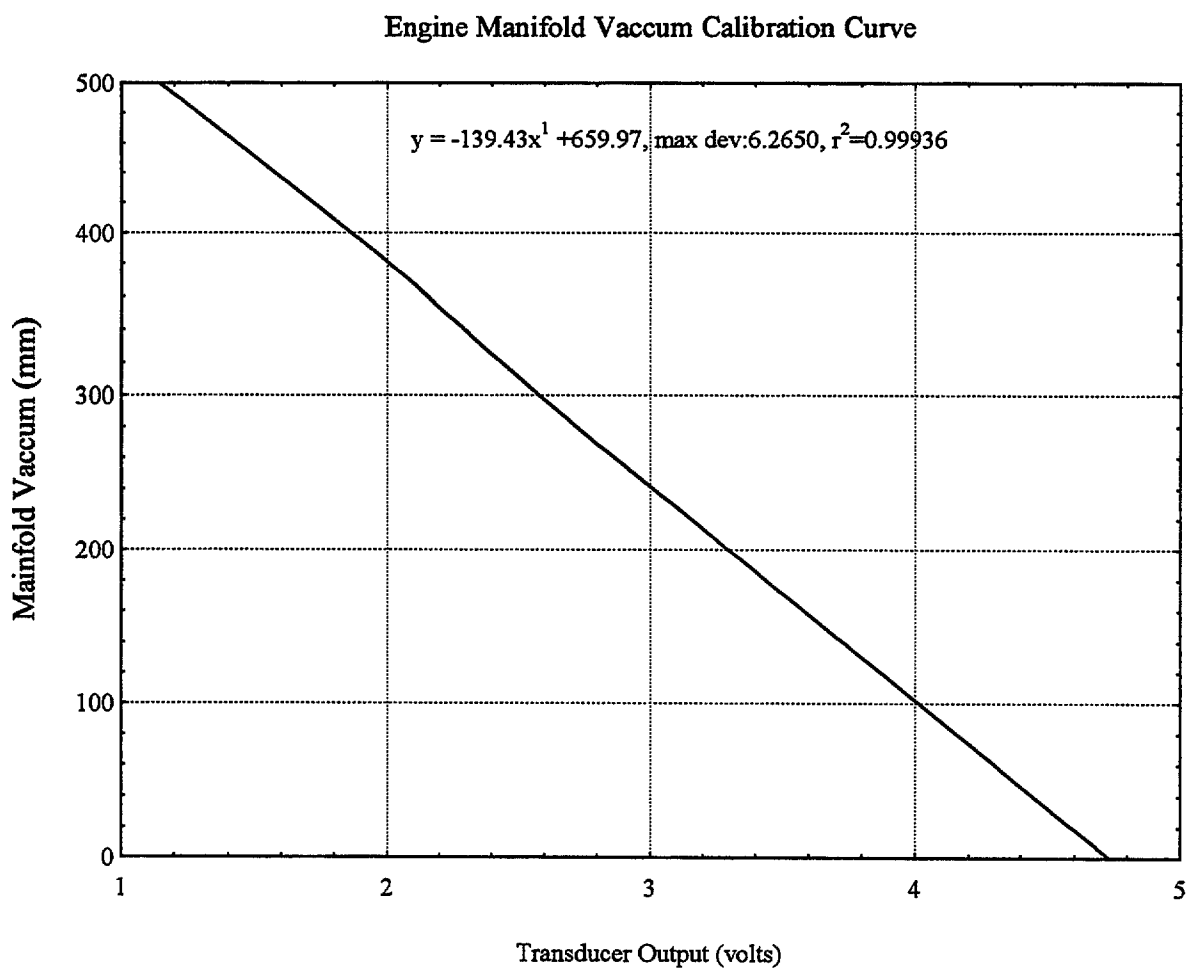

Figure 7. Engine Manifold Vacuum Transducer Calibration Curve.

4.3.1.2 Burnish the brakes by making 200 stops from 50 kph in a stop distance of 36 meters. Cool brakes between stops to a temperature of 55°C to 65°C (the hottest brake). Accelerate at maximum rate to 50 kph immediately and maintain that speed until making the next stop. Speed should not exceed 50 kph between stops. After completion of the burnish, adjust brakes in accordance with manufacturer's recommendation.

4.3.1.3 Measure the unloaded weight of the vehicle <u>without</u> instrumentation installed.

4.3.1.4 Install plug type thermocouples in the approximate center of the facing length and width of the brake shoe or pad, one per brake. The thermocouple may be offset to clear caliper piston(s), however, it should be offset toward the leading edge of the brake pad. See Figure 4 for thermocouple fabrication and installation details.

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4.3.1.5 Install load cell on brake pedal.

4.3.1.6 Install fifth wheel.

4.3.1.7 Install and connect data recorder, sensors, initial temperature record button, and brake application trigger.

4.3.1.8 Install manual counter to indicate the number of stops in each procedure.

4.3.1.9 Install and connect external display (if used).

4.3.1.10 Measure the weight of the test operator.

4.3.1.11 Measure the weight of the instrumentation.

4.3.1.12 The cold tire pressure should be set as specified by the manufacturer for the vehicle test weight and installed tires.

4.3.1.13 Perform an instrumentation check-out prior to testing.

4.3.2 Acceleration Tests

Preparation of the vehicles for testing is outlined below:

4.3.2.1 Inspect and adjust the vehicle as necessary to meet manufacturer's specifications. Tune and time engine, and make all other adjustments, as necessary, in accordance with manufacturer's published procedures. Verify that the tires must have at least 75% of the tread remaining and tread is in good condition. Verify brake adjustments and function. Ensure that brake drag is not excessive. Operate, observe, and reset, if necessary, the throttle linkage to ensure wide open throttle occurs.

4.3.2.2 Commercially available fuel as recommended by the manufacturer will normally be used for test purposes. Lubricants used shall conform to the manufacturer's recommendation for the predominant weather condition in which the vehicle is being tested.

4.3.2.3 Measure the unloaded weight of the vehicle without instrumentation installed.

4.3.2.4 Install fifth wheel, recorder start button, and attaching cables.

4.3.2.5 Install data recorder. Connect fifth wheel and start to data recorder.

4.3.2.6 Install manual counter to indicate the number of stops in each procedure.

4.3.2.7 Install and connect external display (if used).

4.3.2.8 Measure the weight of the test operator.

4.3.2.9 Measure the weight of the instrumentation.

4.3.2.10 The cold tire pressure should be set as specified by the manufacturer for the vehicle test weight and installed tires.

4.3.2.11 Perform an instrumentation check-out prior to testing.

4.3.2.12 Vehicle Warm-Up - The vehicle must be driven a minimum of 15 minutes at an average speed of 40 kph immediately prior to the test. Alternative schedules that provide equivalent vehicle warm-up can be substituted. There should not be more than a 5 min time lapse between the warm-up and the start of test.

4.3.3 Urban Drive Cycle Tests

Preparation of the vehicles for testing is outlined below:

4.3.3.1 Inspect and adjust the vehicle as necessary to meet manufacturer's specifications. Tune and time engine, and make all other adjustments, as necessary, in accordance with manufacturer's published procedures. Verify that the tires are in good condition. Verify brake adjustments and function.

4.3.3.2 Commercially available fuel as recommended by the manufacturer will normally be used for test purposes. Lubricants used shall conform to the manufacturer's recommendation for the predominant weather condition in which the vehicle is being tested.

4.3.3.3 Measure the unloaded weight of the vehicle without instrumentation installed.

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4.3.3.4 Install vehicle speed/distance sensor, engine speed transducer or manifold vacuum transducer, load transducers, and attaching cables.

4.3.3.5 Install data recorder. Connect vehicle speed/distance sensor, load transducers, engine speed transducer, or manifold vacuum transducer to data recorder. Connect data recorder to vehicle battery.

4.3.3.6 Waterproof all connections and components to the extent possible.

4.3.3.7 Verify calibration of vehicle speed/distance sensor, engine speed transducer, load transducers, and manifold vacuum transducer.

4.3.3.8 Measure the weight of the test operator.

4.3.3.9 Measure the weight of the instrumentation.

4.3.3.10 The cold tire pressure should be set as specified by the manufacturer for the vehicle test weight and installed tires.

4.3.3.11 Perform an instrumentation check-out prior to testing.

4.4 Test Conditions

4.4.1 Braking and Acceleration Tests

4.4.1.1 Temperature - The tests shall be conducted at ambient temperatures.

4.4.1.2 Wind - The tests should not be conducted when wind speeds average more than 24 km/h (or when peak wind speeds are more than 32 km/h).

4.4.1.3 Test Surface - The tests shall be conducted on a closed course test track (closed to the public) sufficiently long for measurement and run-off. The roadway (test track) must be dry, clean, smooth, substantially level, and free from loose materials.. A roadway will be considered level if its grade is within ±1%. In addition, the grade should be constant and the roadway should be straight. The road surface should be concrete or rolled asphalt (or equivalent) and in good condition; testing should not be conducted on slippery roads.

Minimum width of roadway will be 3.6 meters (a width of is 7.2 meters recommended). The minimum length of the roadway will be 0.8 km (a length of 1.6 km is recommended).

4.4.1.4 Adverse Weather Conditions - The tests will not be run during foggy or rainy conditions.

4.4.2 Urban Drive Cycle Tests

4.4.2.1 Temperature - No restrictions.

4.4.2.2 Wind Velocity - No restrictions.

4.4.2.3 Test Surfaces -No restrictions.

4.4.2.4 Adverse Weather Conditions - The tests will not be run during extreme weather conditions.

4.5 Vehicle Test Configuration

4.5.1 Taxi

The unloaded vehicle weight of the taxi was 525 kilograms. The instrumentation weight was 7 kilograms. The weight of the test driver was 84 kilograms. The payload for the laden tests of the taxi vehicle was 280 kilograms. The instrumentation package did not interfere with the operation or handling of the vehicle.

Prior to testing, the cold tire pressures for front tire and rear tires were set at 28 psi and 32 psi, respectively.

4.5.2 Cargo

The unloaded vehicle weight of the taxi was 705 kilograms. The instrumentation weight was 7 kilograms. The weight of the test driver was 84 kilograms. The payload for the laden tests of the cargo vehicle was 800 kilograms. The instrumentation package did not interfere with the operation or handling of the vehicle.

Prior to testing, the cold tire pressures for front tire and rear tires were set at 30 psi and

34 psi, respectively.

4.6 Braking Test Procedure

4.6.1 General

4.6.1.1 Safety was the prime consideration during testing and safety procedures were followed during all activities. Maximum test speeds were governed by the handling characteristics of the test vehicle. Test speeds were limited to the maximum at which the test driver determined the vehicle to be completely stable and controllable.

4.6.1.2 Brake Temperature - Unless otherwise specified, the initial brake temperatures were between 55°C and 65°C at the hottest brake.

4.6.1.3 Brake Actuation Forces - The point of initial application of the pedal force is the center of the foot contact pad of the brake pedal. The direction of the force is perpendicular to the foot contact pad on the plane along which the brake pedal rotates, as shown in Figure 8.

4.6.1.4 Speed Tolerance - The specified test speeds shall be subject to a tolerance of ±5 kph.

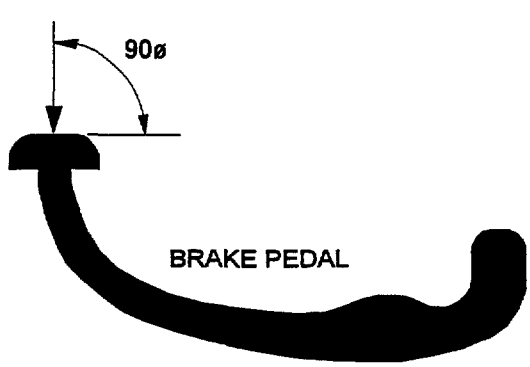

Figure 8. Direction of Brake Pedal Force Application.

4.6.2 Stopping Procedure

4.6.2.1 Record ambient temperature, wind velocity, and wind direction.

4.6.2.2 Record test roadway conditions (surface, grade, etc.).

4.6.2.3 Heat or cool brakes until the hottest brake temperature is not less than 55°C and not more than 65°C (unless otherwise specified). Brakes may be heated by making not more than 10 brake stops from 50 kph at a deceleration of not more than 3 mpsps.

4.6.2.4 Record brake temperatures 300 meters prior to the brake application point.

4.6.2.5 Attain a speed 6 to 12 kph greater than the target test speed and decrease speed smoothly to the test speed as the brake application point is reached.

4.6.2.6 When test speed is reached, relax the throttle or fuel control, disengage clutch, and apply the brake pedal as the specific test requirement dictates.

4.6.2.7 Modulate brake forces and maintain brake application until the vehicle has stopped completely.

4.6.2.8 Stops should be made with the vehicle aligned in the center of the roadway at the start of each brake application. Stops should be made without wheel lockup.

4.6.2.9 Limit use of brakes between test runs and during brake cool down riding.

4.6.3 Braking Tests

Refer to Table 3.

4.6.3.1 Instrumentation Check - Check the instrumentation by making not more than 10 stops from a speed of not more than 50 kph at a deceleration of not more than 3 mpsps. If instrument repair, replacement or adjustment is made, perform an additional check as described above.

4.6.3.2 Effectiveness Test

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TABLE 3 - BRAKING TESTS

Procedure	Initial Speed (km/hr)	Deceleration (m/sec^2)	Loading Condition	Initial Brake Temperature (°C)	Stop Interval	No. of Test Runs
Instrumentation Check	50	≤3	Unloaded	N/A	N/A	≤10
Effectiveness Test	50	Maximum	Unloaded	55 to 65	N/A	6
	50	Maximum	Loaded	55 to 65	N/A	6
Fade and Recovery (Baseline Stops)	50	3	Loaded	55 to 65	N/A	3
Fade and Recovery (Fade Stops)	55 -65	3.0-3.6	Loaded	55 to 65: Prior to 1st Stop Only	0.8 km	10
Fade and Recovery (Recovery Stops)	50	3	Loaded	N/A	≤1.6 km Note 1	5
Re-Burnish	50	≤2.7	Unloaded	55 to 65	Cool brakes to 55 to 65 °C	35
Final Effectiveness Test	50	Maximum	Unloaded	55 to 65	N/A	3
	50	Maximum	Loaded	55 to 65	N/A	3
	65	Maximum	Unloaded	55 to 65	N/A	3
	65	Maximum	Loaded	55 to 65	N/A	3
Water Fade and Recovery (Baseline Stops)	50	3	Loaded	55 to 65	N/A	3
Water Fade and Recovery (Recovery Stops)	40	3.0-3.4	Loaded	N/A	100 m	5

Note 1 - Drive 1.6 km @ 50 kph after completing last fade stop and immediately conduct recovery stops.

4.6.3.2.1 Make 6 stops each from 50 kph at Unloaded and Loaded Test Weight.

4.6.3.3 Fade And Recovery Test - Perform at Loaded Test Weight Only

4.6.3.3.1 Baseline Check Stops

4.6.3.3.1.1 Make 3 stops from 50 kph at 3 mpsps for each stop (stop in 30 m).

4.6.3.3.1.2 Record the average of the maximum brake pedal forces forces required for the stops.

4.6.3.3.2. Fade Stops

4.6.3.3.2.1 Make 10 stops from 55 or 65 kph (dependent on handling and test track size) at a deceleration rate of 3.0 to 3.6 mpsps for each stop. The initial brake temperature shall be between 55°C and 65°C. Achieve the required deceleration as quickly as possible and maintain at least this rate for not less than three-fourths of the total stopping distance for each stop. The interval between the starts of service brake applications shall be 800 meters. After the last fade stop drive 1.6 km at 50 kph and immediately conduct the recovery test.

4.6.3.3.3 Recovery Test

4.6.3.3.3.1 Make 5 stops from 50 kph at a deceleration of 3 mpsps for each stop. The braking interval shall not be more than 1.6 km. After each stop accelerate at maximum rate to 50 kph and maintain that speed until making the next stop.

4.6.3.4 Service Brake System - Reburnish

4.6.3.4.1 Burnish the brakes by making 35 stops from 50 kph in a stop distance of 36 meters. Cool brakes between stops to a temperature of 55°C to 65°C (the hottest brake). Accelerate at maximum rate to 50 kph immediately and maintain that speed until making the next stop. Speed should not exceed 50 kph between stops

4.6.3.4.2 Adjust brakes in accordance with manufacturer's recommendation

4.6.3.5 Final Effectiveness Test

4.6.3.5.1 .Make 3 stops each from 50 kph at Unloaded and Loaded Test Weight.

4.6.3.5.2 Make 3 stops each from 65 kph at Unloaded and Loaded Test Weight.

4.6.3.6 Water Recovery Test - Perform at Loaded Test Weight Only

4.6.3.6.1 Baseline Check Stops

4.6.3.6.1.1 Make 3 stops from 50 kph at 3 mpsps for each stop. Compute the average of the maximum brake pedal forces required for the 3 stops.

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4.6.3.6.2 Wet Brake Recovery Stops

4.6.3.6.2.1 Completely wet the each brake assembly of the vehicle with water for 2 minutes with the brake fully released. Perform the entire wetting procedure in not more than 7 minutes. Water application will be accomplished by thoroughly dousing the brake systems with a water hose for the specified time. Immediately after wetting accelerate at a maximum rate to 40 kph without a brake application. Immediately upon reaching that speed make 5 stops, each from 50 kph at 3 to 3.4 mpsps deceleration for each stop. The braking interval shall be 100 meters. After each stop (except the last) accelerate the vehicle at a maximum rate to 50 kph and begin the next stop.

4.6.3.7 Final Inspection

4.6.3.7.1 Upon completion of all the tests, the brake system will be inspected. Inspect the entire brake system for detachment or fracture of any component.

4.6.3.7.2 Verify instrumentation and fill out the Test Summary. A typical stop for each test procedure shall be entered in the Test Summary data sheet.

4.7 Acceleration Test Procedure

4.7.1 General

4.7.1.1 Safety was the prime consideration during testing and safety procedures were

followed during all activities. Maximum test speeds were governed by the handling characteristics of the test vehicle. Test speeds were limited to the maximum at which the test driver determined the vehicle to be completely stable and controllable.

4.7.1.2 Record atmospheric conditions: wind speed and direction, temperature, and atmospheric pressure.

4.7.1.3 Record test roadway conditions (surface, grade, etc.).

4.7.1.4 Warm up test vehicle per section 4.3.2.12.

4.7.2 Standing Start Acceleration Test

4.7.2.1 From a standing start, the vehicle should be operated to achieve maximum performance with minimum wheel spin. Clutch operation, as well as shift point selection, should be optimized for performance without exceeding the maximum specified engine rpm. Time zero starts at the instant the vehicle begins to move.

4.7.2.2 Perform wide open throttle (WOT) acceleration from a standing start and record the following:

4.7.2.2.1 0 to 50 kph - Record speed vs. elapsed time.

4.7.2.2.2 0 to 65 kph - Record speed vs. elapsed time.

4.7.2.2.3 0.4 km - Record speed and distance vs. elapsed time. Record terminal speed.

4.7.2.2.4 0 to 5 sec - Record speed & distance vs. elapsed time. Record terminal speed.

4.7.2.3 Run a minimum of six individual runs, three in each direction at the Unloaded Test Weight condition. Repeat procedure for the Loaded Test Weight condition. When difficulty is experienced in one run, the pair is excluded.

4.7.3 Passing Acceleration Test

4.7.3.1 Starting from a stabilized 40 kph, accelerate with wide open throttle to 60 kph. Manual transmissions should be run both in top gear and top gear less one, with 4 or 5 speed transmissions. Three speed, manual transmission should be run in top gear only. Manual transmissions should not be downshifted during this test.

4.7.3.2 Perform wide open throttle (WOT) passing acceleration and record the following:

4.7.3.2.1 40 kph to 60 kph - Record Speed and distance vs. elapsed time.

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4.7.3.3 Run a minimum of six individual runs, three in each direction at the Unloaded Test Weight condition. Repeat procedure for the Loaded Test Weight condition. When difficulty is experienced in one run, the pair is excluded.

4.8 Urban Drive Cycle Test Procedure

4.8.1 General

4.8.1.1 Safety was the prime consideration during testing and safety procedures were followed during all activities.

4.8.2 Urban Drive Cycle Tests

4.8.2.1 Measure and record the following items

- Test vehicle fuel level.
- Test vehicle tire pressure.
- Vehicle and driver identification information.
- Weight of driver.

4.8.2.2 Brief driver on test technique.

4.8.2.3 Start data recorder.

4.8.2.4 Begin urban rive cycle data collection.

- Collect data on various routes.
- If feasible test engineers will follow and monitor test vehicle.

4.8.2.5 Measure and record the quantity of fuel added during the test.

4.8.2.6 Download test data from data recorder as required.

5.0 TEST RESULTS

5.1 Braking Tests - Taxi Tuk-Tuk

The results for the taxi Tuk-Tuk braking tests are summarized in Table 4. A typical test run from each procedure is presented in the summary. A complete listing of the test results from each procedure are included in sections 5.1.1 through 5.1.6.

Sound tests were conducted concurrently by MOSTE during the braking tests. The testing was videotaped by MOSTE.

The loaded test conditions were obtained by loading the passenger compartment with 10 kg and 80 kg sacks of sand.

TABLE 4 - Taxi Tuk-Tuk Braking Test Summary

VEH: **Taxi Tuk-Tuk** TEST DATE: **8/27-30/94**

PROCEDURE	SPEED (kph)	DECEL (mpsps) Avg	STOP DIST. (m)	MAX. BRAKE PEDAL FORCE (N)	NUMBER OF TESTS
Effectiveness Test - 50 kph (Unloaded Test Weight))	**51.7**	**-4.55**	**22.6**	**156.5**	**6**
Effectiveness Test - 50 kph (Loaded Test Weight))	**49.3**	**-4.60**	**20.4**	**190.4**	**6**
Fade and Recovery (Baseline)	**48.9**	**-3.07**	**30.1**	**87.2**	**3**
Fade and Recovery (Fade Test)	**58.3**	**-3.45**	**38.0**	**153.9**	**10**
Fade and Recovery (Recovery)	**50.9**	**-3.11**	**32.1**	**149.9**	**5**
2nd Burnish Procedure	- - -	- - -	- - -	- - -	- - -
Final Effectiveness Test - 50 kph (Unloaded Test Weight)	**50.7**	**-4.62**	**21.5**	**71.2**	**3**
Final Effectiveness Test - 65 kph (Unloaded Test Weight)	**64.2**	**-4.78**	**33.3**	**93.0**	**3**
Final Effectiveness Test - 50 kph (Loaded Test Weight)	**48.9**	**-4.82**	**19.1**	**127.2**	**3**
Final Effectiveness Test - 65 kph (Loaded Test Weight)	**65.8**	**-4.42**	**37.8**	**114.8**	**3**
Water Recovery (Base line)	**49.1**	**-3.00**	**31.0**	**107.6**	**3**
Water Recovery (Recovery)	**42.3**	**-2.19**	**31.5**	**73.0**	**5**

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5.1.1 Instrumentation Check

VEH: **Taxi Tuk-Tuk;** AMBIENT TEMP.: **35°C;** DATE: **8/27/94**

WIND VEL/DIRECTION: **Light wind from Northwest.**

TEST DRIVER: **T. Carter**

TIRE PRESSURE (COLD) - FRONT: **28 psi** REAR: **32 psi**

UNLOADED VEHICLE WEIGHT: **525 kg**

UNLOADED TEST WEIGHT: **616 kg**

LOADED TEST WEIGHT: **896 kg**

REQUIREMENTS: Check instrumentation by making not more than 10 stops from 50 kph at a deceleration of not more than 3 mpsps, record results, repeat if necessary.

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)[1]	DECEL (mpsps)[2]	BRAKE TEMP (°C)	
				AVG	LR[3]	RR[4]
Typ.	**50**	—	—	—	—	—

[1]Maximum Rear Brake Pedal Actuation Force (Newtons)
[2]Average Deceleration over the Stop (meters per second per second)
[3]Left Rear Brake Temperature
[4]Right Rear Brake Temperature

5.1.2 Effectiveness Test

VEH: **Taxi Tuk-Tuk;** AMBIENT TEMP.: **35°C** DATE: **8/27/94**

WIND VEL/DIRECTION: **Light wind from Northwest.**

TEST DRIVER: **T. Carter**

TIRE PRESSURE (COLD) - FRONT: **28 psi** REAR: **32 psi**

REQUIREMENTS:

A. Make the following stops:

(1) 6 stops from 50 kph - Unloaded Test Weight
(2) 6 stops from 50 kph - Loaded Test Weight

Initial brake temperature between 55°C and 65°C.

50 KPH DATA - - Unloaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	51.7	22.6	156.5	-4.55	51.1	56.9
2	51.5	28.7	148.5	-3.56	58.0	57.3
3	50.9	23.8	136.5	-4.19	58.3	63.0
4	52.3	23.3	191.3	-4.54	61.8	67.3
5	50.4	23.4	220.6	-4.19	64.0	63.4
6	50.4	22.1	147.2	-4.43	61.6	63.9

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5.1.2 Effectiveness Test....Continued

50 KPH DATA - - Loaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	51.7	23.6	168.1	-4.37	52.9	59.9
2	51.2	23.3	202.8	-4.34	63.5	65.8
3	50.1	21.8	187.3	-4.43	65.8	63.5
4	49.3	20.4	190.4	-4.60	64.6	64.9
5	48.3	21.1	169.9	-4.26	62.9	63.9
6	49.1	21.5	157.5	-4.33	63.8	64.8

5.1.3 Fade and Recovery Test

VEH.: **Taxi Tuk-Tuk;** AMBIENT TEMP.: **33°C;** DATE: **8/29/94**

WIND VEL/DIRECTION: **6 kph from West.**

TEST DRIVER: **T. Carter**

TIRE PRESSURE (COLD) - FRONT: **30 psi** REAR: **34 psi**

REQUIREMENTS:

A. Conduct three 50 kph stops at 3 mpsps, compute average maximum brake pedal forces and record data.

B. Conduct 10 fade stops from 55 to 65 kph at a deceleration rate of 3.0 - 3.6 mpsps with initial brake temperature between 55°C and 65°C, conduct 5 fade recovery stops from 50 kph at 3 mpsps and record data.

C. Testing to be performed at Loaded Test Weight only.

50 KPH DATA - - Fade and Recovery Baseline Data

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	**48.6**	**29.5**	**119.2**	**-3.09**	**64.9**	**63.3**
2	**48.9**	**30.1**	**87.2**	**-3.07**	**64.5**	**64.9**
3	**47.7**	**30.8**	**90.3**	**-2.84**	**63.8**	**64.2**

AVERAGE MAX BRAKE PEDAL FORCE = **98.9 N**

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5.1.3 Fade and Recovery Test....Continued

55 - 65 KPH DATA - - Fade Stops

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	57.5	36.3	118.8	-3.51	60.6	59.6
2	58.1	37.0	117.9	-3.52	84.3	86.0
3	57.6	37.2	145.4	-3.44	108.1	111.6
4	58.3	38.0	153.9	-3.45	125.1	130.6
5	54.6	38.3	156.6	-3.00	136.0	145.4
6	56.4	35.8	189.0	-3.42	144.0	155.0
7	56.5	40.1	180.1	-3.07	147.5	160.4
8	57.0	37.2	174.4	-3.36	150.3	164.2
9	55.4	38.4	207.3	-3.08	152.6	166.5
10	57.5	39.3	221.0	-3.24	156.1	170.0

50 KPH DATA - - Recovery Test

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	48.6	34.4	157.9	-2.65	155.0	166.4
2	48.9	33.4	158.4	-2.77	148.5	154.0
3	50.4	34.0	155.2	-2.87	147.8	150.4
4	50.9	32.1	149.9	-3.11	137.9	138.6
5	50.6	33.4	153.5	-2.94	136.0	135.7

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5.1.4 Re-Burnish Procedure

VEH.: **Taxi Tuk-Tuk;**	AMBIENT TEMP.: **32°F;**	DATE: **8/29/94**
WIND VEL/DIRECTION:	**6 - 11 kph from West.**	
TEST DRIVER: **T. Carter**		
TIRE PRESSURE (COLD) -	FRONT: **30 psi**	REAR: **34 psi**

REQUIREMENTS:

A. Burnish the brakes by making 35 stops from 50 kph at 2.7 mpsps deceleration.

B. The braking interval shall be either the distance necessary to reduce the brake temperature to between 55°C and 65°C or 1.6 km whichever comes first.

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5.1.5 Final Effectiveness Test

VEH.: **Taxi Tuk-Tuk;** AMBIENT TEMP.: **33°C;** DATE: **8/29/94**

WIND VEL/DIRECTION: **10 kph from West.**

TEST DRIVER: **T. Carter**

TIRE PRESSURE (COLD) - FRONT: **30 psi** REAR: **34 psi**

REQUIREMENTS:

A. Make the following stops:

(1) 3 stops from 50 kph - Unloaded Test Weight
(2) 3 stops from 50 kph - Loaded Test Weight
(3) 3 stops from 65 kph - Unloaded Test Weight
(4) 3 stops from 65 kph - Loaded Test Weight

Initial brake temperature between 55°C and 65°C.

50 KPH DATA - - Unloaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	**50.7**	**21.5**	**71.2**	**-4.62**	**63.6**	**57.5**
2	**49.6**	**21.0**	**89.9**	**-4.52**	**65.2**	**61.0**
3	**48.9**	**20.0**	**158.4**	**-4.61**	**65.1**	**62.2**

50 KPH DATA - - Loaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	**49.1**	**21.0**	**180.1**	**-4.43**	**65.3**	**63.7**
2	**48.9**	**19.1**	**127.2**	**-4.82**	**64.9**	**60.4**
3	**51.4**	**23.4**	**147.2**	**-4.34**	**65.1**	**59.0**

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5.1.5 Final Effectiveness Test....Continued

65 KPH DATA - - Unloaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	64.2	34.6	78.3	-4.60	63.3	62.0
2	64.2	33.3	93.0	-4.78	65.4	62.2
3	65.2	35.1	112.1	-4.67	64.6	58.2

65 KPH DATA - - Loaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	65.8	37.8	114.8	-4.42	65.3	59.2
2	62.2	37.0	123.2	-4.02	63.8	56.8
3	65.2	38.7	119.2	-4.24	64.7	58.3

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5.1.6 Water Fade and Recovery Test

VEH.: **Taxi Tuk-Tuk;** AMBIENT TEMP.: **33°C;** DATE: **8/30/94**

WIND VEL/DIRECTION: **6 kph from Southeast.**

TEST DRIVER: **T. Carter**

TIRE PRESSURE (COLD) - FRONT: **30 psi** REAR: **33 psi**

REQUIREMENTS:

A. Conduct three 50 mph stops at 3 mpsps using full brake system, compute average maximum brake pedal forces and record data.

B. Completely wet each brake with water (brakes fully released) for 2 minutes. Wetting to be completed and recovery test started within 7 minutes.

C. Conduct 5 wet fade recovery stops from 40 kph at 3.0-3.4 mpsps using full brake system and record data.

D. Testing to be conducted at Loaded Test Weight.

50 KPH DATA - - Water Fade and Recovery Baseline Data

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	**48.1**	**29.5**	**93.0**	**-3.03**	**62.5**	**57.7**
2	**49.1**	**31.0**	**107.6**	**-3.00**	**64.8**	**63.5**
3	**49.4**	**30.3**	**114.3**	**-3.11**	**62.4**	**60.8**

AVERAGE MAX BRAKE PEDAL FORCE = **105.0 N**

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5.1.6 Water Fade and Recovery Test....Continued

50 KPH DATA - - Water Fade and Recovery Test

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	42.3	31.5	73.0	-2.19	32.1	33.1
2	42.5	32.8	47.2	-2.12	39.2	38.5
3	43.6	32.1	52.0	-2.29	49.8	46.9
4	38.6	30.2	56.5	-1.91	59.2	57.2
5	43.5	30.7	67.2	-2.37	71.1	62.0

REMARKS:

Wetting completed and test started in less than seven minutes.

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5.1.7 Final Inspection

VEH.: **Taxi Tuk-Tuk;** DATE: **8/30/94**

REQUIREMENTS: Inspect the following:

A. The entire brake system for detachment or fracture of any component.

B. Brake linings for detachment from the shoe or pad.

C. Wheel cylinder, master cylinder, and axle seals for fluid or lubricant leakage.

OBSERVATIONS:

Complete braking system intact, no indication of distress in any component.

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5.2 Braking Tests - Cargo Tuk-Tuk

The results for the cargo Tuk-Tuk braking tests are summarized in Table 5. A typical test run from each procedure is presented in the summary. A complete listing of the test results from each procedure are included sections 5.2.1 through 5.2.6.

Sound tests were conducted concurrently by MOSTE during the braking tests. The testing was videotaped by MOSTE.

The loaded test conditions were obtained by loading the passenger compartment with 10 kg and 80 kg sacks of sand.

TABLE 5 - Cargo Tuk-Tuk Braking Test Summary

VEH: **Cargo Tuk-Tuk** TEST DATE: **9/02-03/94**

PROCEDURE	SPEED (kph)	DECEL (mpsps) Avg	STOP DIST. (m)	MAX. BRAKE PEDAL FORCE (N)	NUMBER OF TESTS
Effectiveness Test - 50 kph (Unloaded Test Weight))	**50.4**	**-3.93**	**24.9**	**282.5**	**6**
Effectiveness Test - 50 kph (Loaded Test Weight))	**49.4**	**-3.36**	**28.1**	**375.0**	**6**
Fade and Recovery (Baseline)	**49.4**	**-1.83**	**51.4**	**275.8**	**3**
Fade and Recovery (Fade Test)	**49.9**	**-1.64**	**58.5**	**218.4**	**10**
Fade and Recovery (Recovery)	**50.4**	**-1.74**	**56.1**	**245.1**	**5**
2nd Burnish Procedure	---	---	---	---	---
Final Effectiveness Test - 50 kph (Unloaded Test Weight)	**50.2**	**-3.86**	**25.2**	**311.4**	**3**
Final Effectiveness Test - 65 kph (Unloaded Test Weight)	**63.6**	**-3.44**	**45.3**	**333.2**	**3**
Final Effectiveness Test - 50 kph (Loaded Test Weight)	**49.6**	**-2.38**	**39.9**	**354.5**	**3**
Final Effectiveness Test - 65 kph (Loaded Test Weight)	**63.6**	**-1.81**	**86.2**	**262.0**	**3**
Water Recovery (Base line)	**50.2**	**-1.80**	**54.1**	**295.8**	**3**
Water Recovery (Recovery)	**41.1**	**-1.13**	**57.5**	**447.0**	**5**

5.2.1 Instrumentation Check

VEH: **Cargo Tuk-Tuk;** AMBIENT TEMP.: **29°C;** DATE: **9/02/94**

WIND VEL/DIRECTION: **6 kph from West/Northwest.**

TEST DRIVER: **T. Carter**

TIRE PRESSURE (COLD) - FRONT: **38 psi** REAR: **36 psi**

UNLOADED VEHICLE WEIGHT: **705 kg**

UNLOADED TEST WEIGHT: **796 kg**

LOADED TEST WEIGHT: **1596 kg**

REQUIREMENTS: Check instrumentation by making not more than 10 stops from 50 kph at a deceleration of not more than 3 mpsps, record results, repeat if necessary.

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)[5]	DECEL (mpsps)[6]	BRAKE TEMP (°C)	
				AVG	LR[7]	RR[8]
Typ.	**50**	—	—	—	—	—

[5]Maximum Rear Brake Pedal Actuation Force (Newtons)
[6]Average Deceleration over the Stop (meters per second per second)
[7]Left Rear Brake Temperature
[8]Right Rear Brake Temperature

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5.2.2 Effectiveness Test

VEH: **Cargo Tuk-Tuk;** AMBIENT TEMP.: **29°C** DATE: **9/02/94**

WIND VEL/DIRECTION: **6 kph from West/Northwest.**

TEST DRIVER: **T. Carter**

TIRE PRESSURE (COLD) - FRONT: **38 psi** REAR: **36 psi**

REQUIREMENTS:

A. Make the following stops:

(1) 6 stops from 50 kph - Unloaded Test Weight
(2) 6 stops from 50 kph - Loaded Test Weight

Initial brake temperature between 55°C and 65°C.

50 KPH DATA - - Unloaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	49.1	28.0	269.5	-3.32	55.5	65.3
2	48.6	26.4	257.5	-3.46	57.2	61.5
3	50.4	24.9	282.5	-3.93	55.2	65.4
4	49.4	25.8	280.7	-3.65	55.0	60.6
5	48.1	24.5	283.3	-3.65	63.1	65.2
6	49.4	25.6	277.6	-3.68	62.2	64.6

(Continued on next page)

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5.2.2 Effectiveness Test....Continued

50 KPH DATA - - Loaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	48.6	42.4	266.9	-2.15	65.3	63.6
2	49.9	44.7	265.1	-2.15	63.3	60.7
3	48.6	32.8	375.9	-2.78	63.5	58.0
4	49.4	29.4	428.3	-3.21	65.8	59.8
5	49.4	28.1	375.0	-3.36	64.5	56.8
6	50.1	29.2	379.4	-3.31	65.5	59.2

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5.2.3 Fade and Recovery Test

VEH.: **Cargo Tuk-Tuk;** AMBIENT TEMP.: **29°C;** DATE: **9/02/94**

WIND VEL/DIRECTION: **8 kph from West.**

TEST DRIVER: **T. Carter**

TIRE PRESSURE (COLD) - FRONT: **38 psi** REAR: **36 psi**

REQUIREMENTS:

A. Conduct three 50 kph stops at 3 mpsps, compute average maximum brake pedal forces and record data.

B. Conduct 10 fade stops from 55 to 65 kph at a deceleration rate of 3.0 - 3.6 mpsps with initial brake temperature between 55°C and 65°C, conduct 5 fade recovery stops from 50 kph at 3 mpsps and record data.

C. Testing to be performed at Loaded Test Weight only.

50 KPH DATA - - Fade and Recovery Baseline Data

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	**45.7**	**40.3**	**333.6**	**-2.00**	**60.1**	**65.3**
2	**49.4**	**51.4**	**275.8**	**-1.83**	**58.8**	**65.5**
3	**48.9**	**54.5**	**235.3**	**-1.69**	**59.8**	**64.3**

AVERAGE MAX BRAKE PEDAL FORCE = **281.6 N**

(Continued on next page)

5.2.3 Fade and Recovery Test....Continued

55 - 65 KPH DATA - - Fade Stops

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	49.9	56.5	254.0	-1.70	57.8	65.5
2	49.6	56.6	253.1	-1.67	110.3	81.3
3	49.9	55.5	273.1	-1.73	86.3	96.4
4	48.9	57.4	266.4	-1.61	97.5	108.5
5	48.5	56.8	246.9	-1.59	106.0	118.0
6	49.4	57.7	226.4	-1.63	115.9	125.7
7	49.7	54.7	248.2	-1.75	119.7	130.0
8	49.9	58.5	218.4	-1.64	123.7	133.2
9	46.7	56.1	218.4	-1.50	125.2	135.2
10	48.5	55.6	243.7	-1.63	123.9	132.7

50 KPH DATA - - Recovery Test

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	49.9	62.0	214.8	-1.55	113.7	120.2
2	49.8	58.6	228.6	-1.62	106.1	109.4
3	48.6	56.7	225.5	-1.61	100.7	102.4
4	50.4	56.1	245.1	-1.74	98.1	98.7
5	50.1	58.6	229.5	-1.65	97.3	96.6

REMARKS: **Brake linkage clevis fitting failed - component replaced and testing resumed.**

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5.2.4 Re-Burnish Procedure

VEH.: **Cargo Tuk-Tuk;**	AMBIENT TEMP.: **30°F;**	DATE: **9/02/94**
WIND VEL/DIRECTION:	**6 - 11 kph from West.**	
TEST DRIVER: **T. Carter**		
TIRE PRESSURE (COLD) -	FRONT: **38 psi**	REAR: **36 psi**

REQUIREMENTS:

A. Burnish the brakes by making 35 stops from 50 kph at 2.7 mpsps deceleration.

B. The braking interval shall be either the distance necessary to reduce the brake temperature to between 55°C and 65°C or 1.6 km whichever comes first.

5.2.5 Final Effectiveness Test

VEH.: **Cargo Tuk-Tuk;** AMBIENT TEMP.: **35°C;** DATE: **9/02/94**

WIND VEL/DIRECTION: **3 kph from West.**

TEST DRIVER: **T. Carter**

TIRE PRESSURE (COLD) - FRONT: **38 psi** REAR: **36 psi**

REQUIREMENTS:

A. Make the following stops:

(1) 3 stops from 50 kph - Unloaded Test Weight
(2) 3 stops from 50 kph - Loaded Test Weight
(3) 3 stops from 65 kph - Unloaded Test Weight
(4) 3 stops from 65 kph - Loaded Test Weight

Initial brake temperature between 55°C and 65°C.

50 KPH DATA - - Unloaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	50.2	25.2	311.4	-3.86	56.5	65.2
2	50.1	26.7	317.6	-3.62	59.5	64.9
3	47.5	24.8	350.9	-3.51	59.4	64.8

50 KPH DATA - - Loaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	47.7	38.0	371.0	-2.31	58.0	62.5
2	49.6	39.9	354.5	-2.38	62.2	64.4
3	48.1	46.1	294.9	-1.94	63.4	65.6

(Continued on next page)

5.2.5 Final Effectiveness Test....Continued

65 KPH DATA - - Unloaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	63.1	44.9	327.4	-3.42	63.8	66.0
2	63.6	45.3	333.2	-3.44	62.3	65.2
3	64.4	48.5	320.7	-3.30	62.2	65.1

65 KPH DATA - - Loaded Test Weight

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	63.6	86.2	262.0	-1.81	68.5	72.0
2	62.6	86.8	279.3	-1.74	66.7	69.9
3	62.5	86.8	272.2	-1.73	67.9	67.9

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5.2.6 Water Fade and Recovery Test

VEH.: **Cargo Tuk-Tuk;** AMBIENT TEMP.: **33°C;** DATE: **9/02/94**

WIND VEL/DIRECTION: **3 kph from South.**

TEST DRIVER: **W. Perry**

TIRE PRESSURE (COLD) - FRONT: **38 psi** REAR: **36 psi**

REQUIREMENTS:

A. Conduct three 50 mph stops at 3 mpsps using full brake system, compute average maximum brake pedal forces and record data.

B. Completely wet each brake with water (brakes fully released) for 2 minutes. Wetting to be completed and recovery test started within 7 minutes.

C. Conduct 5 wet fade recovery stops from 40 kph at 3.0-3.4 mpsps using full brake system and record data.

D. Testing to be conducted at Loaded Test Weight.

50 KPH DATA - - Water Fade and Recovery Baseline Data

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	**49.4**	**59.4**	**249.1**	**-1.58**	**56.0**	**63.0**
2	**50.2**	**54.1**	**295.8**	**-1.80**	**61.0**	**65.8**
3	**46.5**	**54.2**	**246.9**	**-1.54**	**60.9**	**65.0**

AVERAGE MAX BRAKE PEDAL FORCE = **263.9 N**

(Continued on next page)

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5.2.6 Water Fade and Recovery Test....Continued

50 KPH DATA - - Water Fade and Recovery Test

RUN NO.	SPEED (kph)	STOP DIST (m)	MAX PEDAL FORCE (N)	DECEL (mpsps)	BRAKE TEMP (°C)	
				AVG	LR	RR
1	41.1	57.5	447.0	-1.13	32.2	38.4
2	41.2	55.8	339.4	-1.17	42.9	55.4
3	40.9	53.3	232.2	-1.21	53.5	66.7
4	43.0	53.5	264.7	-1.33	60.4	73.5
5	41.5	56.4	182.8	-1.18	71.1	76.9

REMARKS:

Wetting completed and test started in less than seven minutes.

5.2.7 Final Inspection

VEH.: **Cargo Tuk-Tuk;** DATE: **9/04/94**

REQUIREMENTS: Inspect the following:

A. The entire brake system for detachment or fracture of any component.

B. Brake linings for detachment from the shoe or pad.

C. Wheel cylinder, master cylinder, and axle seals for fluid or lubricant leakage.

OBSERVATIONS:

Complete braking system intact, no indication of distress in any component.

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5.3 Acceleration Tests - Taxi Tuk-Tuk

The results for the taxi Tuk-Tuk passing acceleration tests are summarized in Table 6. The results for the taxi Tuk-Tuk standing start acceleration tests are summarized in Table 7.

TABLE 6 - Passing Acceleration Tests - 40 to 60 kph - Taxi Tuk-Tuk

Run Number	Loading Condition	Heading	3rd Gear		4rd Gear	
			Elasped Time (sec)	Distance (meters)	Elasped Time (sec)	Distance (meters)
TACC07	Loaded	East	9.8	139	---	---
TACC08	Loaded	West	9.9	143	---	---
*TACC09	Loaded	East	7.7	114	---	---
TACC10	Loaded	West	9.6	138	---	---
TACC11	Loaded	East	9.9	141	---	---
TACC12	Loaded	West	10.2	146	---	---
TACC13	Loaded	East	---	---	12.5	177
TACC14	Loaded	West	---	---	15.8	221
**TACC15	Loaded	East	---	---	19.2	260
TACC16	Loaded	West	---	---	12.9	180
TACC17	Loaded	East	---	---	19.0	268
TACC18	Loaded	West	---	---	12.2	170
TACCU25	Unloaded	East	8.2	114	---	---
TACCU25	Unloaded	West	8.1	114	---	---
TACCU25	Unloaded	East	8.0	113	---	---
TACCU25	Unloaded	West	8.1	116	---	---
TACCU25	Unloaded	East	8.0	115	---	---
TACCU25	Unloaded	West	8.1	115	---	---
TACCU25	Unloaded	East	---	---	9.9	139
TACCU25	Unloaded	West	---	---	9.7	138
TACCU25	Unloaded	East	---	---	9.9	138
TACCU25	Unloaded	West	---	---	10.2	143
TACCU25	Unloaded	East	---	---	10.0	141
TACCU25	Unloaded	West	---	---	10.0	139

*** Initial Speed = 46 kph;** **** End Speed = 57.4 kph**

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TABLE 7 - Standing Start Acceleration Tests - Taxi Tuk-Tuk

Run Number	Loading Condition	Heading	Elasped Time (sec)			Terminal Speed (kph)		Distance (meters)
			0 to 50 kph	0 to 65 kph	0 to 0.4 km	0 to 0.4 km	0 to 5 Seconds	0 to 5 Seconds
TACC01	Loaded	East	15.7	29.5	31.7	65.0	26.4	23.2
TACC02	Loaded	West	15.0	30.8	31.7	59.7	25.6	22.6
TACC03	Loaded	East	14.6	28.2	30.9	60.3	27.4	24.0
TACC04	Loaded	West	15.6	30.8	31.6	59.2	25.6	24.1
TACC05	Loaded	East	15.0	28.4	31.3	61.5	26.9	22.3
TACC06	Loaded	West	15.1	30.6	31.4	61.5	27.4	25.3
TACCU	Unloaded	East	11.6	21.6	29.0	72.9	30.9	26.5
TACCU 19	Unloaded	West	11.7	21.6	28.9	72.4	33.1	26.8
TACCU 20	Unloaded	East	11.7	21.7	29.0	71.9	30.9	24.7
TACCU 21	Unloaded	West	12.0	21.7	29.1	71.9	29.9	24.7
TACCU 22	Unloaded	East	11.5	21.1	28.7	72.6	31.1	26.5
TACCU 23	Unloaded	West	11.6	21.6	28.9	72.2	31.9	27.1

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5.4 Acceleration Tests - Cargo Tuk-Tuk

The results for the taxi Tuk-Tuk passing acceleration tests are summarized in Table 8. The results for the taxi Tuk-Tuk standing start acceleration tests are summarized in Table 9.

TABLE 8 - Passing Acceleration Tests - 40 to 60 kph - Cargo Tuk-Tuk

Run Number	Loading Condition	Heading	3rd Gear		4rd Gear	
			Elasped Time (sec)	Distance (meters)	Elasped Time (sec)	Distance (meters)
CACCL07	Loaded	East	10.7	152	---	---
CACCL08	Loaded	West	10.3	145	---	---
CACCL09	Loaded	East	10.4	147	---	---
CACCL10	Loaded	West	10.4	146	---	---
CACCL11	Loaded	East	10.6	149	---	---
CACCL12	Loaded	West	10.8	157	---	---
CACCL13	Loaded	East	---	---	20.6	286
CACCL14	Loaded	West	---	---	18.3	253
CACCL15	Loaded	East	---	---	17.3	245
CACCL16	Loaded	West	---	---	18.7	260
CACCL17	Loaded	East	---	---	16.3	232
*CACCL18	Loaded	West	---	---	13.3	188
CACCU07	Unloaded	East	5.5	78	---	---
CACCU08	Unloaded	West	5.3	74	---	---
CACCU09	Unloaded	East	5.5	77	---	---
CACCU10	Unloaded	West	5.3	74	---	---
CACCU11	Unloaded	East	5.3	76	---	---
CACCU12	Unloaded	West	5.6	79	---	---
CACCU13	Unloaded	East	---	---	6.8	97
CACCU14	Unloaded	West	---	---	8.0	111
CACCU15	Unloaded	East	---	---	7.7	106
CACCU16	Unloaded	West	---	---	6.7	95
CACCU17	Unloaded	East	---	---	6.7	96
CACCU18	Unloaded	West	---	---	6.7	95

*** Initial Speed = 43.9 kph; End Speed = 58.6 kph**

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TABLE 9 - Standing Start Acceleration Tests - Cargo Tuk-Tuk

Run Number	Loading Condition	Heading	Elasped Time (sec)			Terminal Speed (kph)		Distance (meters)
			0 to 50 kph	0 to 65 kph	0 to 0.4 km	0 to 0.4 km	0 to 5 Seconds	0 to 5 Seconds
CACCL01	Loaded	East	19.2	31.7	32.9	66.1	23.8	19
CACCL02	Loaded	West	18.7	30.4	32.7	65.2	24.9	21
CACCL03	Loaded	East	17.7	28.1	31.8	67.6	25.9	23
CACCL04	Loaded	West	18.2	29.1	32.2	66.6	25.4	21
CACCL05	Loaded	East	17.1	27.3	31.8	68.5	25.4	20
CACCL06	Loaded	West	18.1	29.0	32.2	66.9	25.3	21
*CACCU01	Unloaded	East	- - -	- - -	- - -	- - -	- - -	- - -
CACCU02	Unloaded	West	11.8	17.4	27.7	79.6	30.0	25
CACCU03	Unloaded	East	11.7	17.2	27.7	79.3	30.9	24
CACCU04	Unloaded	West	11.8	17.2	27.6	74.2	28.6	25
CACCU05	Unloaded	East	10.6	15.9	27.0	79.8	31.5	25
CACCU06	Unloaded	West	10.0	15.5	26.7	76.6	33.5	27

***Data Acquisition Error**

5.5 Urban Drive Cycle Tests - Taxi Tuk-Tuk

Histograms of selected segments for the Taxi Tuk-Tuk drive cycle tests are shown in Figures 9 through 14. The histograms indicate the percentage of total test segment time the vehicle is operating within specified speed ranges.

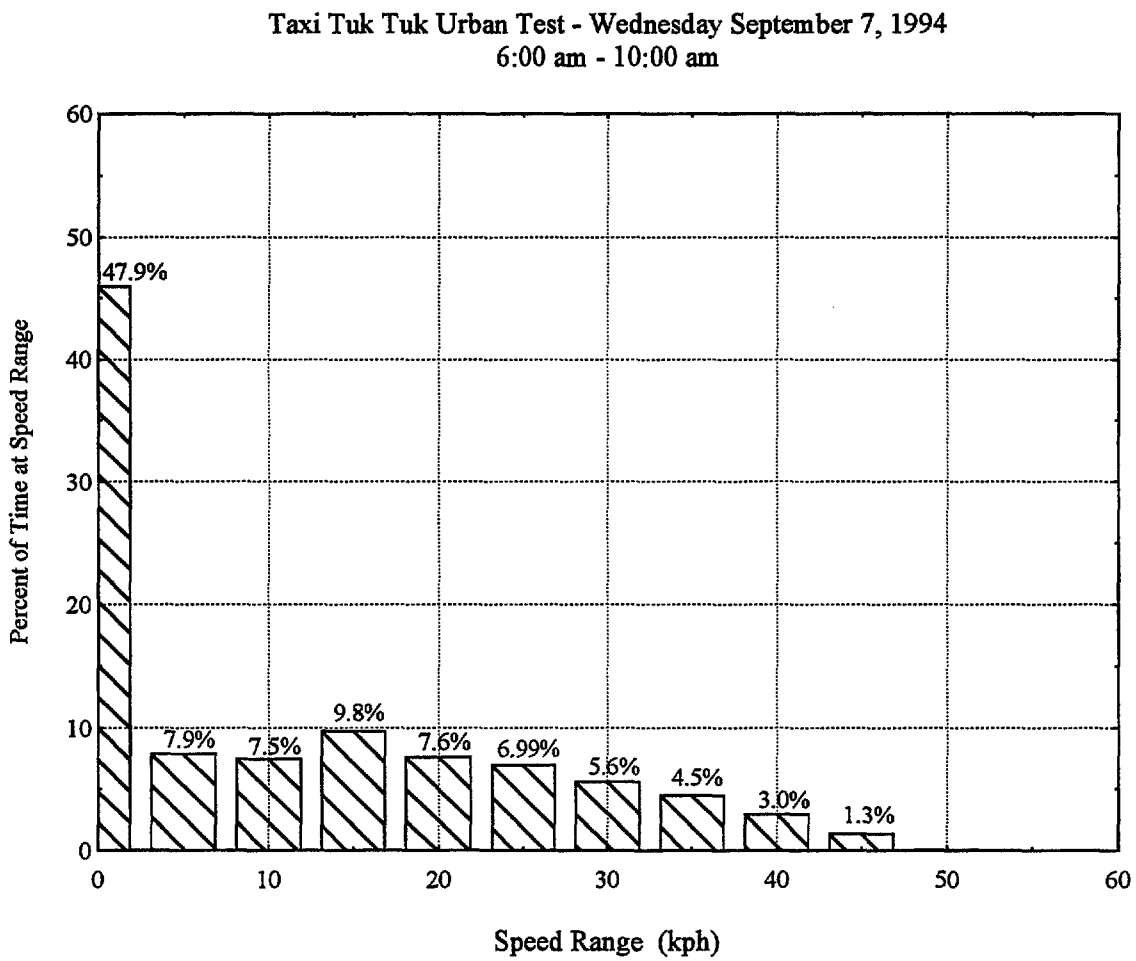

Figure 9. Taxi Urban Drive Cycle - Wednesday - 6:00am to 10:00 am

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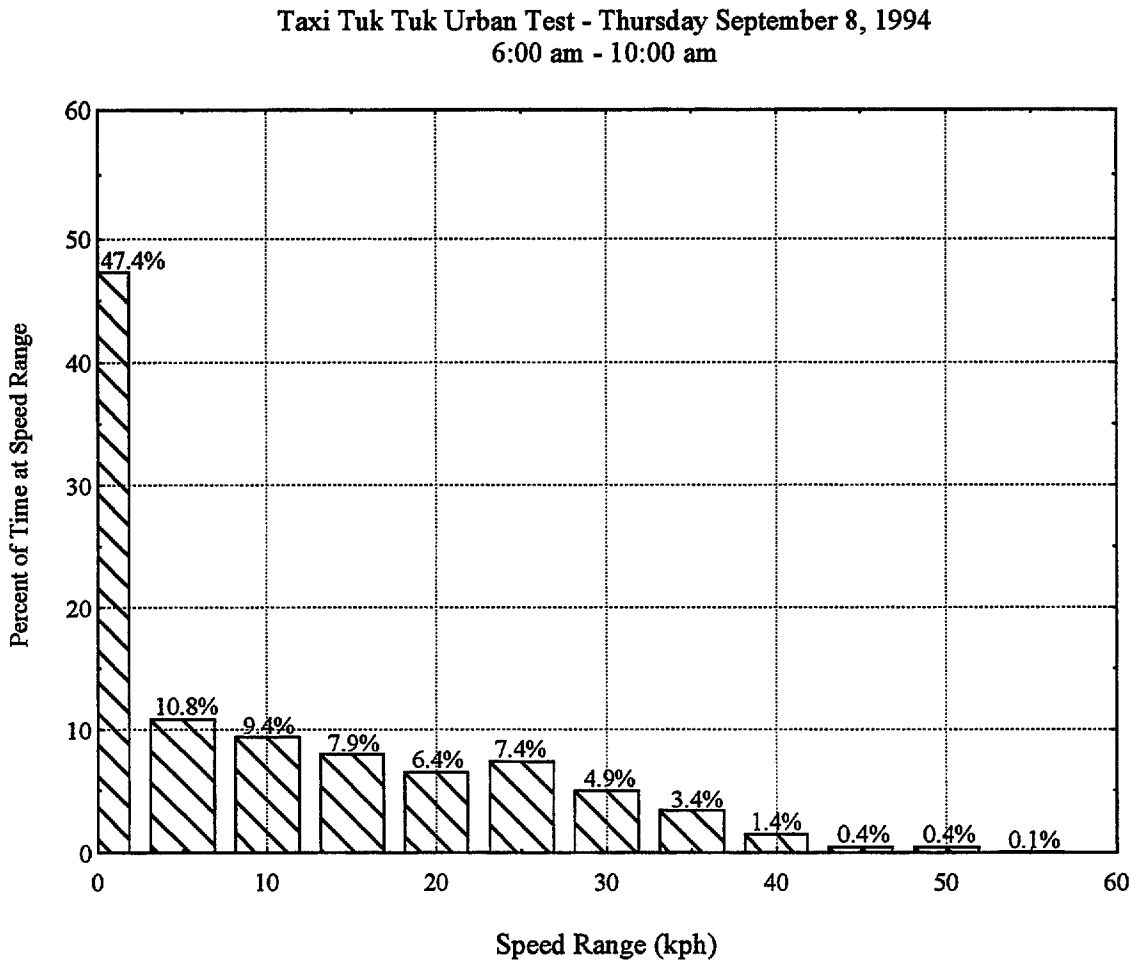

Figure 10. Taxi Urban Drive Cycle - Thursday - 6:00am to 10:00 am

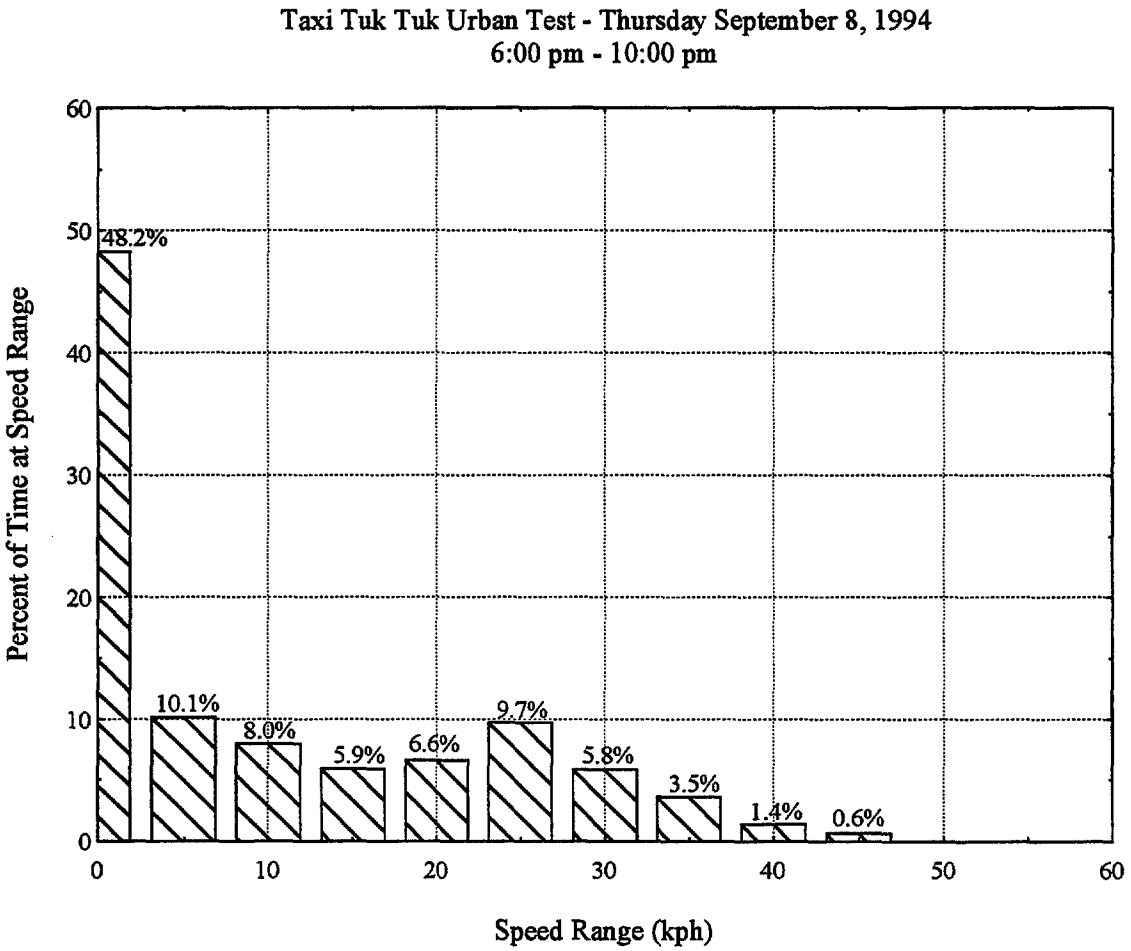

Figure 11. Taxi Urban Drive Cycle - Thursday - 6:00pm to 10:00 pm

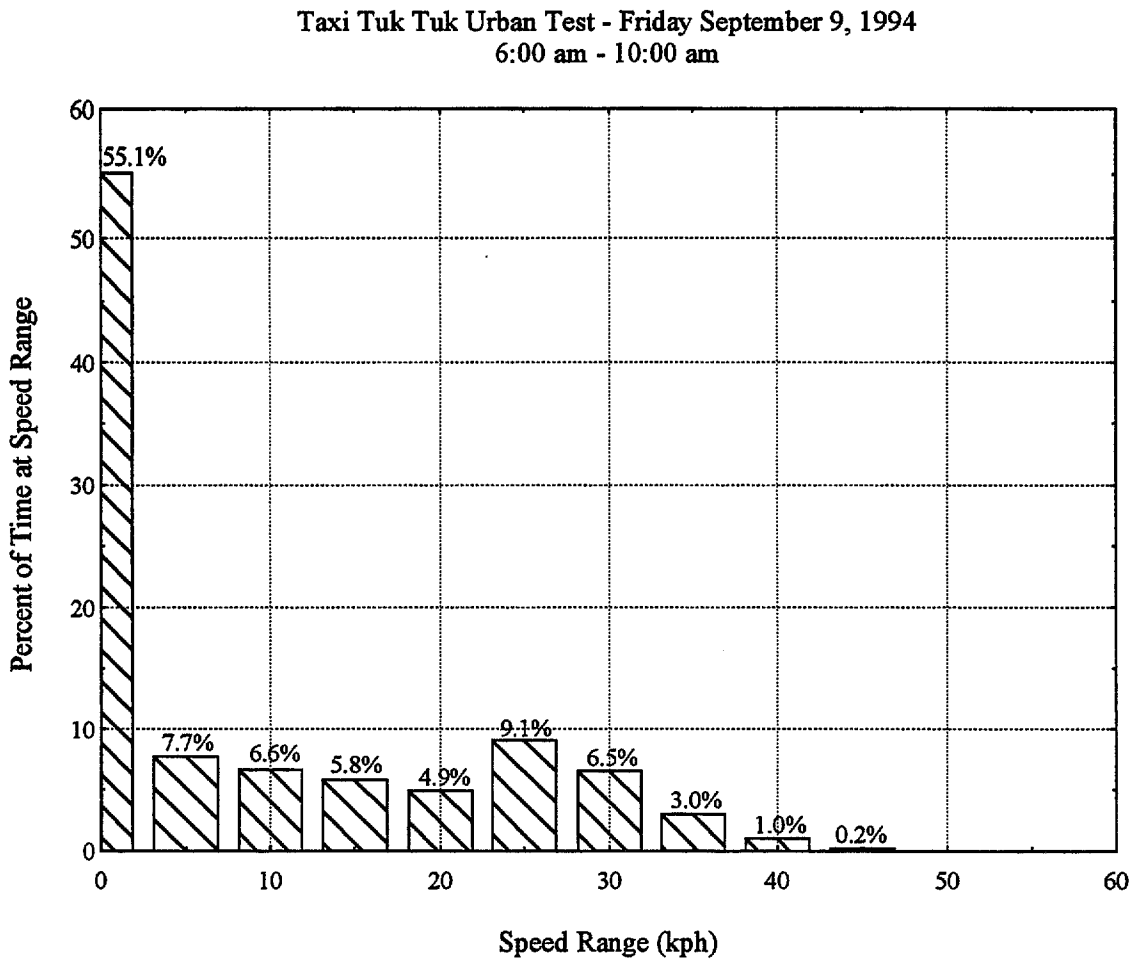

Figure 12. Taxi Urban Drive Cycle - Friday - 6:00am to 10:00am

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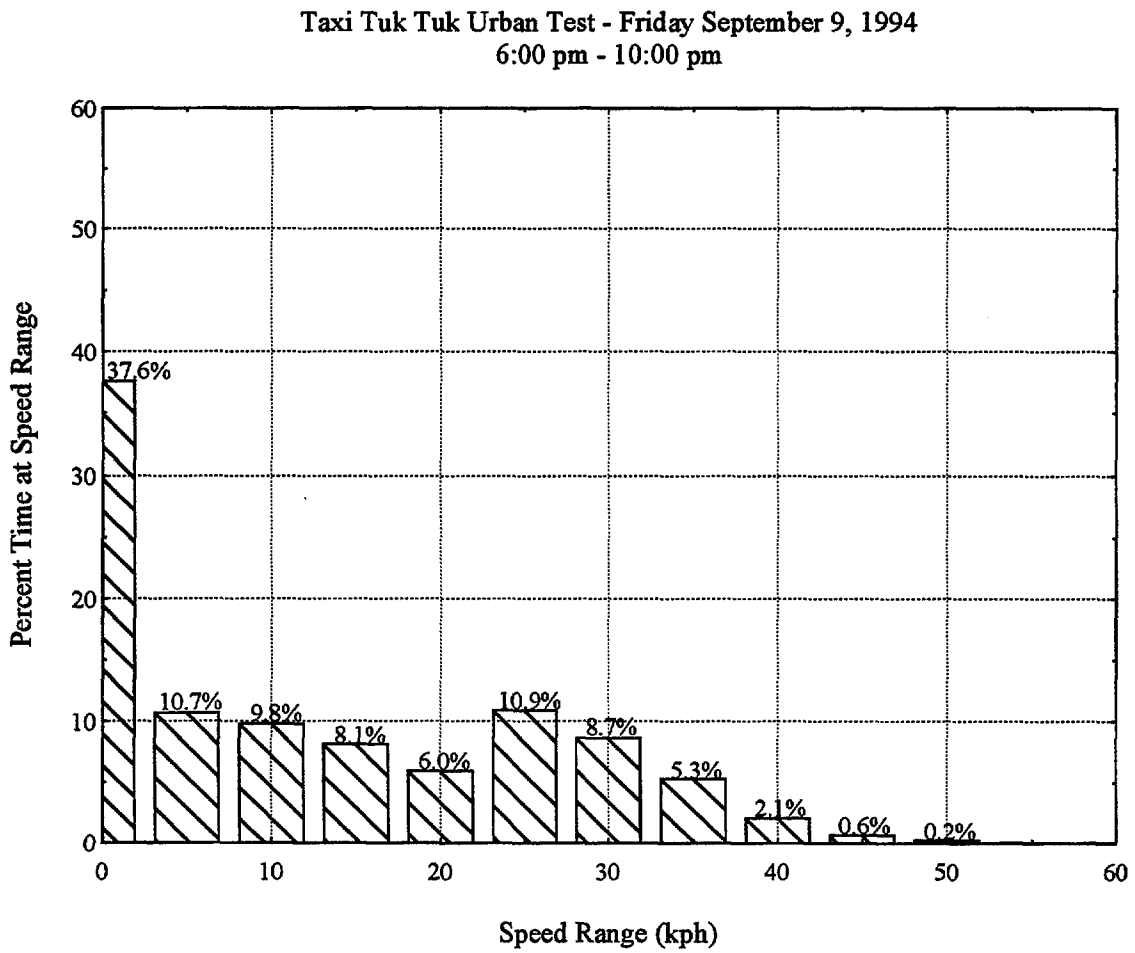

Figure 13. Taxi Urban Drive Cycle - Friday - 6:00pm to 10:00pm

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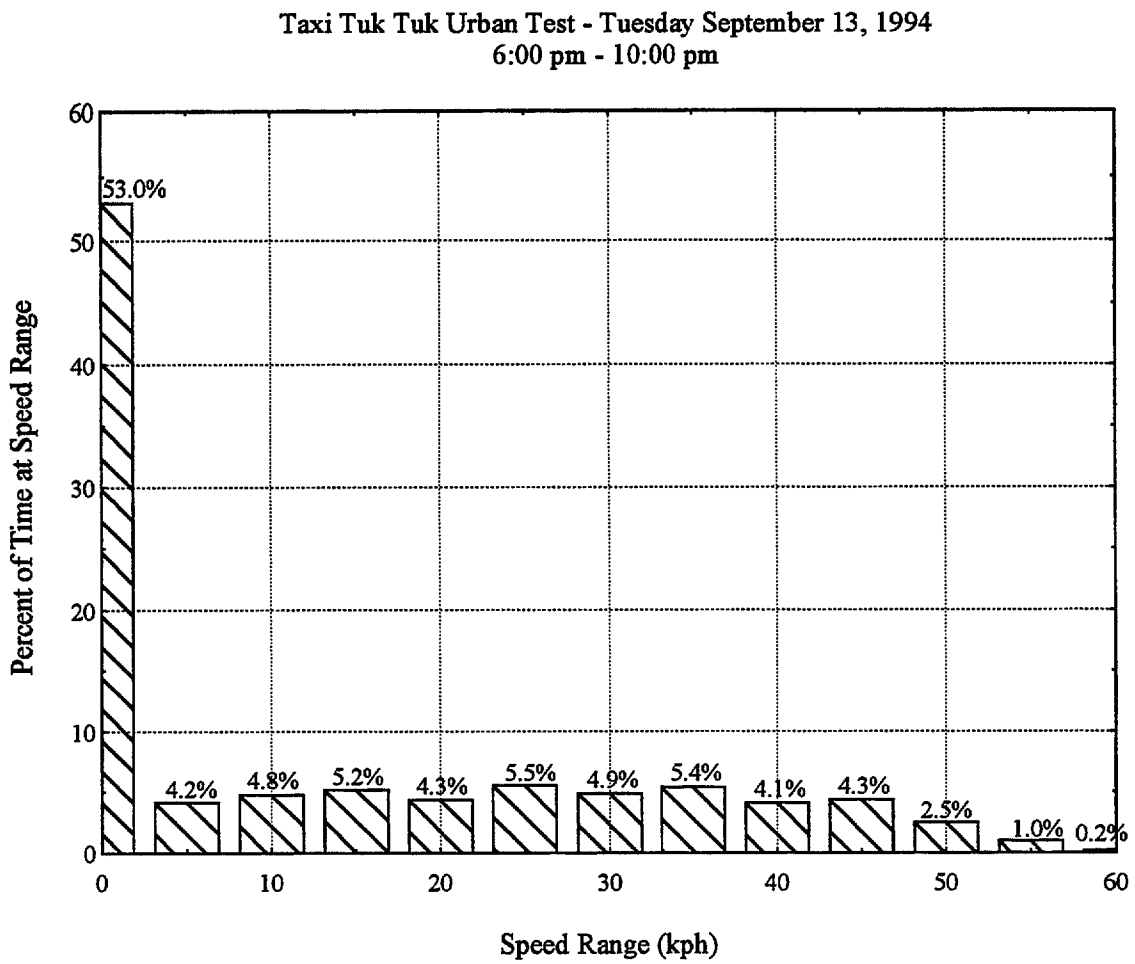

Figure 14. Taxi Urban Drive Cycle - Tuesday - 6:00pm to 10:00pm

5.6 Urban Drive Cycle Tests - Cargo Tuk-Tuk

A histograms of a selected segment for the Cargo Tuk-Tuk drive cycle tests is shown in Figure 15. The histogram indicates the percentage of total test segment time the vehicle is operating within specified speed ranges.

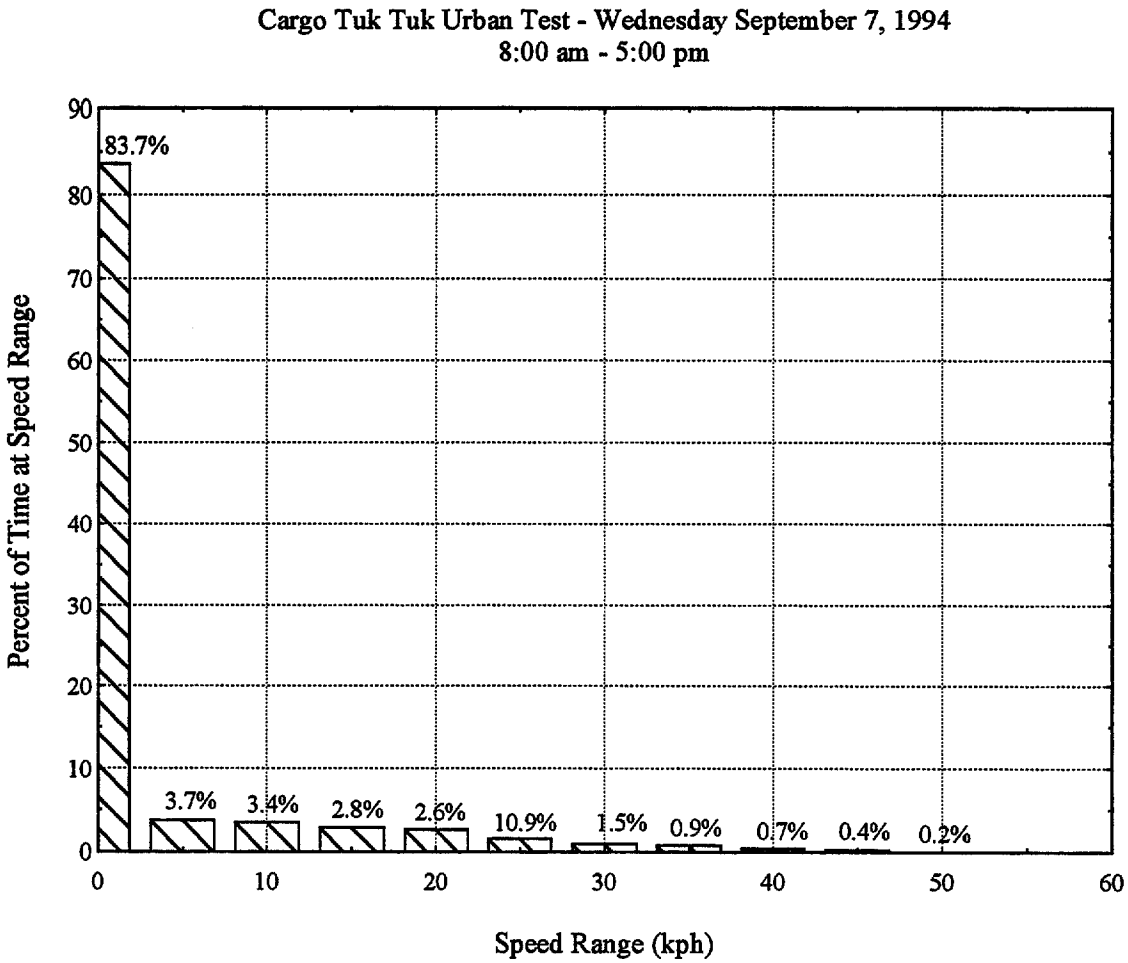

Figure 15. Cargo Urban Drive Cycle - Wednesday - 8:00am to 5:00pm

6.0 REFERENCES

1. Federal Motor Vehicle Safety Standard No. 122, Vehicle Brake Systems, Code of Federal Regulations, Title 49, October 1, 1993.

2. Section 122; Vehicle, Motor Driven Cycle and Moped Brake Systems; Motor Vehicle Safety Test Methods, Transport Canada - Road Safety.

3. SAE J108 Mar 87, Brake System Road Test Code - Motorcycles.

4. International Standard ISO 6597-1980, Road Vehicles - Passenger Car Braking Systems - Measurement of the Braking Performance.

5. Test Plan for Braking Performance Tests, September, 1994, Thomas J. Carter, Carter Engineering.

6. SAE J1491 - JUN 90, Vehicle Acceleration Measurement, SAE Recommended Practice.

7. Test Plan for Acceleration Performance Tests, September, 1994, Thomas J. Carter, Carter Engineering.

8. SAE J1506 - APR93, Emission Test Driving Schedules, SAE Information Report.

9. An On-Board Data Acquisition System for Vehicle Brake Testing, Thomas J. Carter and W.D. Perry, Society of Automotive Engineers, SAE No. 920259.

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APPENDIX A Instrumentation List

Listed below are the test instruments used for this program.

a. Vehicle Fifth Wheel.

- Custom Built by Carter Engineering.
- Tire Circumference: 1.3604 m ±0.227%.
- Tire circumference divided into 500 pulses with BEI Optical Encoder.

b. Brake Pedal Force Transducers.

- Transducer Techniques.
- Model MLP-750-MC.

c. Friction Material Thermocouples.

- Iron-Constantan Thermocouples, Type "K" - Omega.
- Plug Type as per drawings (Reference 1, 2, & 3).

e. Ambient Temperature Thermometer.

- Type "K" Thermocouple Thermometer - Cole Parmer.
- Model 8437-00.

f. Weather Station.

- Wind speed and direction:
- Davis Instruments Weather Monitor II portable weather station.

g. Continuous Data Recorder.

- Omnidata International, Inc.
- Polycorder 700 Series - 2 ea.
- Model No.'s: PC-704 and PC-706.
- Serial No.'s: 0180 and 851-121.

h. Multiplexer.

- 40 Channel.
- Omnidata International, Inc.
- Model No. PA-780-40.
- Serial No. 02-52-32.

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i. Portable Computer.

- Toshiba Model T3400CT.
- Subnotebook Computer: 486-33 MHz, 8 megabyte RAM, 120 megabyte Hard Drive, Color Display.

j. Linear Displacement Transducer.

- Miniature.
- Magnetek.
- Model MP-20A-50G.

k. Fiber Optic Photosensor - For RPM.

- Pulnix-Seeka
- F5H

l. Manifold Vaccum Sensor

- Strain Gauge Manifold Absolute Pressure (MAP) Sensor
- General Motors #039 4150

m. Proximity Sensor

- Turck
- BI 2U-M12-AN4X-H1141

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APPENDIX B Data File Index

Data Files for Taxi Tuk-Tuk Testing

Brake Tests:

T30L.ANL	Taxi 50 kph Loaded Effectiveness - Analysis File
T30U.ANL	Taxi 50 kph Unloaded Effectiveness - Analysis File
TFRL.ANL	Taxi Fade and Recovery - Analysis File
TF.ANL	Taxi Final Effectiveness - Analysis File
TWB.ANL	Taxi Wet Brake - Analysis File
T30L01.DAT	Taxi 50 kph Loaded Effectiveness - Data Files
T30L02.DAT	
T30L03.DAT	
T30L04.DAT	
T30L05.DAT	
T30L06.DAT	
T30U01.DAT	Taxi 50 kph Unloaded Effectiveness - Data Files
T30U02.DAT	
T30U03.DAT	
T30U04.DAT	
T30U05.DAT	
T30U06.DAT	
TFRL01.DAT	Taxi Fade and Recovery - Data Files
TFRL02.DAT	
TFRL03.DAT	
TFRL04.DAT	
TFRL05.DAT	
TFRL06.DAT	
TFRL07.DAT	
TFRL08.DAT	
TFRL09.DAT	
TFRL10.DAT	
TFRL11.DAT	
TFRL12.DAT	
TFRL13.DAT	
TFRL14.DAT	
TFRL15.DAT	
TFRL16.DAT	
TFRL17.DAT	
TFRL18.DAT	

T30LF01.DAT Files T30LF02.DAT T30LF03.DAT	Taxi Final Effectiveness - Loaded - 50 kph - Data
T30UF01.DAT Data Files T30UF02.DAT T30UF03.DAT	Taxi Final Effectiveness - Unloaded - 50 kph -
T40LF01.DAT Files T40LF02.DAT T40LF03.DAT	Taxi Final Effectiveness - Loaded - 65 kph - Data
T40UF01.DAT Data Files T40UF02.DAT T40UF03.DAT	Taxi Final Effectiveness - Unloaded - 65 kph -
TWB01.DAT TWB02.DAT TWB03.DAT TWB04.DAT TWB05.DAT TWB06.DAT TWB07.DAT TWB08.DAT	Taxi Wet Brake - Data Files

Acceleration Tests:

TACCL01.DAT TACCL02.DAT TACCL03.DAT TACCL04.DAT TACCL05.DAT TACCL06.DAT TACCL07.DAT TACCL08.DAT TACCL09.DAT TACCL10.DAT TACCL11.DAT TACCL12.DAT TACCL13.DAT TACCL14.DAT	Taxi Acceleration Tests - Loaded - Data Files

TACCL15.DAT
TACCL16.DAT
TACCL17.DAT
TACCL18.DAT

TACCU01.DAT	Taxi Acceleration Tests - Unloaded - Data Files
TACCU02.DAT	
TACCU03.DAT	
TACCU04.DAT	
TACCU05.DAT	
TACCU06.DAT	
TACCU07.DAT	
TACCU08.DAT	
TACCU09.DAT	
TACCU10.DAT	
TACCU11.DAT	
TACCU12.DAT	
TACCU13.DAT	
TACCU14.DAT	
TACCU15.DAT	
TACCU16.DAT	
TACCU17.DAT	
TACCU18.DAT	

Urban Drive Cycle Testing:

TUW01.DAT	Taxi Urban Wednesday - 0200-1000 hrs (9/7/94)
TUW02.DAT	Taxi Urban Wednesday - 1000-1600 hrs (9/7/94)
TUW03.DAT	Taxi Urban Wednesday - 2200-1000 hrs (9/7/94)
TUH01.DAT	Taxi Urban Thursday - 2200-0600 hrs (9/8/94)
TUH02.DAT	Taxi Urban Thursday - 0600-1000 hrs (9/8/94)
TUH03.DAT	Taxi Urban Thursday - 1000-1800 hrs (9/8/94)
TUH04.DAT	Taxi Urban Thursday - 1800-2200 hrs (9/8/94)
TUF01.DAT	Taxi Urban Friday - 2200-0600 hrs (9/9/94)
TUF02.DAT	Taxi Urban Friday - 0600-1000 hrs (9/9/94)
TUF03.DAT	Taxi Urban Friday - 1000-1800 hrs (9/9/94)
TUF04.DAT	Taxi Urban Friday - 1800-2200 hrs (9/9/94)
TUSAT01.DAT	Taxi Urban Saturday - 2200-0600 hrs (9/10/94)
TUSAT02.DAT	Taxi Urban Saturday - 0600-1000 hrs (9/10/94)
TUSAT03.DAT	Taxi Urban Saturday - 1000-1800 hrs (9/10/94)
TUSAT04.DAT	Taxi Urban Saturday - 1800-2200 hrs (9/10/94)

TUSUN01.DAT	Taxi Urban Sunday - 2200-0600 hrs (9/11/94)
TUSUN02.DAT	Taxi Urban Sunday - 0600-1000 hrs (9/11/94)
TUSUN03.DAT	Taxi Urban Sunday - 1000-1800 hrs (9/11/94)
TUSUN04.DAT	Taxi Urban Sunday - 1800-2200 hrs (9/11/94)
TUM01.DAT	Taxi Urban Monday - 2200-0600 hrs (9/12/94)
TUM02.DAT	Taxi Urban Monday - 0600-1000 hrs (9/12/94)
TUM03.DAT	Taxi Urban Monday - 1800-2200 hrs (9/12/94)
TUT01.DAT	Taxi Urban Tuesday - 2200-0600 hrs (9/13/94)
TUT02.DAT	Taxi Urban Tuesday - 0600-1000 hrs (9/13/94)
TUT03.DAT	Taxi Urban Tuesday - 1000-1800 hrs (9/13/94)
TUT04.DAT	Taxi Urban Tuesday - 1800-2200 hrs (9/13/94)

Data Files for Cargo Tuk-Tuk Testing

Brake Tests:

C30L.ANL	Cargo 50 kph Loaded Effectiveness - Analysis File
C30U.ANL	Cargo 50 kph Unloaded Effectiveness - Analysis File
CFRL.ANL	Cargo Fade and Recovery - Analysis File
CF.ANL	Cargo Final Effectiveness - Analysis File
CWB.ANL	Cargo Wet Brake - Analysis File
C30L01.DAT	Cargo 50 kph Loaded Effectiveness - Data Files
C30L02.DAT	
C30L03.DAT	
C30L04.DAT	
C30L05.DAT	
C30L06.DAT	
C30U01.DAT	Cargo 50 kph Unloaded Effectiveness - Data Files
C30U02.DAT	
C30U03.DAT	
C30U04.DAT	
C30U05.DAT	
C30U06.DAT	
CFRL01.DAT	Cargo Fade and Recovery - Data Files
CFRL02.DAT	
CFRL03.DAT	
CFRL04.DAT	
CFRL05.DAT	
CFRL06.DAT	
CFRL07.DAT	
CFRL08.DAT	
CFRL09.DAT	
CFRL10.DAT	
CFRL11.DAT	
CFRL12.DAT	
CFRL13.DAT	
CFRL14.DAT	
CFRL15.DAT	
CFRL16.DAT	
CFRL17.DAT	
CFRL18.DAT	
T30LF01.DAT	Cargo Final Effectiveness - Loaded - 50 kph - Data Files
C30LF02.DAT	

C30LF03.DAT	
C30UF01.DAT	Cargo Final Effectiveness - Unloaded - 50 kph - Data Files
C30UF02.DAT	
C30UF03.DAT	
C40LF01.DAT	Cargo Final Effectiveness - Loaded - 65 kph - Data Files
C40LF02.DAT	
C40LF03.DAT	
C40UF01.DAT	Cargo Final Effectiveness - Unloaded - 65 kph - Data Files
C40UF02.DAT	
C40UF03.DAT	
CWB01.DAT	Cargo Wet Brake - Data Files
CWB02.DAT	
CWB03.DAT	
CWB04.DAT	
CWB05.DAT	
CWB06.DAT	
CWB07.DAT	
CWB08.DAT	

Acceleration Tests:

CACCL01.DAT	Cargo Acceleration Tests - Loaded - Data Files
CACCL02.DAT	
CACCL03.DAT	
CACCL04.DAT	
CACCL05.DAT	
CACCL06.DAT	
CACCL07.DAT	
CACCL08.DAT	
CACCL09.DAT	
CACCL10.DAT	
CACCL11.DAT	
CACCL12.DAT	
CACCL13.DAT	
CACCL14.DAT	
CACCL15.DAT	
CACCL16.DAT	
CACCL17.DAT	
CACCL18.DAT	
CACCU01.DAT	Cargo Acceleration Tests - Unloaded - Data Files

CACCU02.DAT
CACCU03.DAT
CACCU04.DAT
CACCU05.DAT
CACCU06.DAT
CACCU07.DAT
CACCU08.DAT
CACCU09.DAT
CACCU10.DAT
CACCU11.DAT
CACCU12.DAT
CACCU13.DAT
CACCU14.DAT
CACCU15.DAT
CACCU16.DAT
CACCU17.DAT
CACCU18.DAT

Urban Drive Cycle Testing:

CUW01.DAT	Cargo Urban Wednesday - (9/7/94)
CUW02.DAT	
CUH01.DAT	Cargo Urban Thursday - (9/8/94)
CUH02.DAT	
CUFO1.DAT	Cargo Urban Friday - (9/9/94)
CUSAT01.DAT	Cargo Urban Saturday - (9/10/94)
CUM01.DAT	Cargo Urban Monday - (9/12/94)
CUT01.DAT	Cargo Urban Tuesday - (9/13/94)

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APPENDIX C

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
Bureau for Global Programs, Field Support and Research
Center for Environment
Office of Energy, Environment, and Technology

THAILAND TUK-TUK ELECTRIC VEHICLE DEMONSTRATION PROJECT

ELECTRIC TUK-TUK PERFORMANCE EVALUATION

Final Draft Report

February 1995

Prepared for:

Royal Thai Government
Ministry of Science, Technology and Environment
Pollution Control Department

Prepared by:

Energy Technology Innovation Project
Contract No. DHR-5741-C-00-1061-00
Prime Contractor: Bechtel Corporation
Subcontractor: Core International, Inc.

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ELECTRIC TUK-TUK PERFORMANCE EVALUATION
FINAL REPORT

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ATTACHMENTS

Attachment 1 - Statement of Work
Attachment 2 - List of Laboratories to Conduct Emission Tests
Attachment 3 - Tuk-Tuk Motorized Three-Wheeler Description
Attachment 4 - Electric Drive Motor Description
Attachment 5 - Input Data Files for "Hybrid"
Attachment 6 - Computer Simulation Runs

3.5 Inch Diskette of Computer Simulation Runs

February 10, 1995
Revision 1: March 8, 1995

ELECTRIC TUK-TUK PERFORMANCE EVALUATION

FINAL REPORT

INTRODUCTION

This technical report summarizes the electric Tuk-Tuk performance evaluation based on driving cycles derived from testing current LPG powered Tuk-Tuk vehicles in Bangkok, Thailand. The objective of this effort was to assist ETIP in their economic analysis of the electric Tuk-Tuk demonstration program. The vehicle performance evaluation was performed using a computer simulation model developed for electric/hybrid vehicles. The work was performed in accordance with the Statement of Work dated November 2, 1994 (Attachment 1).

A. DEVELOPMENT OF DRIVING CYCLES

A1. Driving Cycles for Tuk-Tuk Vehicle Dynamometer Testing

To determine the emissions of LPG and gasoline powered Tuk-Tuk vehicles, the EPA procedures for Urban Driving Schedule (UDS) are recommended (40 CFR Part 86- EPA; Control of Air Pollution from New and In-Use Motor Vehicles and New and In-Use Motor Vehicle Engines; Certification and Test Procedures). The same UDS driving schedule is recommended by SAE for "Electric Vehicle Energy Consumption and Range Test Procedure" in accordance with SAE J1634 publication, which is identical to the EPA driving cycle. The driving cycles for use in conducting dynamometer testing for emissions produced by the conventionally fueled Tuk-Tuks (LPG and gasoline), in typical taxi and cargo vehicle in-service usage, should be based on the UDS procedures but will require certain modifications. Driving cycles for dynamometer emissions testing are discussed further in Section A3.

There are numerous independent commercial and private laboratories recognized as knowledgeable and properly equipped to perform emission tests using dynamometer facilities in accordance with applicable procedures. A list of such facilities supplied by the California Air Resources Board is included in Attachment 2.

The Urban Driving Schedule (UDS) defined by EPA/SAE consists of a series of non-repetitive idle, acceleration, cruise and deceleration modes of various time sequences and rates. The UDS has a time duration of 1372 seconds, is 12 KM (7.45 Miles) long and the average speed is 31.5 KPH (19.6 MPH).

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To be able to evaluate electric Tuk-Tuk vehicle performance over the UDS driving schedule, a route input data file was developed for the HYBRID computer simulation program as presented in Table 1.

TABLE 1 — SAE/EPA URBAN DRIVING SCHEDULE (SAEJ1634.RTE)

1 SAE J1634 - EPA UDS DUTY CYCLE	Dist Feet	Elev Feet	Speed MPH	Acl Ft/Sec2	Dcl Ft/Sec2	Dwel Sec
Zero ground level	0	140	0	1.0	1.0	0
CBD #01	112	140	19	3.5	1.0	0
CBD #02	3497	140	32	0.2	4.7	38
CBD #03	846	140	24	4.4	1.0	0
CBD #04	9169	140	54	2.8	2.6	14
CBD #05	1955	140	35	4.3	4.3	6
CBD #06	771	140	30	4.5	4.9	18
CBD #07	2393	140	35	4.7	4.3	6
CBD #08	1094	140	25	2.3	4.9	16
CBD #09	375	140	17	4.2	1.0	0
CBD #10	903	140	27	0.7	4.9	25
CBD #11	898	140	26	3.2	3.5	13
CBD #12	733	140	21	2.9	3.6	3
CBD #13	971	140	27	3.6	4.0	2
CBD #14	7367	140	28	3.2	4.6	3
CBD #15	1994	140	25	3.9	5.2	25
CBD #16	1160	140	27	3.8	1.6	4
CBD #17	1470	140	25	3.3	5.2	16
CBD #18	344	140	26	4.2	4.3	11
CBD #19	1058	140	20	2.5	2.9	11
CBD #20	340	140	22	1.6	1.0	0
CBD #21	1230	140	28	0.3	5.1	25
CBD #22	656	140	21	4.1	3.4	25

Note: Dwell times occur at the end of each line event, i.e. Acceleration, Cruise and Deceleration. Furthermore, these dwell times for the conventional fueled vehicles are all with the engine idling.

A2. Development of Driving Cycles for Electric Tuk-Tuk Vehicle Performance Evaluation

To establish realistic driving cycles for Tuk-Tuk taxi and cargo vehicle operation, a comprehensive test program was conducted by Carter Engineering in Bangkok, Thailand central city area in September, 1994 using local drivers over randomly selected routes during one week. A digital data recorder was programmed to record distance, engine rotational speed, suspension displacement and manifold vacuum versus time. Speed was calculated from distance versus time data. The raw data was provided on 24 computer diskettes for our evaluation.

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The most important information to establish drive cycles from the test data is the distance and speed versus time relationships. Distance was measured by a proximity sensor mounted at the front wheel, counting pulses as the wheel rotates. Due to instrumentation noise/interference, the proximity sensor picked up extraneous pulses (sometimes even when the vehicle was not moving) resulting in an error in distance and speed measurements. Reviewing some typical data recordings in detail and correcting for the extraneous pulses (i.e. eliminating extraneous pulses and obviously incorrect pulses), it appears that the distance/speed measurements are about 15 % too high.

A2.1 Taxi Driving Cycles

To establish a typical 24 hour driving cycle for Tuk-Tuk taxis, the raw test data was reduced and the distance travelled during each day was calculated. A summary of the data is presented in Table 2 as derived from actual tests and it does not include any adjustments for the instrumentation errors described earlier.

TABLE 2
Tuk-Tuk Taxi Driving Cycle Testing - Summary
(Daily Travel in KM)

Time Period	Thu 9/8	Fri 9/9	Sat 9/10	Sun 9/11	Mon 9/12	Tue 9/13	Average KM	Average MI
2200-0600	99.1	79.1	68.1	97.7	76.6	61.9	80.4	50.2
0600-1000	36.7	38.5	70.2	54.3	75.5	112.6	64.6	40.4
Shift No.1	135.8	117.6	138.3	152.0	152.1	174.5	145.0	90.6
1000-1800	63.5	73.4	186.2	94.2	N.A.	45.8	92.6	57.9
1800-2200	34.8	38.6	46.6	44.9	36.7	40.0	40.2	25.1
Shift No.2	98.3	112.0	232.8	139.1	N.A.	85.8	132.8	83.0
Total/Day	234.1	229.6	363.1	291.1	188.8	260.3	277.8	173.6

Because of the error in distance and speed measurements caused by faulty instrumentation during the testing in Bangkok as discussed earlier, we adjusted the total average daily taxi travel from 173.6 miles to 150 miles (down by approximately 15 %), 80 miles in the first and 70 miles in the second shift.

To develop specific driving schedules to be used in the computer simulation program, two representative taxi drive cycle test data were selected for detailed analysis as follows.

Shift No.1.: Tuesday - 9/13, 2200-0600 - File No. TUT01.DAT
Shift No.2.: Tuesday - 9/13, 1800-2200 - File No. TUT04.DAT

The speed versus time was plotted for these two representative files so that the acceleration, cruise speed, deceleration and dwell time can be determined for each "stop-and-go" segment as illustrated in Figure 1 given as an example. The resulting route data files generated for the HYBRID computer simulation program are shown in Table 3 and Table 4 for Shift No.1 and Shift No.2, respectively. The distance and velocity data in these tables have been reduced by 11.7 % for Shift 1 and 15.7 % for Shift 2 to yield an overall reduction of about 15 % for the combined Shifts 1 and 2 as described in the preceding paragraph.

The above driving cycles are also considered representative for use in determining total emissions generated by the LPG and gasoline powered Tuk-Tuks during typical Shift 1 and 2 operations.

FIGURE 1 - Typical Speed vs. Time Plot for Taxi Operation

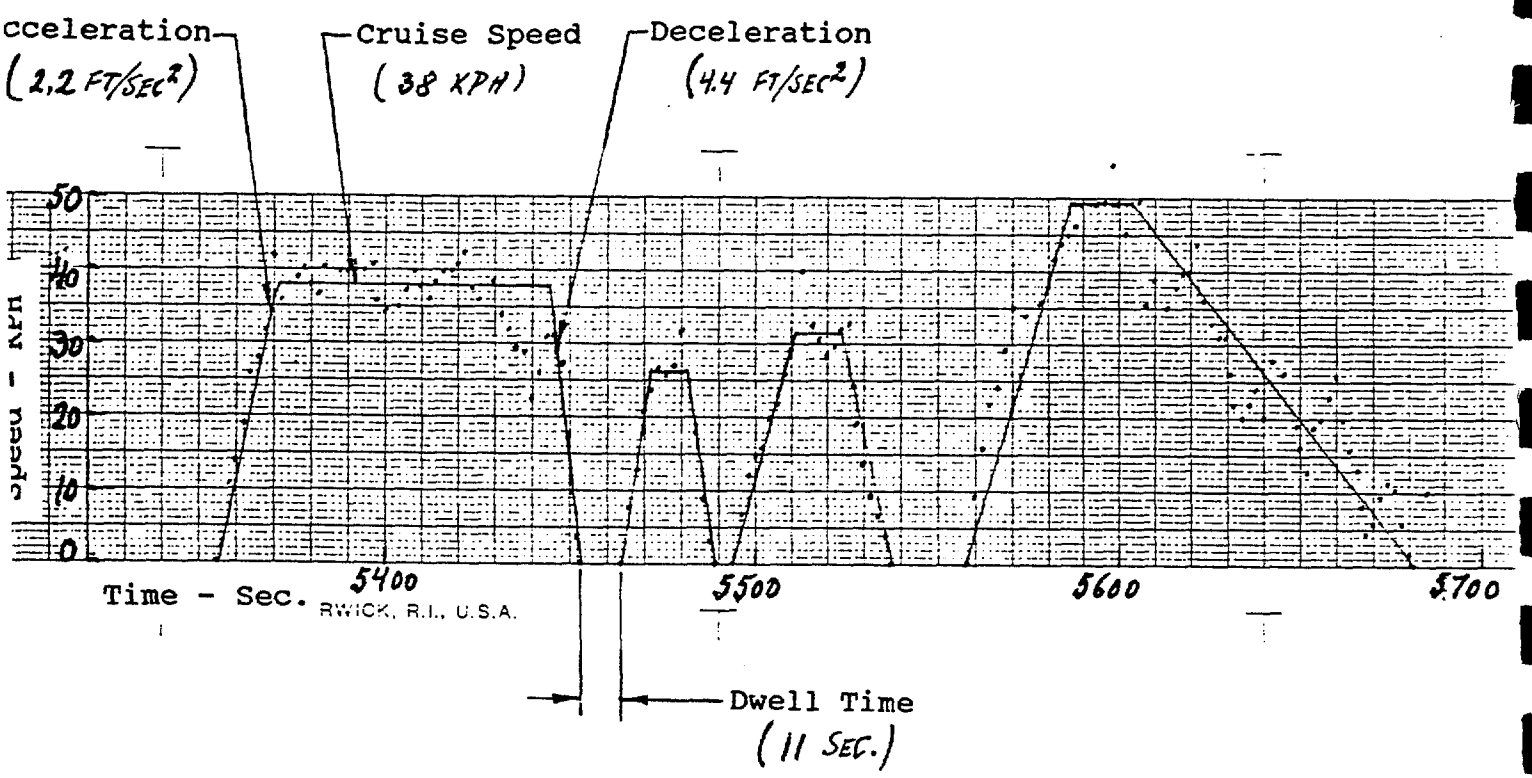

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TABLE 3 – TUK-TUK TAXI DRIVE CYCLE - SHIFT 1 (TAXI-SH1.RTE)

1	TUK-TUK TAXI-Shift No.1;2200-1000	Dist Feet	Elev Feet	Speed MPH	Acl Ft/Sec2	Dcl Ft/Sec2	Dwel Sec
Zero ground level		0	140	0	1.0	1.0	0
CBD #01	Start of Night Run - 2200-0600	377	140	8	1.0	2.0	1044
CBD #02		6872	140	20	0.6	3.9	11
CBD #03		3565	140	20	2.0	1.1	2
CBD #04		3083	140	21	0.8	4.4	48
CBD #05	Note: Distances have been reduced	8987	140	22	1.6	1.5	20
CBD #06	by approximately 15 % to correct	220	140	10	2.0	3.0	347
CBD #07	for instrumentation errors	4116	140	12	0.8	4.1	5
CBD #08	(80 miles distance in Shift 1)	3339	140	16	2.1	4.6	28
CBD #09		2230	140	20	2.0	1.0	12
CBD #10		3726	140	18	1.1	3.0	12
CBD #11		15442	140	20	1.0	2.0	27
CBD #12		1788	140	22	1.5	4.2	13
CBD #13		12702	140	20	1.4	4.0	43
CBD #14		2509	140	25	1.1	2.5	7840
CBD #15		230	140	15	3.0	3.0	45
CBD #16		8466	140	20	2.5	4.5	64
CBD #17		7134	140	18	2.8	4.2	33
CBD #18		5218	140	18	3.5	4.4	52
CBD #19		6944	140	20	1.2	3.1	27
CBD #20		4418	140	25	3.3	3.5	123
CBD #21		4517	140	18	1.5	4.0	23
CBD #22		866	140	15	1.0	4.0	67
CBD #23		1132	140	18	1.4	4.3	5
CBD #24		8062	140	20	2.5	4.0	21
CBD #25		3756	140	12	1.7	1.2	50
CBD #26		8430	140	18	1.6	4.1	33
CBD #27		8790	140	20	3.0	4.0	26
CBD #28		735	140	10	0.8	2.0	23
CBD #29		1496	140	22	1.4	4.3	66
CBD #30		8954	140	20	1.5	2.5	12
CBD #31		3040	140	20	3.0	3.2	57
CBD #32		4035	140	25	1.6	3.3	37
CBD #33		5419	140	25	1.2	4.5	9
CBD #34		3546	140	26	2.0	4.5	67
CBD #35		4048	140	15	2.0	3.0	9
CBD #36		9328	140	16	1.6	1.1	1444
CBD #37		1601	140	25	1.7	4.0	10
CBD #38		1099	140	25	1.6	4.1	61
CBD #39		6632	140	22	1.5	3.1	3
CBD #40		1171	140	25	2.5	4.0	80
CBD #41		4290	140	20	2.4	1.0	4
CBD #42		459	140	17	2.1	2.5	7
CBD #43		6176	140	20	1.2	0.7	23
CBD #44		3316	140	17	2.5	3.0	4
CBD #45		3395	140	23	1.6	4.3	81
CBD #46	End of Night Run	377	140	12	2.0	3.0	5400
CBD #47	Beginning of Morning Run - 0600-1000	6895	140	20	4.0	3.0	3
CBD #48		14173	140	16	2.2	3.8	33
CBD #49		8502	140	18	2.1	4.0	34
CBD #50		5064	140	20	1.7	3.5	19
CBD #51		994	140	18	2.0	1.3	29
CBD #52		6298	140	21	1.9	3.0	3
CBD #53		11080	140	12	3.5	2.0	3
CBD #54		223	140	15	3.5	3.0	19
CBD #55		148	140	12	3.8	4.0	6
CBD #56		5034	140	12	2.5	3.5	42
CBD #57		4388	140	20	1.5	3.0	5
CBD #58	5	335	140	19	2.0	4.0	25

TABLE 3 - CONT.

CBD #59	761	140	15	2.5	2.0	7
CBD #60	3860	140	18	2.8	1.5	4
CBD #61	361	140	18	2.0	4.0	2
CBD #62	236	140	7	1.7	0.8	37
CBD #63	2427	140	12	3.5	1.8	49
CBD #64	7186	140	14	2.6	1.8	399
CBD #65	2768	140	15	1.7	2.0	18
CBD #66	5409	140	18	1.9	4.0	21
CBD #67	92	140	7	3.0	2.5	6
CBD #68	203	140	7	2.5	0.7	33
CBD #69	2627	140	12	1.8	4.0	10
CBD #70	5763	140	12	1.0	2.0	6
CBD #71	269	140	12	3.8	3.5	18
CBD #72	197	140	11	2.0	3.0	40
CBD #73	1345	140	10	2.0	3.0	4
CBD #74	4641	140	15	3.8	2.0	4
CBD #75	1856	140	22	1.3	3.7	8
CBD #76	2270	140	11	1.2	3.8	8
CBD #77	1499	140	18	2.5	3.2	19
CBD #78	174	140	5	2.0	1.0	2
CBD #79	682	140	20	2.0	3.8	25
CBD #80	3565	140	23	2.0	3.2	52
CBD #81	3595	140	20	1.5	1.5	32
CBD #82	2398	140	16	1.8	4.0	36
CBD #83	4353	140	18	0.9	2.0	1
CBD #84	10600	140	13	1.9	3.0	23
CBD #85	1804	140	18	3.0	3.0	10
CBD #86	1095	140	18	2.5	3.0	51
CBD #87	1312	140	15	3.0	2.5	9
CBD #88	289	140	11	2.7	3.2	13
CBD #89	1000	140	26	1.6	4.0	20
CBD #90	508	140	8	1.9	4.1	16
CBD #91	427	140	14	1.6	1.8	5
CBD #92	935	140	14	2.0	4.0	60
CBD #93	3588	140	20	1.5	2.2	19
CBD #94	381	140	13	2.0	2.0	58
CBD #95	2073	140	20	1.6	2.6	9
CBD #96	5173	140	21	3.0	3.6	30
CBD #97	3690	140	15	2.0	1.8	25
CBD #98	1722	140	12	3.8	0.6	1605
CBD #99	4454	140	18	2.0	2.5	20
CBD#100	2195	140	11	3.0	3.0	46
CBD#101	1073	140	10	2.0	0.8	12
CBD#102	18804	140	20	3.6	4.0	3
CBD#103	932	140	20	2.0	4.0	1
CBD#104	1318	140	20	2.0	3.0	40
CBD#105	285	140	6	1.0	1.0	160
CBD#106	3149	140	18	2.0	1.0	9
CBD#107	433	140	9	2.2	0.9	10
CBD#108	469	140	12	2.5	0.5	2
CBD#109	4333	140	12	1.0	4.0	140
CBD#110	2886	140	23	2.2	2.2	2
CBD#111	705	140	10	2.2	3.0	44
CBD#112	6485	140	20	1.4	0.8	2
CBD #113	1371	140	22	2.2	3.5	7
CBD#114	2060	140	20	3.0	2.5	78
CBD#115	7505	140	20	2.8	3.0	2
CBD#116	121	140	10	3.0	1.5	32
CBD#117	1176	140	24	3.5	4.0	10

Note: Start and end times of runs are nominal times

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TABLE 4 —TUK-TUK TAXI DRIVE CYCLE - SHIFT 2 (TAXI-SH2.RTE)

1 TUK-TUK TAXI-Shift No.2; 1000-2200	Dist Feet	Elev Feet	Speed MPH	Acl Ft/Sec2	Dcl Ft/Sec2	Dwel Sec
Zero ground level	0	140	0	1.0	1.0	0
CF #01 Start of Day Run	220	140	10	2.0	3.0	347
Cb #02	4116	140	12	0.8	4.1	5
CBD #03	3339	140	16	2.1	4.6	28
CBD #04	2230	140	20	2.0	1.0	12
CBD #05	3726	140	18	1.1	3.0	12
CBD #06	15442	140	20	1.0	2.0	27
CBD #07	1788	140	22	1.5	4.2	13
CBD #08	12660	140	20	1.4	4.0	43
CBD #09	2509	140	25	1.1	2.5	6730
CBD #10	230	140	15	3.0	3.0	45
CBD #11	8466	140	20	2.5	4.5	64
CBD #12	7134	140	18	2.8	4.2	33
CBD #13	5218	140	18	3.5	4.4	52
CBD #14	6944	140	20	1.2	3.1	27
CBD #15	4418	140	25	3.3	3.5	123
CBD #16	4517	140	18	1.5	4.0	23
CBD #17	866	140	15	1.0	4.0	67
CBD #18	1132	140	18	1.4	4.3	5
CBD #19	8062	140	20	2.5	4.0	21
CBD #20	3756	140	12	1.7	1.2	50
CBD #21	8430	140	18	1.6	4.1	33
CBD #22	8790	140	20	3.0	4.0	26
CBD #23	735	140	10	0.8	2.0	23
CBD #24	1496	140	22	1.4	4.3	66
CBD #25	8954	140	20	1.5	2.5	12
CF #26	3040	140	20	3.0	3.2	57
C #27	4035	140	25	1.6	3.3	37
CBD #28	5419	140	25	1.2	4.5	9
CBD #29	3546	140	26	2.0	4.5	67
CBD #30	4048	140	15	2.0	3.0	9
CBD #31	9328	140	16	1.6	1.1	1444
CBD #32	1601	140	25	1.7	4.0	10
CBD #33	1099	140	25	1.6	4.1	61
CBD #34	6632	140	22	1.5	3.1	3
CBD #35	1171	140	25	2.5	4.0	80
CBD #36	4290	140	20	2.4	1.0	4
CBD #37	459	140	17	2.1	2.5	7
CBD #38	6176	140	20	1.2	0.7	23
CBD #39	3316	140	17	2.5	3.0	4
CBD #40	3395	140	23	1.6	4.3	81
CBD #41	377	140	12	2.0	3.0	60
CBD #42	697	140	11	2.2	3.0	45
CBD #43	721	140	12	3.8	0.8	2
CBD #44	902	140	15	2.3	4.0	38
CBD #45	1844	140	20	3.5	3.5	80
CBD #46	1755	140	15	1.8	2.0	15
CBD #47	1624	140	10	0.8	2.2	16
CBD #48	216	140	15	3.5	2.0	82
CBD #49	2109	140	30	1.0	3.5	32
CBD #50	2444	140	20	1.4	1.0	1140
CBD #51	4280	140	20	2.0	3.5	3
C #52	6527	140	18	1.0	1.4	4
CBD #53	8561	140	19	1.4	3.0	690
CBD #54	377	140	8	1.0	2.0	1044
CBD #55	6872	140	20	0.6	3.9	11
CBD #56	3565	140	20	2.0	1.1	2
CBD #57	3083	140	21	0.8	4.4	48
CBD #58	8987	140	22	1.6	1.5	20

Note: Distances have been reduced by approximately 15 % to correct for instrumentation errors (70 miles distance in Shift 2)

TABLE 4 - CONT.

CBD #59 End of Day Run - 1000-1800	6484	140	20	2.5	3.5	3706
CBD #60 Start of Evening Run - 1800-2200	685	140	15	2.1	3.0	3
CBD #61	1852	140	14	3.0	2.2	71
CBD #62	4775	140	15	3.5	2.5	8
CBD #63	1848	140	25	1.4	3.5	6
CBD #64	3610	140	20	2.0	2.2	44
CBD #65	62	140	3	0.5	1.0	7
CBD #66	1902	140	27	2.1	4.0	10
CBD #67	958	140	25	3.0	3.5	76
CBD #68	2152	140	26	2.0	2.0	61
CBD #69	1215	140	15	2.2	2.2	37
CBD #70	1539	140	13	2.8	3.0	2
CBD #71	45	140	3	2.2	2.0	3211
CBD #72	220	140	4	3.0	0.5	253
CBD #73	1200	140	15	2.0	4.0	74
CBD #74	4590	140	20	1.5	4.0	67
CBD #75	2918	140	22	2.1	2.5	11
CBD #76	425	140	15	3.3	3.0	4
CBD #77	835	140	20	2.0	2.5	20
CBD #78	3995	140	20	3.0	0.8	40
CBD #79	789	140	9	3.0	0.9	36
CBD #80	6993	140	21	0.8	3.5	66
CBD #81	2410	140	20	2.0	1.6	86
CBD #82	183	140	7	0.5	0.4	37
CBD #83	90	140	5	1.8	1.0	24
CBD #84	264	140	8	2.0	0.7	69
CBD #85	816	140	12	2.0	2.0	8
CBD #86	2731	140	20	1.0	4.2	30
CBD #87	682	140	16	2.0	3.0	2
CBD #88	5590	140	16	3.0	0.9	32
CBD #89	3553	140	15	2.0	3.8	23
CBD #90	1084	140	20	2.2	2.3	53
CBD #91	3777	140	25	1.7	3.0	37
CBD #92	4172	140	30	0.8	3.0	61
CBD #93	915	140	30	2.0	4.0	25
CBD #94	300	140	15	3.0	2.6	63
CBD #95	1983	140	10	3.3	3.5	6
CBD #96	508	140	8	1.0	1.9	3
CBD #97	288	140	8	1.2	1.5	2
CBD #98	1322	140	12	1.5	1.5	2
CBD #99	4997	140	20	0.8	3.8	25
CBD#100	1381	140	25	2.0	4.0	43
CBD#101	2035	140	25	1.5	2.8	15
CBD#102	732	140	13	2.1	0.8	17
CBD#103	441	140	18	1.8	3.5	37
CBD#104	978	140	11	3.8	4.0	9
CBD#105	4762	140	20	3.0	3.2	90
CBD#106	10813	140	22	1.3	1.0	31
CBD#107	5139	140	18	3.0	3.5	60
CBD#108	2305	140	22	3.8	3.0	42
CBD#109	6665	140	23	1.2	3.0	4
CBD#110	2509	140	20	1.8	1.4	343
CBD#111	9086	140	20	2.8	0.8	0

Note: Start and end times of runs are nominal times

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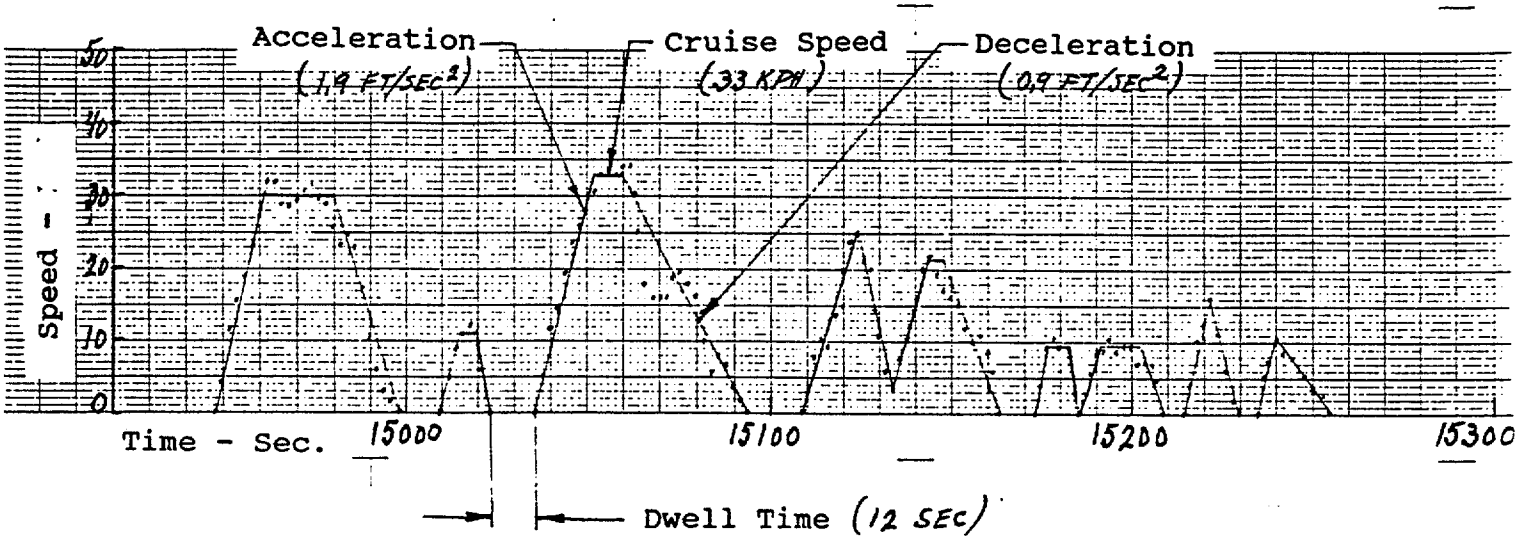
A2.2 Cargo Van Driving Cycle

The development of the driving cycle for Tuk-Tuk cargo vans was the same as for the taxis described previously. Testing indicates that cargo vehicles are operating in one shift only. The drive test cycle selected as representative for cargo vans was

File No. CUM01.dat; Monday - 9/12

The speed versus time was again plotted for this file and the acceleration, cruise speed, deceleration and dwell time were determined as illustrated in the example given in Figure 2. The route data file generated for the Tuk-Tuk cargo van is shown in Table 5.

FIGURE 2 - Typical Speed vs. Time Plot for Cargo Van Operation



A2.3 Driving Cycle Characteristics

The characteristics of the driving cycles developed for taxis and cargo vans as representative for operation in the city of Bangkok are summarized in Table 6. The EPA/SAE Urban Driving Schedule (UDS) is also shown in the table for comparison. Comparing the taxi and cargo driving cycles, it can be seen that the cargo van travels less distance at lower speeds and stops more frequently than the taxi. It is also evident from Table 6 that EPA/SAE drive schedule is more severe in terms of speed, acceleration and the frequency of stops than the Bangkok urban driving cycle.

TABLE 5 — TUK-TUK CARGO VAN DRIVE CYCLE (CARGOSH1.RTE)

1 TUK-TUK CARGO VAN ROUTE

Zero ground level

	Dist Feet	Elev Feet	Speed MPH	Acl Ft/Sec2	Dcl Ft/Sec2	Dwel Sec
CI #01	0	140	0	1.0	1.0	0
CBD #02	266	140	4	1.3	4.0	11
CBD #03	535	140	10	3.0	1.8	40
CBD #04	335	140	8	0.8	1.3	3
CBD #05	51	140	3	3.0	0.7	120
CBD #06	9020	140	18	2.7	4.0	7
CBD #07	258	140	5	4.0	4.0	5
CBD #08	348	140	6	1.2	2.0	6920
CBD #09	4878	140	12	2.6	2.8	4
CBD #10	38	140	2	1.5	3.0	815
CBD #11	64	140	3	2.1	2.0	4988
CBD #12	730	140	10	2.0	2.6	33
CBD #13	1102	140	10	0.7	0.8	5
CBD #14	3432	140	20	1.8	2.4	27
CBD #15	332	140	6	4.0	1.8	38
CBD #16	1122	140	10	3.6	1.4	11
CBD #17	43	140	4	2.0	4.0	54
CBD #18	63	140	4	3.0	3.0	18
CBD #19	112	140	8	4.0	3.0	40
CBD #20	236	140	4	1.5	2.0	10
CBD #21	250	140	5	2.0	4.0	8
CBD #22	43	140	4	3.0	2.0	12
CBD #23	477	140	10	1.8	1.0	72
CBD #24	828	140	12	2.5	3.0	80
CBD #25	936	140	13	3.6	2.0	10
CI #26	88	140	7	3.0	4.5	14
CBD #27	960	140	13	4.0	2.0	16
CBD #28	662	140	10	3.0	2.4	11
CBD #29	240	140	6	3.0	2.3	16
CBD #30	112	140	5	4.0	2.6	6
CBD #31	112	140	5	4.0	2.0	102
CBD #32	200	140	6	1.5	1.4	116
CBD #33	73	140	4	3.0	3.0	5
CBD #34	1177	140	10	3.5	3.0	25
CBD #35	242	140	5	0.5	2.0	7
CBD #36	795	140	12	1.6	2.1	42
CBD #37	792	140	10	1.3	1.7	516
CBD #38	120	140	4	0.5	3.0	4
CBD #39	232	140	7	2.0	2.2	132
CBD #40	148	140	7	0.8	2.5	81
CBD #41	401	140	6	2.5	3.0	66
CBD #42	144	140	4	3.0	1.2	4
CBD #43	12167	140	18	1.0	1.5	4
CBD #44	2640	140	12	3.0	4.0	87
CBD #45	1197	140	10	2.6	4.0	23
CBD #46	5919	140	13	4.0	3.5	11
CBD #47	323	140	6	3.0	2.0	5810
CBD #48	148	140	3	1.5	2.5	318
CBD #49	5337	140	10	1.6	3.5	4
CBD #50	1320	140	10	4.0	3.5	14
CBD #51	1633	140	12	3.5	3.0	22
C #52	568	140	13	4.0	2.6	60
CBD #53	3140	140	15	2.5	2.5	3
CBD #54	3636	140	20	2.0	4.0	56
CBD #55	3345	140	15	4.0	3.0	84
CBD #56	3648	140	15	3.0	1.8	25
CBD #57	825	140	6	4.0	2.0	202
CBD #58	60	140	4	3.0	3.0	8
	178	140	7	3.0	0.7	349

TABLE 5 - CONT.

CBD #59	2416	140	12	1.0	1.5	63
CBD #60	3679	140	17	3.5	4.5	52
CBD #61	2688	140	18	3.0	4.0	33
CBD #62	287	140	9	4.0	3.0	157
CBD #63	467	140	8	2.6	3.3	7
CBD #64	491	140	9	1.5	1.5	5
CBD #65	931	140	10	2.0	3.0	4
CBD #66	1299	140	22	2.2	4.0	6
CBD #67	119	140	8	4.0	4.0	93
CBD #68	2450	140	23	2.5	3.3	25
CBD #69	2967	140	25	1.6	4.0	23
CBD #70	12325	140	22	2.4	1.0	4
CBD #71	132	140	3	3.0	0.3	66
CBD #72	52	140	4	3.0	3.0	12
CBD #73	115	140	4	1.0	2.0	77
CBD #74	187	140	3	3.0	1.0	60
CBD #75	96	140	6	3.0	2.5	11
CBD #76	65	140	4	2.5	2.5	13
CBD #77	323	140	7	3.0	3.5	3
CBD #78	2379	140	16	4.0	2.0	32
CBD #79	2907	140	23	2.0	0.7	2460

TABLE 6

DRIVING CYCLE CHARACTERISTICS

CARACTERISTICS	TAXI SHIFT 1	TAXI SHIFT 2	CARGO SHIFT 1	EPA/SAE J1634
Total Distance, Mi	80.0	70.0	21.7	7.45
Total Time, Hrs	10.8	10.3	8.6	0.38
Dwell Time, Hrs	5.8	6.2	6.9	0.07
Average Speed, MPH	7.4	6.8	2.5	19.60
Avg Running Speed,MPH	16.0	17.0	12.8	24.00
Number of Stops	117	111	79	22
Stops per Mile	1.5	1.6	3.6	2.95

Note: Distances and velocities for the Taxi data in Table 6 have been reduced by a nominal 15 % of measured values.

A3. Discussion of Driving Cycles for use in Emission Testing

The driving cycles for Taxi Shifts 1 and 2 (Tables 3 and 4) and for the Cargo Van Shift 1 (Table 5) are considered representative of driving cycles for use in both 1) the electric Tuk-Tuk performance simulation and 2) for determining the emissions of the LPG and gasoline fueled vehicles. It is neither practical nor cost effective, however, to test the vehicles on a dynamometer for the periods of time (up to 24 hours) in these representative driving schedules and a shorter test period is recommended.

The driving cycles for the Tuk-Tuks, although of a much longer duration, are more benign than that of the EPA/SAE Urban Drive Schedule (UDS). This can be seen in Tables 6 and 9. The shorter UDS of 7.45 miles and 0.38 hours (SAE J1634) is more demanding with its higher velocities and more stops per mile than the Tuk-Tuk driving cycles. However,the UDS can be modified to more accurately describe the Tuk-Tuk operation, by proportionally reducing its cruising speed to those of the Tuk-Tuk driving cycles (by a factor of 0.667 for taxi and 0.533 for the cargo van). The accelerations and decelerations in the UDS are similar to those measured for the Tuk-Tuks and do not require adjustment.

By referring to Table 6, it can be seen that the average running speed of the taxi in Shift 1 (16 MPH) is 0.667 of that of the EPA/SAE (24 MPH). The modified EPA/SAE UDS can then be used for

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Tuk-Tuk emission testing on the dynamometer. To obtain total emissions per shift, the emissions measured on the UDS dynamometer must be multiplied by the ratio of distances travelled. The multiplying factor for Shift 1 is 80/7.45 = 10.7. The multiplying factor for Shift 2 is 70/7.45 = 9.4. For a 24 hour day (Shift 1 and 2), the Tuk-Tuk taxi emissions can be obtained by multifying the emissions measured in the modified EPA/SAE UDS dynamometer tests by a factor of 10.7 + 9.4 = 20.1. The same method can be applied to the cargo van driving cycle where the multiplying factor would be 21.7/7.45 = 2.91.

The standard EPA/SAE Urban Driving Schedule (SAE J1634-unmodified) should also be tested on the dynamometer to determine emissions for comparing the conventionally fueled Tuk-Tuks with other vehicles using this accepted standard.

B. ELECTRIC TUK-TUK PERFORMANCE ANALYSIS

B1. Information Gathering

In order to develop input data files for the electric Tuk-Tuk vehicles, information was gathered regarding the characteristics of the vehicles to be analyzed, the electric propulsion system, the mechanical transmission and the batteries planned to be used. Information was obtained from the original Tuk-Tuk vehicle brochures, reports prepared by Advanced Electric Car Technology, Inc. (AECT) who is responsible for the electric conversion of the vehicles, the electric motor manufacturer (Advanced D.C. Motors, Inc.) and battery manufacturers (Electrosource and Yuasa-Exide, Inc.). Additional information was supplied by ETIP representatives.

Tuk-Tuk Vehicles

The original Tuk-Tuk vehicle is a three-wheeler powered by 350 or 550 cc motorcyle engine and a four speed transmission. A general description of the basic vehicle is provided in Attachment 3.

The performance analysis was performed for five different electric Tuk-Tuk vehicles as follows.

1. Taxi-Daihatsu with Horizon batteries
   Curb Weight: 1600 Lbs (including 700 Lbs of batteries)
   Payload: 500 Lbs (including driver)

2. Taxi-Daihatsu with Yuasa batteries
   Curb Weight: 1800 Lbs (including 900 Lbs of batteries
   Payload: 500 Lbs (including driver)

3. Taxi-Bajaj with Horizon batteries
   Curb Weight: 1400 Lbs (including 700 Lbs of batteries)
   Payload: 500 Lbs (including driver)

4. Taxi-Bajaj with Yuasa batteries
   Curb Weight: 1600 Lbs (including 900 Lbs of batteries)
   Payload: 500 Lbs (including driver)

5. Cargo Van with Yuasa batteries
   Curb Weight: 1800 Lbs (including 900 Lbs of batteries)
   Payload: 750 Lbs (including driver)

The tire size for all electric Tuk-Tuk vehicles is 5.00 x 10. The frontal area is calculated at 22.7 sq.ft. The air drag coefficient is estimated at CD=0.50.

The above vehicle weights are estimates only. Once the prototype vehicles have been fabricated and vehicle weights determined, the performance predictions with computer simulation should be repeated if the weights are significantly different from those used here.

Electric Motor/Controller

The electric motor selected for the Tuk-Tuk's is series wound D.C. motor with a continuous power rating of 16 KW (40 KW intermittent). The maximum motor speed is 6000 FPM and the nominal voltage is 120 Volt. A general description of the motor is included in Attachment 4. The performance characteristics are illustrared in Figure 3 and are based on the 57 bar commutator motor as modified to AECT specifications.

The motor controller is a pulse width modulated chopper using MOSFET and IGBT transistors. The current limit is set at 450 Amps.

Mechanical Drive Line

The original 4-speed transmission is retained for the electric Tuk-Tuk's also. The transmission and axle gear ratios are shown in Table 7 for both the Daihatsu and Bajaj vehicles. The upshift and downshift speeds were selected at 5000 and 4000 motor RPM to optimize electric motor efficiency.

Batteries

Two types of batteries are planned to be used for the electric Tuk-Tuk vehicles; an advanced technology lead-acid battery developed by Electrosource and a conventional sealed lead-acid battery supplied by Yuasa-Exide. Battery characteristics were supplied for both types of batteries as summarized in Table 8.

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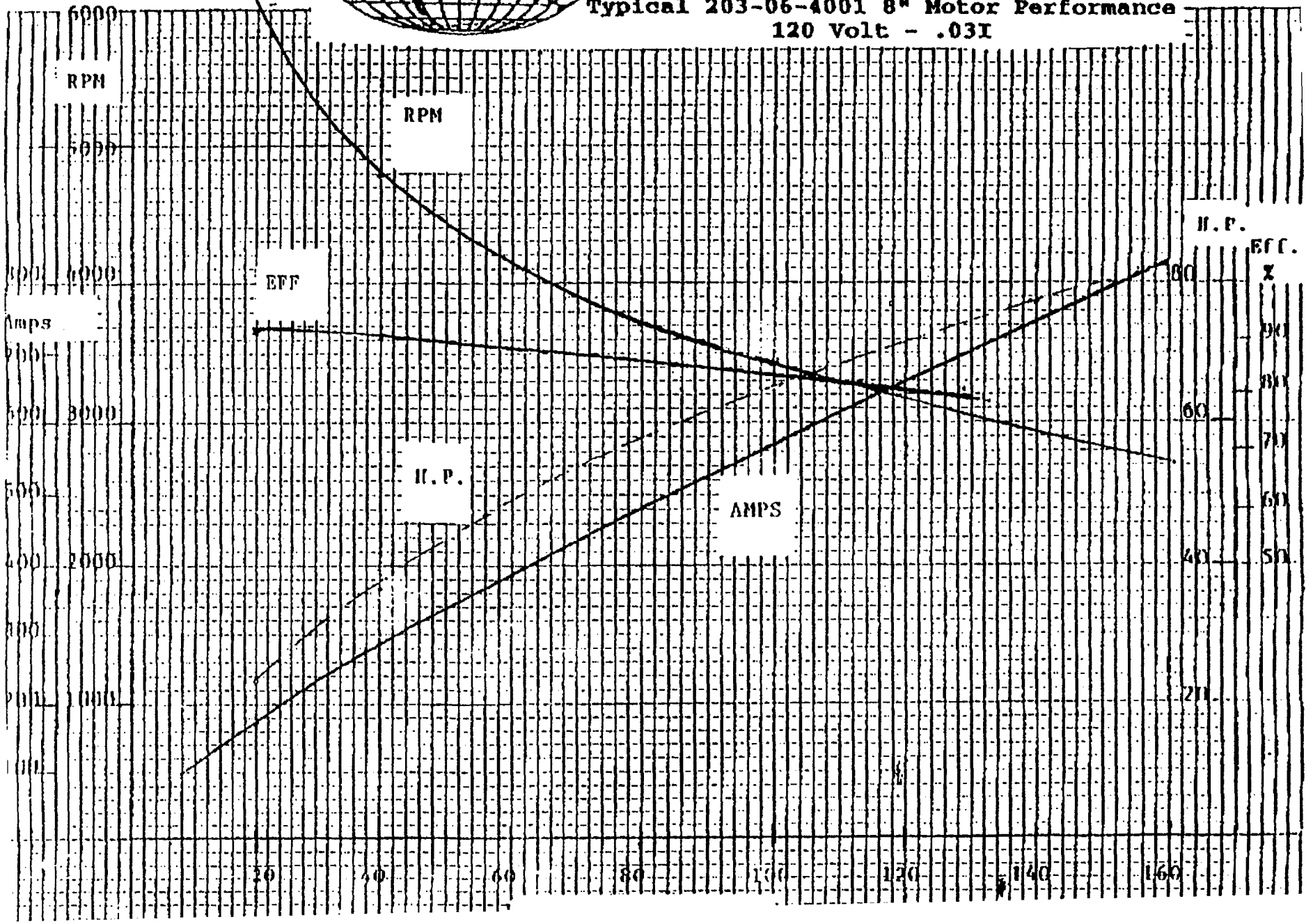
Advanced D.C. Motors, Inc.

Typical 203-06-4001 8" Motor Performance
120 Volt - .03I



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Electric Tuk-Tuk Demonstration Project
Transmission and
Axle Gear
Ratios

	Gear	Input Ratio	Gear Ratio	Axle Gear Ratio	Transmission Gear Ratio
Dihatsu					
	Forward				
	1	1	4.75	6.75	32.06
	2	1	2.94	6.75	19.85
	3	1	2.14	6.75	14.45
	4	1	1.41	6.75	9.52
	Reverse	1	4.75	4.45	21.14
Bajaj					
	Forward				
	1	3.05	4.75	1.74	25.21
	2	3.05	2.94	1.74	15.60
	3	3.05	2.14	1.74	11.36
	4	3.05	1.41	1.74	7.48
	Reverse	3.05	4.75	3.95	57.23

Transmission Gear Ratio = Input Ratio X Gear Ratio X Axle Gear Ratio

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TABLE 8

ELECTRIC TUK-TUK BATTERY CHARACTERISTICS

CHARACTERISTICS	HORIZON	YUASA
Battery Model	12N95	NPG18-12
Nominal Module Voltage	12	12
Number of Modules Used	10	60*
Nominal Capacity, AH @ C/5	95	87
Battery Weight, Lbs	605	822
Specific Energy, WH/LB	18.8	12.7
Cycle Life Expectancy		
@ 80 % DOD	600	250
@ 60 % DOD	900	350
@ 40 % DOD	1200	600

* 6 modules parallel, 10 modules in series connetion

The battery cycle life expectancy in the above table represents the estimated number of cycles to which the batteries can be subjected to if they are drawn down consistently to the Depth of Discharge (DOD) shown in the table.

B2. Development of Input Data Files

Using the information on the electric Tuk-Tuk vehicles and their components described previously, input data files were developed in the proper format for the HYBRID computer simulation program. For further details concerning the omputer simulation program, refer to the manual "HYBRID 30, Computer Simulation Program for a Fuel Cell/Battery Powered Vehicle", September 1992.

The HYBRID computer simulation program requires five input data files as follows.

- o Vehicle Configuration
- o Electric Drive Motor/Controller
- o Battery Power Source
- o Fuel Cell Power Source
- o Route (Driving Cycle)

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B2.1 Vehicle Configuration

As discussed earlier, five different Tuk-Tuk vehicles were considered. The input data files for these five different configurations are included in Attachment 5 as follows.

- o Taxi-Daihatsu with Horizon Batteries : TAXI-DH.DAT
- o Taxi-Daihatsu with Yuasa Batteries : TAXI-DY.DAT
- o Taxi-Bajaj with Horizon Batteries: TAXI-BH.DAT
- o Taxi-Bajaj with Yuasa Batteries: TAXI-BY.DAT
- o Cargo Van-Bajaj with Yuasa Batteries: CARGO-BY.DAT

B2.2 Electric Motor/Controller

All Tuk-Tuk vehicles used the same motor/controller discribed earlier. The input data file developed for the motor/controller is also included in Attachment 5.

- o 25 KW D.C. Motor with Chopper Controller: MOTDC25.DAT

B2.3 Batteries

Input data files were developed for two types of batteries as follows.

- o Horizon Type 12N95 Battery: HOR12N95.DAT
- o Yuasa-Exide Type NPG18 Battery: YU-NPG18.DAT

The battery input data files are included in Attachment 5.

B2.4 Fuel Cell Power Source

The Tuk-Tuk vehicles are powered by batteries without another power source. Since HYBRID was configured for hybrid electric vehicles using a fuel cell as one of the power sources, we developed a fuel cell input data file with zero power. This input file is also included in Attachment 5 as follows.

- o Fuel Cell with Zero Power Output: PAFC-0NU.DAT

B2.5 Route (Driving Cycle) Input Files

The route input data files developed for Tuk-Tuk vehicle operation were discussed in Section A of this report and are included in Tables 1, 3 ,4 and 5.

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B3. Computer Simulation

B3.1 Computer Simulation Runs

A series of computer simulation runs were made for the various combinations of vehicles, batteries and driving cycles to predict electric Tuk-Tuk performance. Computer simulation runs performed are listed in the following.

1. Taxi-Daihatsu with Horizon Batteries in Shift 1 : TAXIDHS1.RUN
2. Taxi-Daihatsu with Horizon Batteries in Shift 2 : TAXIDHS2.RUN
3. Taxi-Daihatsu with Yuasa Batteries in Shift 1 : TAXIDYS1.RUN
4. TAXI-Daihatsu with Yuasa Batteries in Shift 2 : TAXIDYS2.RUN
5. Taxi-Bajaj with Horizon Batteries in Shift 1 : TAXIBHS1.RUN
6. Taxi-Bajaj with Horizon Batteries in Shift 2 : TAXIBHS2.RUN
7. Taxi-Bajaj with Yuasa Batteries in Shift 1 : TAXIBYS1.RUN
8. Taxi-Bajaj with Yuasa Batteries in Shift 2 : TAXIBYS2.RUN
9. Cargo Van with Yuasa Batteries in Cargo Shift 1 : CARGOYS1.RUN

In addition to the simulation runs for Bangkok urban drive cycles listed above, computer runs were also made for the EPA/SAE Urban Driving Schedule (UDS) and for a test cycle to establish Tuk-Tuk vehicle performance limits.

10. Taxi-Daihatsu with Horizon Batteries/SAE Cycle : TAXIDH-J.RUN
11. Taxi-Daihatsu with Horizon Batteries/Test Cycle : TAXIDH-T.RUN

Computer runs for all the above listed simulations are included in Attachment 6 containing the input data file summaries, simulation runs for the first few segments of operation and a summary for the complete driving cycle. The summary includes the total distance, total time, dwell time, battery energy output, battery State of Charge at the end of cycle, etc.

B3.2 Evaluation of the Computer Simulation Runs

The results of the computer simulation runs are summarized in Table 9 for Tuk-Tuk vehicles with Horizon batteries and in Table 10 for Tuk-Tuk's with Yuasa batteries.

TABLE 9.- SUMMARY OF COMPUTER SIMULATION
TUK-TUK TAXI WITH HORIZON BATTERIES

CHARACTERISTICS	TAXI-DAIHATSU		TAXI-BAJAJ		TAXI-DAIHATSU
	Shift1	Shift2	Shift1	Shift2	SAE J1634-UDS
Total Distance, Mi	80.0	70.0	80.0	70.0	7.47
Total Time, Hrs	10.8	10.3	10.8	10.3	0.38
Operating Time, Hrs	5.0	4.1	5.0	4.1	0.31
Average Speed, MPH	7.4	6.8	7.4	6.8	19.65
Avg Battery Current,A	15.9	17.7	15.0	16.7	41.70
Energy Cons., WH/Mi	124	129	117	122	215
Battery State at End					
State of Charge, %	18	25	22	29	86
Depth of Discharge,%	82	75	78	71	14

TABLE 10.-SUMMARY OF COMPUTER SIMULATION
TUK-TUK VEHICLES WITH YUASA BATTERIES

CHARACTERISTICS	TAXI-DAIHATSU		TAXI - BAJAJ		CARGO VAN
	Shift1	Shift2	Shift1	Shift2	Shift1
Total Distance, Mi	80.0	70.0	80.0	70.0	21.7
Total Time, Hrs	10.8	10.3	10.8	10.3	8.6
Operating Time, Hrs	5.0	4.1	5.0	4.1	1.7
Average Speed, MPH	7.4	6.8	7.4	6.8	2.5
Avg Battery Current,A	17.0	19.0	16.1	17.9	15.2
Energy Cons., WH/Mi	129	135	122	128	149
Battery Status at End					
State of Charge, %	5	13	10	18	72
Depth of Discharge,%	95	87	90	82	28

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The summary of the computer simulation runs with Horizon batteries (Table 9) shows that both types of Tuk-Tuk taxis can complete one shift (12 hours) of operation on a single battery charge, implying that only one battery exchange is required during a 24 hour cycle. The battery of the heavier Daihatsu taxi is depleted to a depth of discharge (DOD) of 82 % which is only slightly exceeds the recommended maximum DOD of 80 % for this type of batteries. Anticipated ranges for the Bajaj and Daihatsu taxi versions at a DOD of 80 % are 82 and 78 miles, respectively.

It can also be seen from Table 9 that the drive cycles for the Tuk-Tuk taxis operating in the urban area of Bangkok are more benign than the EPA/SAE standard Urban Driving Schedule (UDS).

The simulation runs for the Tuk-Tuk taxis with Yuasa batteries (Table 10) indicate that none of the taxis can complete one 12 hour shift within safe limits of DOD allowed for this type of batteries. This implies that two battery pack exchanges would be required during a 24 hour driving cycle.

The cargo van with Yuasa batteries can easily complete a daily driving cycle on a single battery charge as can be seen in Table 10. The DOD is only 28 % at the end of the day assuring long cycle life for these type of batteries.

The vehicle range as a function of battery depth of discharge (DOD) is illustrated in Figure 4 for the Tuk-Tuk taxis with Horizon batteries. It can be seen that the vehicle range is almost a linear function of battery DOD; this is due to the excellent performance of the Horizon battery as reported with their Peukert curve (capacity is unaffected by the discharge current down to 80 % DOD). The number of life cycles obtainable at various DOD levels are also indicated on the graph.

The vehicle range for the Tuk-Tuk vehicles with Yuasa batteries is illustrated in Figure 5 as a function of DOD. The significantly lower range obtainable with these type of batteries is evident from the graph. The acceptable DOD limitation on the Yuasa batteries is uncertain and may be only a DOD of 70 %. The range of the various vehicles using the Yuasa batteries are listed below for various levels of DOD.

VEHICLE RANGE IN MILES

Vehicle Type	60 % DOD	70 % DOD	80 % DOD
Taxi-Bajaj/Yuasa Batt.	54	62	69
Taxi-Daihatsu/Yuasa Batt.	51	59	66
Cargo-Bajaj/Yuasa Batt.	46	52	59

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FIGURE 4 - VEHICLE RANGE VS. BATTERY DEPTH OF DISCHARGE
TUK-TUK'S WITH HORIZON BATTRIES

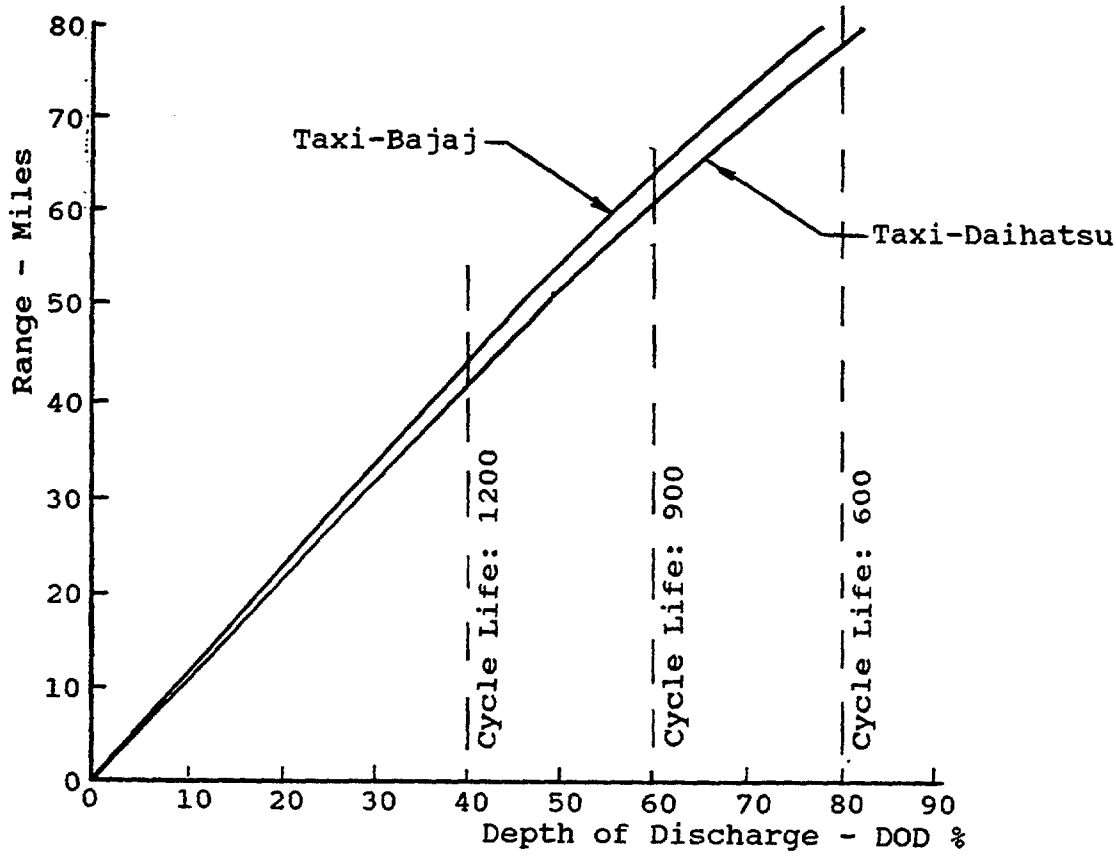
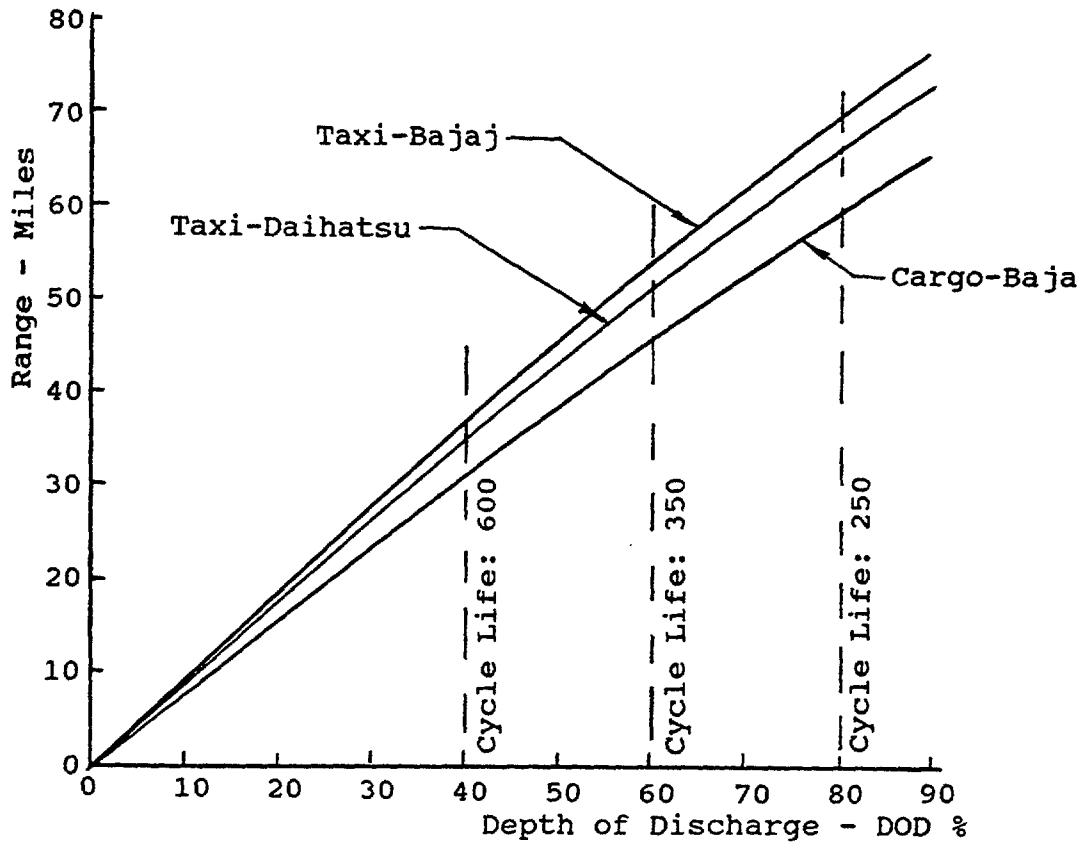


FIGURE 5 - VEHICLE RANGE VS. BATTERY DEPTH OF DISCHARGE
TUK-TUK'S WITH YUASA BATTERIES



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B3.3 Comparison of Predicted Electric Tuk-Tuk Performance with Other Electric Vehicles

The energy consumption of the Tuk-Tuk vehicles as predicted by the computer simulation program was compared to test results for typical electric vehicles developed in the U.S. to verify the validity of the analysis. A comparison of the energy consumption of known electric vehicles developed in the U.S. with the Electric Tuk-Tuk vehicle (Taxi Daihatsu version using Horizon batteries) is made in Table 11 using normalized values (WH/Mile per 1000 Lb GVW) indicating a very good correlation.

A summary of electric vehicle specificatons compiled by Southern California Edison Company is included in Table 12.

A special computer simulation run was made for the Tuk-Tuk taxi over the test route established by DOT/FTA for transit buses to establish the capabilities of the electric Tuk-Tuk vehicles. This test route consists of a high speed run on level ground and runs on grades from 2.5 % to 16 %. This test simulation run is included in Attachment 6 as TAXIDH-T.RUN. The results indicate that the electric Tuk-Tuk taxi has more than adequate power to meet or exceed the DOT/FTA requirements with the exception of the top speed operation of 60 MPH (the speed of the electric Tuk-Tuk is limited to 36 MPH by the maximum allowable motor speed of 6000 RPM).

TABLE 11

ENERGY CONSUMPTION OF ELECTRIC VEHICLES

Vehicle Type	Gross Vehicle Weight - Lb	Battery/GVW Ratio	Energy Consumption	
			WH/Mi	WH/Mi/1000Lb
GM Impact	2910	0.34	190	65
LA 301	3984	0.28	250	63
G - Van	8600	0.29	600	70
Chrysler Van	5930	0.28	480	80
AC Propulsion	2920	0.38	170	58
Solectria	2448	0.31	170	69
Esoro 301	2203	0.26	140	63
Tuk-Tuk Taxi	2100	0.33	124	59

TABLE 1?

SUMMARY OF ELECTRIC VEHICLE SPECIFICATIONS

	GM Impact Prot.	GM Impact 4#	Clean Air Transport LA. 301	Conceptor G-Van Wagon/Cargo#	Chrysler 1994 Electric Minivan#	AC Propulsion ELX#	Solectria Force#	Esoro E301
Seating Capacity	2	2	4	7/2	5	2	2+2	2+2
Curb Weight (lb)	2200	2910	3240	7672/7050	5130	2920	2130	1366
GVWR (lb)	2550	NA	3984	8600/8600	5930	NA	2448	2203
Payload (lb)	350	NA	744	928/1550	800	NA	318	837
Wheel Base (in)	95	99	109	125	112	101	89	NA
Length(in)	163	170	161	202	178	160	146	121
Width (in)	68.2	69	67.3	79	72	67	62	61
Ground Clearance (in)	6.0	NA	6.0	7.0	5.1	4.3	NA	NA
Battery Type	Sealed Lead-Acid	Sealed Lead-Acid	Sealed Lead-Acid	Flooded Lead-Acid	NiCd or NiFe(1)	Sealed Lead Acid	Lead-Acid	Nickel Cadmium
Battery Weight (lb)	870	NA	1100	2500	1680	1120	756	573
Battery Voltage (V)	320	312	156	216	180	336	144	NA
Battery/Curb Weight Ratio	.40	NA	.34	.32/.25	.32	.38	.35	.42
Battery/Gross Weight Ratio	.34	NA	.28	.29/.29	.28	NA	.31	.26
Battery Energy (kWh)	14	17	11	35	40	15.5	10	9
Motor Type	AC (2 units)	AC	DC	DC	DC	AC	AC	AC
Traction Motor Power (HP)	114	137	46	60	70	60 (120 peak)	25	28
Auxiliary Power Unit (kW)	--	--	30	--	--	--	--	--
Power Loading (GVWR/hp)	22	NA	87	143	85	NA	98	79
Range--Battery Alone (miles)	120	70-90	60	60†	80	66†(2)	46**	62-93
Range with APU (miles)	--	--	>150	--	--	--	--	--
DC kWh/mile	.11*	.19	.25	.60	.48	.17	.17	.14
AC kWh/mile	NA	NA	NA	1.1	NA	.30	.23	.16
Top Speed (mph)	75	75	60	53	65	85	60	75
Acceleration 0-30 (sec)	NA	NA	<9.0	12	11.0 (0-40)	4.2	8	7.5
Acceleration 0-60 (sec)	8.0	8.5	NA	NA	53.0	7.8	31***	NA
Max AC Charger Current (A)	50 (400V)	30 (220V)	13 (208V)	50 (208V)	40 (3 ϕ/208V) 20 (1 ϕ/240V)	50 (208V)	20 (110V)	NA
Charging Time (H)	NA	2-3	8	8	7 (3 ϕ) 12 (1 ϕ)	3	5-8	6
Features	Front wheel drive Single ratio trans. On-board charger	Front wheel drive Single ratio trans. Aluminum frame Composite body Inductively coupled charger	Front wheel drive Two speed auto. trans. On-board charger Parallel hybrid	Rear wheel drive Single ratio trans.	Front wheel drive Two speed manual transmission	Cruise control Traction control Battery monitoring system Automatic temperature control of battery pack	Front wheel drive Single ratio transmission On-board chargers	All composite "High Tech" multipurpose neighborhood EV

\# Being tested or to be tested by SCE
* Constant 55 mph
** FUDS
*** 0-50
NA Not Available
-- Not Applicable
† on "Pomona Loop"
††

(1) will be tested with other advanced batteries by SCE
(2) has achieved 106 miles on "Pomona Loop" with improved batteries

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C. SUMMARY AND RECOMMENDATIONS

Summary

The objectives of this study were 1) to establish a driving cycle for dynamometer emissions testing, 2) to evaluate the performance of the electric Tuk-Tuk vehicles and 3) to assist ETIP in their economic analysis of the program. The vehicle performance evaluation was conducted using "HYBRID", a computer simulation program developed for Georgetown University. Hybrid is a PC compatible performance projection model which simulates the effects of various routes and driving cycles on a hybrid-electric or battery-electric vehicle. The model projections have been correlated with actual results of road tests.

The results of the analysis indicate that the performance of the electric Tuk-Tuk's can meet the average performance of the LPG or gasoline powered vehicles in typical urban driving cycles derived from actual testing in Bangkok, Thailand. The electric Tuk-Tuks cannot, however, achieve the maximum ranges in a shift measured for the LPG taxi versions in the Bangkok tests.

The output of the computer simulation program also provided information on the electric energy consumption and the expected range of the various Tuk-Tuk vehicle configurations which can be used as a realistic basis for the economic analysis.

The performance evaluation indicates that the Tuk-Tuk taxis with Horizon batteries can complete one average 12 Hour shift on a single battery charge implying that only one battery exchange is required during a daily 24 hour cycle. Taxis with the Yuasa batteries can not complete even one 12 hour shift within safe limits of battery depth of discharge (DOD). The cargo van version of the Tuk-Tuk can easily complete the daily driving cycle without battery exchange due to the much lower driving distance required.

The test data obtained from actual driving cycle testing in Bangkok proved to be unreliable due to some instrumentation errors. Although adjustments were made to correct for the errors, there remains some uncertainty concerning the validity of the driving cycles used in the analysis.

The standard EPA/SAE Urban Driving Schedule (SAE 1634) can be modified for velocities and distance travelled to adequately describe driving cycles suitable for dynamometer emissions testing of conventional Tuk-Tuks.

Recommendations

1. It is recommended to use the EPA/SAE Urban Driving Schedule,as modified for velocities and distance as discussed in Section A3, for LPG and gasoline powered Tuk-Tuk vehicle dynomometer testing

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to determine the emission levels of the existing Tuk-Tuks. There are numerous laboratories equipped with dynamometer test facilities and set up for emission and fuel consumption tests in accordance with applicable procedures.

2. The results of this study provides energy consumption in terms of DC energy required from the battery. To calculate electric energy consumption in the economic analysis, the charger and battery efficiencies must also be considered. Table 13, developed by Southern California Edison Company can serve as a guideline.
3. Energy consumption of the electric Tuk-Tuk prototype vehicles can be performed on a dynamometer (same facility used for emission testing) in accordance with SAE Test Procedure No. SAE J1634. The EPA/SAE Urban Driving Schedule should be modified to reflect the lower avarage speed of the Tuk-Tuk vehicles as tested in the Bangkok urban area.

4. The prototype electric Tuk-Tuk's to be used for in-situ testing in Bangkok should be properly instrumented and checked out. It is recommended to use a "fifth wheel" for calibration of measurements of distance and speed from the proximity sensor mounted on the wheel. Re-calibration should be made frequently during the test program to ensure accuracy.

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APPENDIX D

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
Bureau for Global Programs, Field Support and Research
Center for Environment
Office of Energy, Environment, and Technology

THAILAND TUK-TUK ELECTRIC VEHICLE DEMONSTRATION PROJECT

PROCEDURES FOR PERFORMANCE TESTING BRAKING, ACCELERATION AND URBAN IN-SERVICE

Final Draft Report

Prepared for:

Royal Thai Government
Ministry of Science, Technology and Environment
Pollution Control Department

DECEMBER 1995

Prepared By:

Energy Technology Innovation Project
Contract No. DHR-5741-C-00-1061-00
Prime Contractor: Bechtel Corporation

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II Vehicle and Motor Data
III Battery Data
IV Instrumentation Checklist

DEFINITIONS/TERMINOLOGY

Battery Ampere-Hour Capacity: The capacity of a battery or battery pack in ampere-hours obtained from a battery/pack discharged at a constant C/3 current rate such that a specified minimum cut-off terminal voltage is reached.

Braking Interval: The distance measured from the start of one brake application to the start of the next brake application.

Cruising Interval: The distance traveled between stops during the braking test.

C/3 Current Rate: The constant current at which the battery can be discharged in three hours.

CTT: Coventional tuk-tuk; internal combustion engine fueled by either LPG or gasoline.

Cut-off Terminal Voltage: The manufacturer-recommended minimum voltage as a function of load after which battery damage could occur.

Depth of Discharge (DOD): The ampere-hours removed from a battery or battery pack expressed as a percentage of the battery/pack capacity.

End Of Test: The point (in time and distance) at which the vehicle has been decelerated to a rest (zero velocity) condition after the appropriate test termination criteria have been met and the key switch is placed in the "off" position.

ETT: Electric-driven tuk-tuk

Initial Brake Temperature: The temperature of the hottest service brake after a minimum 200 meter travel distance and before any brake application.

Initial Speed or Test Speed: The travel speed of the vehicle at the moment the brake is applied.

Loaded Test Weight: The weight of the vehicle as built with production parts with 1) a full complement of batteries installed and 2) recommended capacity of fluids necessary for operation of the vehicle, 3) the weight of the driver and instrumentation, and 4) ballast that simulates a nominally full passenger/cargo load.

LVDT (Linear Voltage Difference Transmitter): A devise used to assess physical characteristics by measuring displacement in an object. In the performance tests, LVDT is used to determine payload by measuring displacement in the shock absorbers of the vehicles.

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Resolution: The smallest unit of a measuring devise (e.g. 1/16" may be the smallest unit available on a yardstick)

Start Of Brake Application: The initial movement of the brake system control pedal and/or lever.

Start Of Test: The point during a test at which the vehicle key switch is first placed in the "on" position, after following applicable manufacture "starting" procedures.

State Of Charge (SOC): The residual capacity in ampere-hours of a battery after a discharge (full or Partial) expressed as a percent of the ampere-hour capacity as defined above. A gauge is installed on each vehicle which indicates the approximate SOC of the battery pack.

Stopping Distance: The distance traveled by a vehicle from the start of the brake application to the point where the vehicle stops.

Unloaded Test Weight: The weight of the vehicle as built with production parts with 1) a full complement of batteries installed, 2) recommended capacity of fluids necessary for operation of the vehicle, and 3) the weight of the driver and instrumentation.

Unloaded Vehicle Weight: The weight of the vehicle as built with production parts with 1) a full complement of batteries installed and 2) recommended capacity of fluids necessary for operation of the vehicle.

SECTION I

INTRODUCTION

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A. BACKGROUND

The Thailand Electric Vehicle Demonstration Project was undertaken to determine the performance characteristics, economics, and environmental benefits of converting the Bangkok Metropolitan Area (BMA) tuk-tuk fleet from petroleum to electric power. Tuk-tuks are three wheeled vehicles used in Asia as taxis and to haul cargo.

The Project includes performance tests based on those previously used for petroleum powered tuk-tuks (fueled by LPG and gasoline) conducted in September 1994, but modified to accommodate the characteristics of electric vehicles. The tests to be conducted are listed below:

Controlled Braking

Controlled Acceleration

Urban In-Service

The results of these tests for the electric tuk-tuks (ETTs) will be compared with the petroleum powered tuk-tuks and the comparison will be published for review.

The petroleum powered tuk-tuk control performance tests are presented in *Energy Technology Innovation Project Report CE-94-TT01*, December, 1994.

A.1 Test Vehicle Descriptions:

1.1 <u>Three</u> electric prototype vehicles will be tested for performance. <u>Two</u> ETTs are configured as passenger taxi vehicles and <u>one</u> as an enclosed cargo van:

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	ELECTRIC TAXI		ELECTRIC CARGO
	TAXI 1	TAXI 2	CARGO 3
Body	Fiberglass	Fiberglass	Fiberglass
Color	Blue	Green	Red
Tires	155R 13	5.00-10	5.00-10
Cold Tire Inflation	32 PSI	32 PSI	32 PSI
Wheelbase	93"	93	93"
Turning Radius	12.0'	12.0'	12.0'
Overall Length	124"	122"	122"
Overall Width	54"	54"	54"
Ground Clearance	6"	5"	5"
Electrical System	96 volt; Approx. 90 amp-hr	120 volt; Approx. 90 amp-hr	120 volt; Approx. 90 amp-hr
Curb Weight	1800 lbs	1700 lbs	1650 lbs
Payload	600 lbs	350 lbs	350 lbs
Batteries	Yuasa; Model NPG18-12	Horizon; Model 12N95	Yuasa; Model NPG18-12
Motor	15 hp, avg Brushed DC	15 hp, avg Brushed DC	35 hp, avg Brushed DC
Frame	Rectangular Steel	Rectangular Steel	Rectangular Steel
Transmission	Dana 1-speed	Dana 1-speed	Daihatsu 1-Speed

1.2 Each vehicle is equipped with an instrumentation package to record and store various vehicle performance parameters for use primarily in the urban in-service testing program.

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A.2 Test Criteria:

2.1 **Personnel:** The following positions shall be identified prior to testing:

Test Engineer	Responsible for overall testing procedure
Instrument Engineer	Responsible for ensuring instrumentation is in proper working order
Designated Test Driver	Must follow direction of Test and Instrumentation Engineers

2.2 **Safety:** Safety concerns shall control all activities; all testing must be discontinued immediately upon instruction from the Test Engineer.

2.3 **Test Speed:** Maximum test speeds will be governed by the handling characteristics of the test vehicle. The test speeds will be limited to the maximum at which the vehicle is completely stable and controllable

B. TEST VEHICLE PREPARATION

B.1 General:

1.1 **Documentation:** Detailed notes shall be taken by the Test Engineer, which include the following information:

1) Driver name and weight for each test;
2) Weather conditions at time of testing;
3) Road conditions (level, length, etc.);
4) Instrumentation checkout, note any problems, see Attachment IV;
5) General Information, including: date, type of test, vehicle identification, battery pack identification, vehicle weight, start and completion time;
6) Any repairs, alterations, or adjustments performed on the vehicle or instrumentation.

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EXAMPLE for BRAKING EFFECTIVENESS TEST

Date: September 15, 1995
Vehicle: Taxi 1, Serial # ETT-001
Battery ID: Horizon, Serial # H001
Test: Braking Effectiveness - Unloaded
Driver: RJ Doe
Weight 185 lbs (based on actual weight of driver)
Test Engineer C Hall
Instrumentation Engineer G Smith
Weather:

Temperature	95 F
Wind	Easterly, 5mph
Road Conditions	Dry, level, sufficent length

Forecasting rain in afternoon
Instruments in working order, calibration current

9:15 AM	Effectiveness Testing -unloaded Trouble with 5th wheel. Ran over glass; need to replace inner tube; checked calibration - ran baseline to ensure accuracy
9:45 AM	Resume Testing, RJ Doe still driver Wind is picking up, will monitor
10:00 AM	Test completed, preliminary data review is satisfactory

1.2 **Vehicle Component Numbering:** Serial numbers shall be given to each battery pack and vehicle/motor to keep track of replacements. Data shall be recorded onto Attachments II and III.

1.3 **Manufacturer's Specifications:** The vehicles shall be inspected and adjusted where necessary to meet manufacturer's specifications.

1.4 **Brakes:** Verify brake adjustments and function, ensuring that brake drag is not excessive.

B.2 Instrumentation:

2.1 The Instrumentation Engineer shall have sole responsibility for ensuring that test instrumentation is in proper working order.

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2.1.1 The Instrumentation Engineer shall record in the notes the status of the Instruments on a daily basis.

2.1.2 An instrumentation check shall be carried out on a periodic basis at the discretion of the Test or Instrumentation Engineer. Use Attachment IV to document calibration activities.

2.2 **Data Storage:** The recorder is a FLUKE Hydra Data Bucket with 21 analog, 8 digital and 1 totalizer channels with 2 megabytes of static RAM storage capability.

2.2.1 Time stamp rate for chosen channels shall be confirmed prior to test.

2.2.2 Instrumentation Engineer shall verify that channels and channel set-up setting necessary for the given test are in proper working order.

2.3 **Electromagnetic Noise Interference:** The instrumentation shall be installed in a manner that will encounter the least amount of electromagnetic noise. Shielded wires should be used.

2.3.1 Instrumentation will be monitored to detect abnormal readings due to electromagnetic noise.

2.4 Equipment must be installed so as not to hinder vehicle operation or alter the operating characteristics of the vehicle.

2.5 **Calibration**

A lightweight, on-board, vehicle instrumentation package is used for data acquisition during vehicle operation. The package contains a digital data recorder, power supplies and sensors. The instrumentation used for each type of data gathering is described below.

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The digital data recorder consists of a Fluke Hydra Data Bucket into which are wired the following inputs:

Channel Number	Input
1	Battery Voltage
2	Motor Voltage
3	Battery Current
4	Motor Current
5	Right Brake Temp.
6	Left Brake Temp.
7	Front Brake Temp.
8	Right Vertical Displacement
9	Left Vertical Displacement
10	Front Wheel Magnetic Pickup (Hz)
11	Front Wheel Speed (kph)
Totalizer	Front Wheel Pulse Counter

In addition to calibrating the above instrumentation, the Fluke data bucket allows the input readings to be modified to better represent what is being measured by means of a "Mx+B" scaling factor. The M represents a multiplier and B represents an offset.

Listed below are the calibration procedures.

Battery Voltage. ±0.023% accuracy. No calibration is required. Input wired from the "cold" side of the key-activated contactor directly into the universal input module, channel 1. Note, channel 1 must be used for the battery voltage. Channel 1 is the only input capable of handling up to 300 volts, all other channels are limited to 150 volt maximum input. During the change cycle, battery voltage may exceed 150 volts.

To confirm the Fluke data bucket, select channel 1 and press the FUNC key to access the SET FUNC (set function) menu. Press the up/down arrow keys until V DC (volts dc) is displayed, then press ENTER key. Next select the measurement scale by pressing the up/down arrow keys until the 300 volts scale is displayed, then press ENTER key.

Motor Voltage. ±0.023% accuracy. No calibration required. Input wired from motor controller directly into the universal input module, channel 2.

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To configure the Fluke data bucket, select channel 2 and press the FUNC key to access the SET FUNC (set function) menu. Press the up/down arrow keys until V DC (volts dc) is displayed, then press ENTER key. Next select the measurement scale by pressing the up/down arrow keys until the 150 volts scale is displayed, then press ENTER key.

Battery Current. LEM-Hal series current transducers. ±1% accuracy. Calibration accomplished by adjusting the gain (left side of plug) and offset (right side of plug) trim-pots located on the sensor. Located near the motor controller and wired directly into the universal input module, channel 3.

To configure the Fluke data bucket, select channel 3 and press the FUNC key to access the SET FUNC (set function) menu. Press the up/down arrow keys until V DC (volts dc) is displayed, then press ENTER key. Next select the measurement scale by pressing the up/down arrow keys until the 30 volts scale is displayed, then press ENTER key. Press the Mx+B key to access the Mx+B menu. Press the up/down arrow and left/right arrow keys to enter a five digit number that defines the numerical value for the measurement multiplier. The column being configured has a bright display. Press the left/right arrow keys to position the decimal point in the number selected. When the decimal point is correct, press the ENTER key. Press the up/down arrow keys to select the desired scale modifier. When the scale modifier is correct, press the ENTER key.

Thermocouples. Omega Thermocouples, type "K." ±2% accuracy. No calibration required. The thermocouples are mounted on the brake pad of each brake and connected directly to the universal input module as analog inputs on channels 5, 6, and 7.

To configure the Fluke data bucket, select channel 5 (right rear), 6 (left rear), or 7 (front) and press the FUNC key to access the SET FUNC (set function) menu. Press the up/down arrow keys until °C (centigrade) is displayed, then press the ENTER key. Then using the up/down arrow keys, select the "K" type thermocouple.

Linear Displacement Transducers. Lucas-Schaevitz model 3000 DC-E. ±0.04% accuracy. Located by each of the rear springs, and wired directly into the universal input module on channels 8 and 9. Calibration is

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accomplished by manually adjusting the vertical core in an empty vehicle until a zero reading is achieved. Then additional readings are recorded for known weights placed in the rear of the vehicle, such as 50 kg, 100 kg, 150 kg..

To configure the Fluke data bucket, select channel 8 or 9 and press the FUNC key to access the SET FUNC (set function) menu. Press the up/down arrow keys until V DC (volts dc) is displayed, then press ENTER key. Next select the measurement scale by pressing the up/down arrow keys until the 30 volts scale is displayed, then press ENTER key. Press the Mx+B key to access the Mx+B menu. Press the up/down arrow and left/right arrow keys to enter a five digit number that defines the numerical value for the measurement multiplier. The column being configured has a bright display. Press the left/right arrow keys to position the decimal point in the number selected. When the decimal point is correct, press the ENTER key. Press the up/down arrow keys to select the desired scale modifier. When the scale modifier is correct, press the ENTER key.

Front Wheel Magnetic Pickup. Effector model 1E2002FROG. ±1% accuracy. The sensor is mounted on the front wheel frame and wired directly into the universal input module, channel 10, the totalizer and into the frequency to voltage converter board. The only calibration required is that the sensing range must not be greater than 2mm.

To configure the Fluke data bucket, select channel 10 and press the FUNC key to access the SET FUNC (set function) menu. Press the up/down arrow keys until Hz (Hertz) is displayed, then press ENTER key. Next select the measurement scale by pressing the up/down arrow keys until the 90 Hz scale is displayed, then press ENTER key. Press the Mx+B key to access the Mx+B menu. Press the up/down arrow and left/right arrow keys to enter a five digit number that defines the numerical value for the measurement multiplier. The column being configured has a bright display. Press the left/right arrow keys to position the decimal point in the number selected. When the decimal point is correct, press the ENTER key. Press the up/down arrow keys to select the desired scale modifier. When the scale modifier is correct, press the ENTER key.

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Front Wheel Speed. Burr-Brown model VFC32KP frequency to voltage converter. The voltage output from the converter board is wired directly into the universal input module, channel 11. Calibration is accomplished by adjusting the offset (R1) and gain (R3) trim-pots mounted on the board. Adjustments should be made against zero speed and known operating speeds such as 35 kph, 50 kph and 65 kph. Signal damping can be accomplished by installing a capacitor across the output.

To configure the Fluke data bucket, select channel 11 and press the FUNC key to access the SET FUNC (set function) menu. Press the up/down arrow keys until V DC (volts dc) is displayed, then press ENTER key. Next select the measurement scale by pressing the up/down arrow keys until the 30 volts scale is displayed, then press ENTER key. Press the Mx+B key to access the Mx+B menu. Press the up/down arrow and left/right arrow keys to enter a five digit number that defines the numerical value for the measurement multiplier. The column being configured has a bright display. Press the left/right arrow keys to position the decimal point in the number selected. When the decimal point is correct, press the ENTER key. Press the up/down arrow keys to select the desired scale modifier. When the scale modifier is correct, press the ENTER key.

Totalizer. The signal from the front wheel magnetic pickup is wired directly into the totalizer channel. No calibration is required.

Saving Calibration Settings. Upon completion of the calibration procedure, the configurations can be saved to a PC memory card. To store the configurations, press the FILES key on the Fluke data bucket to access the FILES menu. Press the up/down arrow keys until SEtUP is displayed, then press the ENTER key. Press the up/down arrow keys until StorE is displayed in the SEtUP menu, then press the Enter key. The menu changes to StorE and a file name is displayed.

B.3 Battery Charging:

Refer to Manufacturer's Operations and Repair Manual.

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SECTION II

CONTROLLED TESTING

A. BACKGROUND

This section pertains to Braking and Acceleration Controlled tests.

B. TEST VEHICLE PREPARATION

B.1 General:

1.1 Refer to Section I.A and B.

1.2 **Tires:** The tires must have at least 75% of the tread remaining and tread must be in good condition; and must have at least 150 km of run-in before test.

1.2.1 The cold tire pressure shall be as specified by the manufacturer for the vehicle test weight and installed tires.

B.2 Batteries:

2.1 **Battery SOC:** Battery packs shall not go below a state of charge (SOC) of 20% as this is detrimental to the batteries.

2.1.1 When a battery pack reaches 20% SOC, the vehicle shall be taken out of service to be recharged, or the discharged battery pack will be replaced with an adequately charged battery pack of the same make and model.

2.1.2 An exception to this rule is when the acceleration test requires an SOC at 20%.

B.3 Test Conditions:

3.1 **Temperature:** Where practical, temperature during vehicle and battery soak periods and during testing should be in the range of 16 to 32 °C (40 to 90 °F).

3.2 **Wind Velocity:** Testing should not be conducted when wind speeds average more than 24 kph (or when peak wind speeds are more than 32 kph).

3.3 **Test Surface:** Testing shall be conducted on a test track with sufficient length for measurement and run-off.

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3.3.1 The roadway (test track) must be dry, clean, smooth, substantially level, and free from loose materials.

3.3.2 The roadway grade shall be no more than a constant 1%.

3.3.3 The road surface should be concrete or rolled asphalt (or equivalent) and in good condition; testing shall not be conducted on slippery roads.

3.3.4 Minimum width of roadway shall be 3.6 meters (a width of 7.2 meters is recommended).

3.3.5 The minimum length of the roadway will be 0.8 km (a length of 1.6 km is recommended).

3.4 **Weather Conditions:** Ambient temperature, wind speed, and atmospheric pressure will be obtained from local weather station and recorded on the appropriate test checksheet.

3.5 **Adverse Weather Conditions:** Controlled testing will not occur during foggy or rainy conditions.

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SECTION II-A

CONTROLLED BRAKING TESTS

A. BACKGROUND

A.1 Braking Tests/Operations to be Conducted: The following table lists the braking tests to be performed:

Sect	Procedure		Initial Brake Temperature		Initial Speed km/hr	Deceleration m/sec²	Test Weight	Test Interval km	No. of Test Stops
			Range Celsius	Monitoring Frequency					
C.2	Burnish Procedure		55-65	each stop	50	≤2.7 (36 m)	Unloaded	1.5	200
C.3	Effectiveness Test		55-65	each stop	50	Maximum	Unloaded	not an issue	6
			55-65	each stop	50	Maximum	Loaded	not an issue	6
C.4	Fade and Recovery	Baseline Stops	55-65	each stop	50	3.0 (32 m)	Loaded	not an issue	3
		Fade Stops	55-65	1st stop only	55-65	3.0-3.6 (42 m)	Loaded	0.8	10
		Recovery Stops	N/A	not an issue	50	3.0 (32 m)	Loaded	not to exceed 1.6.	5
C.5	Re-Burnish		55-65	each stop	50	≤2.7 (36 m)	Unloaded	1.5	35
C.6	Final Effectiveness Test		55-65	each stop	50	Maximum	Unloaded	not an issue	3
			55-65	each stop	50	Maximum	Loaded	not an issue	3
			55-65	each stop	65	Maximum	Unloaded	not an issue	3
			55-65	each stop	65	Maximum	Loaded	not an issue	3
C.7	Water Fade and Recovery	Baseline Stops	55-65	each stop	50	3.0 (32 m)	Loaded	not an issue	3
		Recovery Stops	N/A	not an issue	50	3.0-3.4 (28-32 m)	Loaded	not an issue	6
C.8	Final Inspection		N/A	N/A	N/A	N/A	N/A	N/A	N/A

B. TEST VEHICLE PREPARATION

B.1 General:

1.1 **Brake Condition:** New brake drums, shoes/linings, and brake hardware shall be installed every 500 km traveled.

B.2 Condition of Battery Pack:

2.1 Full charge should be established using battery pack re-charging procedures. Refer to Manufacturer's Operations and Repair Manual.

C. TEST PROCEDURE

C.1 General:

1.1 **Brake Temperature:** Unless otherwise specified, the initial brake temperature should be between 55°C and 65°C (the hottest brake).

1.2 **Speed Tolerance:** The specified test speeds shall be subject to a tolerance of +/- 5 kph.

1.3 **Run/Stopping Procedure:**

1.3.1 Verify initial brake temperature when required.

1.3.2 Attain a speed 6 to 12 kph greater than the target test speed (as indicated by the vehicle speedometer) and decrease speed smoothly to the test speed as the brake application point is reached.

1.3.3 Relax the power pedal, disengage clutch, and apply the brake pedal as the specific test requirement dictates.

1.3.4 Modulate brake forces and maintain brake application until the vehicle has stopped completely.

1.3.5 Keep vehicle in center of roadway.

1.3.6 Stops should be made without wheel lockup.

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1.3.7 **Limit use of brakes between test runs and during brake cool down riding.**

C.2 Burnishing the Brakes:

2.1 Brake burnishing shall be completed prior to beginning of test in accordance with the following instructions:

2.1.1 The hottest brake temperature at beginning of each run shall be between 55°C and 65 °C.

2.1.2 Make 200 stops from 50 kph at 2.7 mpsps deceleration (Approximately 36 meters).

2.1.3 The cruising interval is not an issue.

2.2 After burnishing is completed, adjust brakes in accordance with manufacturer's recommendations.

C.3 Effectiveness Test:

3.1 The hottest brake temperature at beginning of each run shall be between 55 °C and 65 °C.

3.2 Make 6 stops each from 50 kph at Unloaded and Loaded Test Weight.

3.3 The cruising interval is not an issue.

3.4 Stops shall be undertaken at the maximum deceleration rate, safely and without locking the brakes.

C.4 Fade And Recovery Test:

4.1 Perform all tests with Loaded Test Weight.

4.2 Baseline Stops.

4.2.1 The hottest brake temperature at beginning of each run shall be between 55 °C and 65 °C.

4.2.2 Make 3 stops from 50 kph at 3 mpsps for each stop (approximately 32 meters).

4.2.3 The cruising interval is not an issue.

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4.3 **Fade Stops**

4.3.1 Initial hottest brake temperature shall be between 55°C and 65°C prior to 1st stop only.

4.3.2 Make 10 stops from 55-65 kph at a deceleration rate of 3.0 to 3.6 mpsps for each stop (approximately 42 meters).

4.3.3 The cruising interval shall be 800 meters.

4.3.4 Achieve the required deceleration as quickly as possible and maintain at least this rate for not less than three-fourths of the total stopping distance for each stop.

4.3.5 After the last fade stop drive 0.8-1.6 km at 50 kph and immediately conduct the recovery test.

4.4 Recovery Stops

4.4.1 Initial brake temperature is not an issue.

4.4.2 Make 5 stops from 50 kph at a deceleration of 3 mpsps for each stop (approximately 32 meters).

4.4.3 The cruising interval shall not exceed 1.6 km

4.4.4 After each stop accelerate at a maximum rate to 50 kph and maintain that speed until making the next stop.

C.5 Service Brake System - Re-burnish:

5.1 The hottest brake temperature at beginning of each run shall be between 55°C and 65 °C.

5.2 Make 35 stops from 50 kph at a deceleration rate not to exceed 2.7 mpsps (approximately 36 meters).

5.3 The cruising interval is not an issue.

5.4 Accelerate at a maximum rate to 50 kph immediately and maintain that speed until making the next stop.

5.5 Adjust brakes in accordance with manufacturer's recommendations.

C.6 Final Effectiveness Test:

6.1 The hottest brake temperature at beginning of each run shall be between 55 °C and 65 °C.

6.2 Make 3 stops each from 50 kph at Unloaded and Loaded Test Weight.

6.3 Make 3 stops each from 65 kph at Unloaded and Loaded Test Weight.

6.4 The cruising interval is not an issue.

6.5 Stops shall be undertaken at the maximum deceleration rate, safely and without locking the brakes.

C.7 Water Recovery Test:

7.1 Perform all tests with Loaded Test Weight

7.2 Baseline Stops

7.2.1 The hottest brake temperature at beginning of each run shall be between 55 °C and 65 °C.

7.2.2 Make 3 stops from 50 kph at 3 mpsps for each stop (approximately 32 meters).

7.2.3 The cruising interval is not an issue.

7.3 Wet Brake Recovery Stops

7.3.1 Brake temperature is not an issue.

7.3.2 Completely wet each brake assembly of the vehicle with water for 2 minutes with the brake fully released, ensuring that brake pads are thoroughly wet.

7.3.3 Immediately after wetting, accelerate at a maximum rate to 50 kph without a brake application then decelerate at 3 to 3.4 mpsps (28 - 32m).

7.3.4 Repeat the process in 7.3.3 until 5 start/stops have been completed.

7.3.5 The cruising interval shall be 100 meters

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C.8 Final Inspection:

8.1 Upon completion of all the tests, the brake system shall be inspected and the results shall become part of the final report.

D. DATA MANIPULATION

D.1 General:

1.1 The application of the brake marks the initial speed.

1.2 **Average deceleration:** Calculate average deceleration using the following equation:

$$a = V^2/2d$$

Where: a = Average deceleration
d = Stopping distance (feet)
V = Velocity

1.3 The following table lists the information that shall be recorded for each test:

Information Recorded	Effectiveness	Fade and Recovery			Final Effectiveness	Water Fade and Recovery	
		Baseline	Fade	Recovery		Baseline	Recovery
Time Stamp	X	X	X	X	X	X	X
Totalizer	X	X	X	X	X	X	X
Battery Pack Voltage and Current (to monitor SOC only)	X	X	X	X	X	X	X
Braking Force	X	X	X	X	X		X
Brake Temperature	X	X	X	N/A	X	N/A	N/A
Stopping Distance	X	X	X	X	X	X	X

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SECTION II.B

CONTROLLED ACCELERATION TESTING

A. BACKGROUND

A.1 Tests To Be Conducted:

Battery SOC	Standing Start		Passing Acceleration	
	Unloaded Test Weight	Loaded Test Weight	Unloaded Test Weight	Loaded Test Weight
100%	X	X	X	X
60%	X	X	X	X
20%	X	X	X	X
Number of Runs/Test	6	6	12	12

1.2 Battery packs for each vehicle are interchangeable, but for the purposes of these tests, the batteries will be used in the following manner:

Vehicle	Battery Type	
	Horizon	Yuasa
TAXI 1		X
TAXI 2	X	
CARGO 3	X	X

B. VEHICLE PREPARATION

B.1 Condition of Battery Pack:

1.1 **Battery Charging:** Full charge is to be established using battery pack re-charging procedures. Refer to Manufacturer's Operating and Repair Manual.

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1.2 **Testing Effects of SOC:** For tests in which the effects of battery initial SOC are to be investigated, tests should be conducted with the battery SOCs at 100%, 60% and 20%.

1.3 **Tests Requiring 100% SOC:** A minimum 8 hour soak period at ambient temperature shall be allotted after completion of charging and before starting tests initiated with a fully charged battery pack.

1.4 **Tests Requiring X% SOC:** Discharge the battery to the required SOC by driving the vehicle at a recommended maximum cruise speed or by discharging the battery through a load at an equivalent constant power.

1.4.1 Tests shall begin no later than 10 minutes after the desired SOC is reached.

1.5 **SOC Tolerances:**

SOC %	Range %
100	90-100
60	55-65
20	15-30

C. TEST PROCEDURE

C.1 **Standing Start Acceleration Test:**

1.1 From a standing start, make 6 runs with an Unloaded Test Weight and 6 runs with a Loaded Test Weight, accelerating at the maximum extent to 65 kph.

2.1.1 Maintain top speed for not less than 0.4 km.

1.2 Repeat each series of unloaded and loaded runs at SOCs of 60% and 20%.

2.2.1 While conducting testing at 20% SOC, complete testing regardless of vehicle performance (whether or not the vehicle can reach 65 kph).

1.3 **Manual Transmission Operating Procedure:** From a standing start, the vehicle should be operated to achieve maximum performance with minimum wheel spin.

1.3.1 Clutch operation, as well as shift point selection, should be optimized for performance without exceeding the maximum specified engine rpm.

1.4 Test data will be analyzed at 0.4 km, 5 sec, 50 kph, and 65 kph (See Data Manipulation). Driver shall maintain top speed until the vehicle passes the 0.4 km marker. It is recommended that cones or markers be set up at 0.4 km to assist the driver.

1.5 Record time stamp, battery voltage, battery current, totalizer.

1.5.1 Totalizer shall be zeroed after each pass (two runs).

C.2 **Wide Open Throttle (WOT) Passing:**

2.1 From a stabilized 40 kph, accelerate at the maximum extent to 65 kph.

2.1.1 Carry out the following series of 24 individual runs at 100% SOC: 12 unloaded TWC and 12 loaded TWC. For each test weight condition 6 runs shall be in one direction, and 6 shall be in the opposite direction.

2.1.2 When difficulty is experienced in one run, the pair is excluded.

2.1.3 Maintain top speed for not less than 0.4 km.

2.2 Repeat each series of unloaded and loaded runs at SOCs of 60% and 20%.

2.2.1 While conducting testing at 20% SOC, complete testing regardless of vehicle performance (whether or not the vehicle can reach 65 kph).

2.3 **Manual Transmission Operating Procedure:**

2.3.1 **Four and 5 speed transmissions:** Begin from a stabilized 40 kph in the top gear less one, accelerate to 65 kph while shifting to the top gear.

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2.3.2 **Three speed transmissions:** Test shall be conducted in third gear only.

2.3.3 **Downshifting:** Downshifting should not occur during testing.

2.4 **State Of Charge (SOC):** Record the SOC at start and end of each test.

2.5 Record time stamp, battery voltage, battery current, totalizer.

2.5.1 Totalizer shall be zeroed after each pass (two runs).

D. DATA MANIPULATION

1.1 **Data Calculation:** Simple averages will be calculated for all valid multiple test observations (pairs of data).

1.2 **Data Presentation:** Data should be presented in summary format, i.e., elapsed times, terminal speeds, and distance covered.

1.2.1 Continuous plots will be charted as follows: speed/time, distance/time, SOC, and other data considered appropriate.

1.2.2 Analyze the data at 5 sec, 50 Kph, 65 Kph, and 0.4 km. Once vehicle has reached top speed, vehicle shall remain at that speed until the 0.4 km marker has been reached.

The following analysis shall be undertaken:

- Average acceleration rate of 5 sec, and to reach 50 and 65 Kph.
- Speed at evaluation points.
- Time to reach evaluation points.

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1.3 The following table lists the information that shall be recorded for each test:

Data Recorded	Standing Start		Wide Open Throttle Passing	
	Unloaded Test Weight @ Specified SOC	Unloaded Test Weight @ Specified SOC	Unloaded Test Weight @ Specified SOC	Unloaded Test Weight @ Specified SOC
Time	X	X	X	X
Battery Pack Voltage	X	X	X	X
Battery Pack Current	X	X	X	X
Totalizer	X	X	X	X
Distance	X	X	X	X

1.4 **Charging Current:** Charging current will be recorded during battery charging only and is not measured during Acceleration tests.

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SECTION III

URBAN IN-SERVICE TESTING

A. BACKGROUND

A.1 Tests To Be Conducted:

1.1 Actual Taxi Service

1.2 Actual Delivery/Cargo Service

A.2 Driver Training:

2.1 Each driver shall receive training from MOSTE prior to urban in-service tests.

A.3 General:

3.1 **Safety:** Safety concerns shall control all activities

3.1.1 No test shall be conducted without the approval of the Test Engineer.

3.1.2 If a problem occurs, discontinue testing and contact the Test or Instrumentation Engineer.

3.2 Battery pack charging operations shall be conducted as stipulated in Section I.B.3.

A.4 Batteries to be Used in Tests for Each Vehicle:

Taxi 1 (Blue ETT): Yuasa

Taxi 2 (Green ETT): Horizon

Cargo 3 (Red ETT): Yuasa

4.1 **USE ONLY THE BATTERY TYPE SPECIFIED FOR EACH VEHICLE**

A.5 Test Conditions:

5.1 There are no weather restrictions.

B. VEHICLE PREPARATION

B.1 General:

1.1 The vehicles shall be inspected and adjusted where necessary to meet manufacturer's specifications, particularly if vehicle is exhibiting abnormal

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performance characteristics during acceleration. Document nature and date of adjustments.

1.1.2 Make adjustments, as necessary, and functional checks in accordance with manufacturer's published procedures.

B.2 Condition of Battery Pack:

2.1 **Battery Charging:** Full charge is to be established using battery pack re-charging procedures. Refer to Manufacturer's Operating and Repair Manual.

B.3 Test Instrumentation:

3.1 **Calibration:** See Section I.B.2

B.4 Shift Preparation Procedure:

4.1 **General, Battery, and Test Preparation Information:** Fill in information requested in **Attachment I:** vehicle ID, date, shift, driver name and weight, battery ID, SOC %, date of last recharge, duration of recharge, energy used for recharge (Kwh), time, odometer reading, physical condition of vehicle, instrument calibration status, tire pressure, weather conditions, temperature, and signature.

4.2 **Electronic Data Collection:** Insert disc into data recorder, verify data recorder is functioning and readouts are appropriate.

4.2.1 Totalizer should be zeroed every three hours of operation.

4.2.2 Fluke memory card (SRAM) is two megabytes. It is recommended that the information be downloaded every eight hours of operation. REFER TO APPENDIX A for more specific information for handling data.

C. TEST PROCEDURE

C.1 General:

1.1 **Test Engineer:** A Test Engineer shall be responsible for ensuring proper vehicle preparation, documentation, and data collection for each shift.

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1.2 **Test Operator:** A trained Test Operator shall report to Test Engineer any mechanical or electrical or other problems effecting testing.

1.3 **BATTERY SOC: THE DRIVER SHALL RETURN TO FLEET HEADQUARTERS WHEN SOC IS 20%**

C.2 Vehicle Operation:

2.1 Test Operator shall perform normal business routine.

C.3 Post Test Activities:

3.1 Download test data.

3.2 Complete checksheet, **Attachment I**: Record time, SOC, odometer, physical condition, and signature.

3.3 Visually check physical condition of vehicle and report any problems to the Test Engineer.

C.4 Recharging Batteries:

4.1 Battery pack shall be removed and visually examined.

4.2 Refer to Manufacturer's Operating and Repair Manual.

D. DATA MANIPULATION

1.1 Data shall be acquired in one second intervals.

1.2 The following table lists the information that shall be recorded for each urban in-service test:

Information Recorded	Test Service	Delivery/Cargo Service
Time	x	x
Distance (Totalizer or Pulse Count)	x	x
Test Weight	x	x
Battery Pack Voltage	x	x
Battery Pack Current	x	x
Right Vertical Displacement	x	x
Left Vertical Displacement	x	x
Motor Current	x	x

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1.3 Data to be recorded when using Stationery Charger System is: time, voltage, and current.

1.4 **Downloading Data for Input to Hybrid Performance Model:**

1.4.1 Make any necessary changes to the input files to reflect alteration of the vehicle or its components.

1.4.2 Develop a drive cycle input file in the correct format, which includes distance, elevation, velocity, acceleration, and deceleration.

1.4.3 Verify that input files reflect initial conditions at beginning of drive cycle.

1.4.4 **REFER TO APPENDIX A for specific recommendations for data recording, storage, and manipulation.**

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REFERENCES

Electric Tuk-Tuk Demonstration Program - Phase 1 Test Report - Baseline Braking and Acceleration Performance and Drive Cycle Testing of Conventional Taxi and Cargo Tuk-Tuk Vehicles, December 1994, Energy Technology Innovation Project Report No. CE-94-TT01

Federal Motor Vehicle Safety Standard No. 122, Motorcycle Brake Systems

International Standard ISO 6597-1980, Road Vehicles - Passenger Car Braking Systems - Measurement of the Braking Performance

SAE J108 Mar 87, Brake System Road Test Code - Motorcycles

SAE J1491 - JUN 90, Vehicle Acceleration Measurement, SAE Recommended Practice

SAE J1634 - May 93, Electric Vehicle Energy Consumption and Range Test Procedure

SAE J1666 May 93, Electric Vehicle Acceleration, Gradeability, and Deceleration Test Procedure

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Vehicle ID_____

Week_____

ATTACHMENT I
URBAN DRIVING TEST CHECKSHEET

General Information								
Shift								
Driver Name/ weight (kilos)								
Battery Data								
ID Number								
Battery SOC (%)								
Date of Last Recharge								
Duration of Recharge (hours)								
Energy Used During Recharge (Kwh)								
Test Preparation								
Time								
Odometer Reading								
Physical Condition of Vehicle (OK, Dent, Mechanical Problem)								
Instrumentation/ Calibration (Ok, Not Ok)								
Tire Pressure (Ok, Not Ok)								
Weather Conditions (Dry/Rain)								
Temperature								
Verified By:								
Post-Test Data								
Time								
Battery SOC (%)								
Odometer Reading								
Physical Condition of Vehicle (Ok, Dent, Mechanical Problem)								
Transfer SRAM Card to Computer								
Verified By:								

Recorders Name_____
Date_____

ATTACHMENT II
VEHICLE AND MOTOR DATA

Item		TAXI 1	TAXI 2	CARGO 3
Vehicle				
	ID Number			
	Color			
	Dimensions Length Width Height			
	Unloaded Vehicle Weight			
	Loaded Test Weight			
	Brake Type			
	Tire Size/Pressure			
Motor				
	Number			
	Rating			

Recorder's Name_____

Date_____

ATTACHMENT III
BATTERY DATA

Battery ID Number					
Manufacturer					
Type/Model Number					
Normal Rating (C/3)					
Normal Rating (Voltage)					
Number of Batteries					
Serial Numbers of Batteries					
Manufactured Date					
No. of Charge/Discharge Cycles To Date					
Last Recharge: date SOC voltage at start voltage at end power consumed					

Vehicle ID_____

ATTACHMENT IV
INSTRUMENTATION CHECKLIST

Check Number	1	2	3	4	5
Date					
Magnetic Marker					
Pulse and Voltage Converter					
LVDT-Left					
LVDT-Right					
Transducer for Charging Current					
Transducer for Main Battery Pack Current					
Multimeter for Main Battery Pack					
Fifth Wheel					
Thermocouple-Left					
Thermocouple-Right					
Test Engineer					

F:\TSTPROC.001

U. S. AGENCY FOR INTERNATIONAL DEVELOPMENT
Bureau of Global Programs, Field Support and Research
Center for Environment
Office of Energy, Environment and Technology

THAILAND ELECTRIC VEHICLE DEMONSTRATION PROJECT

ELECTRIC TUK-TUK BRAKING AND ACCELERATION PERFORMANCE TEST RESULTS

FINAL DRAFT

PREPARED FOR:

Royal Thai Government
Ministry of Science, Technology and Environment
Pollution Control Department

April 1996

PREPARED BY:

Energy Technology Innovation Project
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Prime Contractor: Bechtel Corporation

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1.0 INTRODUCTION

The Thailand Electric Vehicle Demonstration Project was undertaken to determine the economic and environmental benefits of converting the Bangkok Metropolitan Area (BMA) tuk-tuk fleet from fossil fuel to electric power. Tuk-tuks are three-wheeled vehicles used in Asia as taxis and to haul cargo.

The purpose of this test program was to acquire baseline braking and acceleration performance data on electric powered tuk-tuk vehicles. A comparison of this data to the performance tests conducted on conventional tuk-tuks (fueled by LPG/gasoline) in September 1994, is also provided. The conventional tuk-tuk performance tests are presented in Energy Technology Innovation Report CE-94-TT01, December 1994.

Three electric tuk-tuks were constructed and tested for performance. Two were configured as a passenger taxi and one as an enclosed cargo van. Table 1 provides a general description of the vehicles and Figures 1 through 3 detail the various features of each vehcle.

Two of the vehicles, Taxi 2 and Cargo 3, were constructed and tested prior to the construction of the third vehicle, Taxi 1. The initial production vehicles, while similar, incorporated different components to permit the testing and in-service evaluation of the units thereby allowing the third vehicle to be constructed incorporating those components and designs that proved to be more reliable and yielded superior performance.

Taxi 1 is a replacement electric tuk-tuk (RETT) for the original Taxi 1 which experienced several component failures while being tested in Thailand. Rather than repair and modify the vehicle, it was decided to construct an entirely new vehicle incorporating the successful design features and "leasons learned" from the previous three vehicles.

All three vehicles were put through a controlled testing program in California. The controlled tests for Cargo 3 were duplicated in Thailand using different batteries from those used in California. This provided the opportunity to compare vehicle performance using a different battery technology. Additional testing was conducted on Taxi

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1 using a dynamometer to record motor performance. A graph detailing the dynamometer tests is in Appendix D.

The controlled testing programs for Taxi 2 and Cargo 3 were conducted in California in June, 1995. Cargo 3 was also tested in Thailand in October 1995. Controlled testing for Taxi 1 was conducted in California in January 1996.

Each vehicle was equipped with an instrumentation package to record and store various vehicle performance parameters.

TABLE 1

	TAXI 1	TAXI 2	CARGO 3
Motor	6.7 inch Series Wound DC Traction Motor, 15 hp avg. Internal cooling fan	6.7 inch Series Wound DC Traction Motor, 15 hp avg.	8 inch Series Wound DC Traction Motor, 35 hp avg.
Differential	High Efficiency 12.25:1 ratio Gear Drive Single Speed - Dana Spicer	High Efficiency 12:1 ratio Gear Drive Single Speed - Dana Spicer	High Efficiency 6.5:1 ratio Gear Drive Single Speed - Daihatsu
Rear Suspension	Coil over shock absorbers	Coil over shock absorbers	Coil over shock absorbers
Brake System	Hydraulically actuated drum on rear -- Disc on front	Hydraulically actuated drum system on 3 wheels	Hydraulically actuated drum system on 3 wheels
Steering	Tricycle type	Tricycle type	Tricycle type
Chassis	Welded high tensile rectangular steel tubing	Welded high tensile rectangular steel tubing	Welded high tensile rectangular steel tubing
Body	High impact self-supporting fiberglass. Taxi style with single rear passenger seat and fabric roof.	High impact self-supporting fiberglass. Taxi style with single rear passenger seat and fabric roof.	High impact self-supporting fiberglass. Pickup style with utility bed.
Tires	155R - 13	5.00 - 10	5.00 - 10
Wheelbase	93 inches	93 inches	93 inches
Turning Radius	10.5 feet	10.5 feet	10.5 feet
Overall Length	122 inches	122 inches	122 inches
Overall Width	54 inches	54 inches	54 inches
Ground Clearance	6 inches	5 inches	5 inches
Electrical System	120 Volt - 90 Amp-Hr 450 Amp Controller	120 Volt - 90 Amp-Hr 275 Amp Controller	120 Volt - 90 Amp-Hr 275 Amp Controller
Curb Weight	2000 lbs.	1700 lbs.	1650 lbs.
Payload Used	350 lbs.	350 lbs.	350 lbs.
Batteries	Yuasa Model No. NGP 18-12	Horizon Model No. 12N95	Yuasa Model No. NGP 18-12

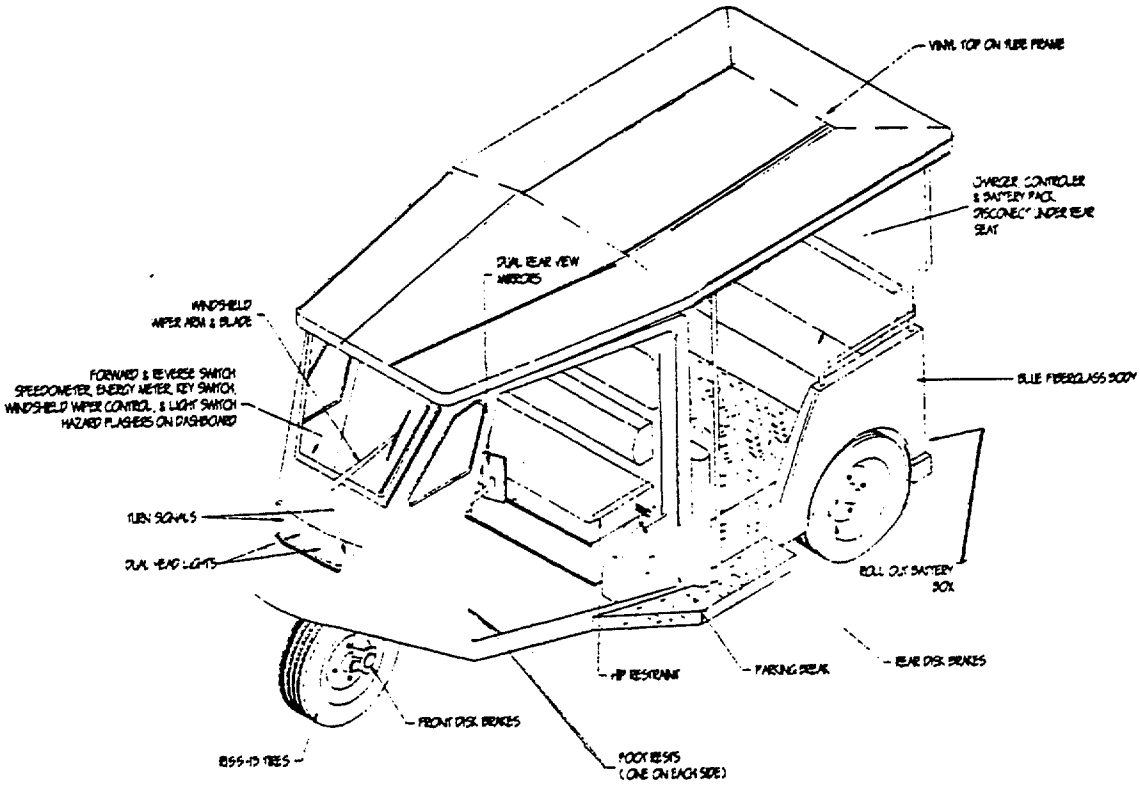

FIGURE 1. TAXI 1

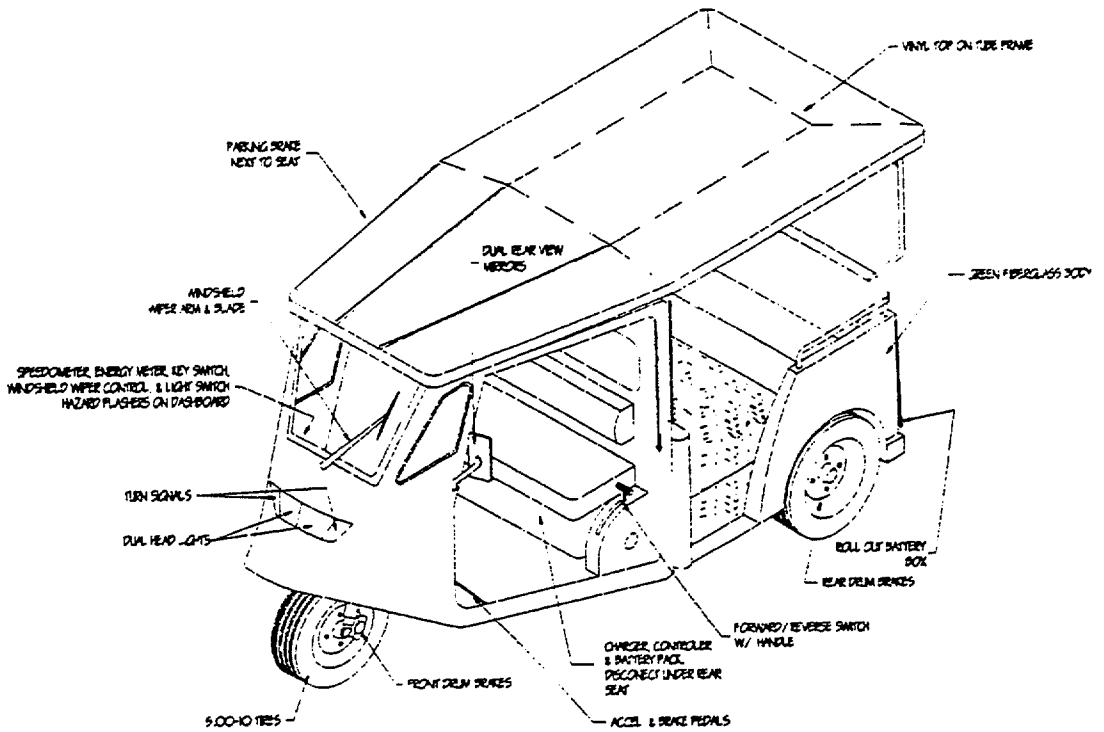

FIGURE 2. TAXI 2

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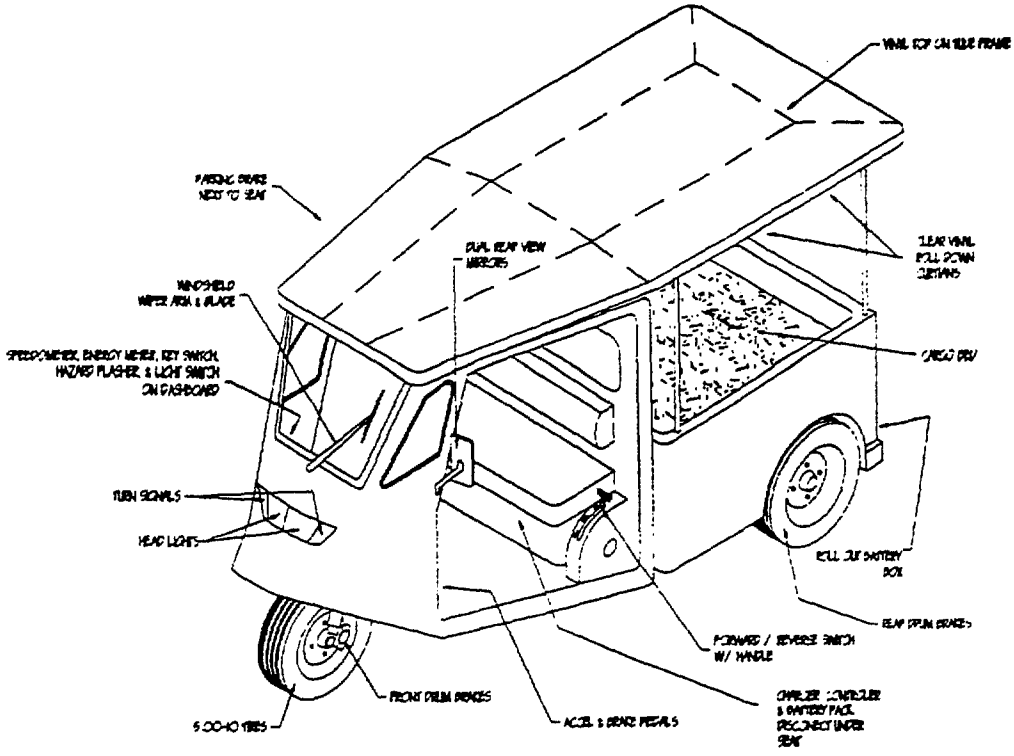

FIGURE 3. CARGO 3

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2.0 DEFINITIONS/TERMINOLOGY

Battery Ampere-Hour Capacity: The capacity of a battery or battery pack in ampere-hours obtained from a battery/pack discharged at a constant **C/3 current rate** such that a specified minimum **cut-off terminal voltage** is reached.

Braking Interval: The distance measured from the start of one brake application to the start of the next application.

Cruising Interval: The distance traveled between stops during the braking test.

CTT: Conventional LPG or gas-powered Tuk-Tuk vehicle.

C/3 Current Rate: The constant current at which the battery can be discharged in 3 hours.

Cut-off Terminal Voltage: The manufacturer-recommended minimum voltage as a function of load after which battery damage could occur.

Depth of Discharge (DOD): The ampere-hours removed from a battery or battery pack expressed as a percentage of the battery/pack capacity.

ETT: Electric Tuk-Tuk vehicle.

End of Test: The point (in time and distance) at which the vehicle has been declared to a rest (zero velocity) condition after the appropriate test termination criteria have been met and the key switch is placed in the "off" position.

Initial Brake Temperature: The temperature of the hottest service brake after a minimum 300 meter travel distance and before any brake application.

Initial Speed or Test Speed: The travel speed of the vehicle at the moment the brake is applied.

Loaded Test Weight: The weight of the vehicle as built with production parts with 1) a full complement of batteries installed, 2) recommended capacity of fluids necessary for operation of the vehicle, 3) the weight of the driver and instrumentation, and 4) ballast that simulates a nominally full passenger/cargo load.

LVDT (Linear Voltage Difference Transmitter): A device used to assess physical characteristics by measuring displacement in an object. In the performance tests, LVDTs are used to determine payload by measuring displacement in the shock absorbers of the vehicles.

Resolution: The smallest unit of a measuring device (e.g. 1/16" may be the smallest unit available on a yardstick).

Start of Brake Application: The initial movement of the brake system control pedal and/or lever.

Start of Test: The point during a test at which the vehicle key switch is first placed in the "on" position, after following applicable manufacture "starting" procedures.

State of Charge (SOC): The residual capacity in ampere-hours of a battery after a discharge (full or partial) expressed as a percent of the ampere-hour capacity as defined above. A gauge is installed on each vehicle which indicates the approximate SOC of the battery pack.

Stopping Distance: The distance traveled by a vehicle from the start of the brake application to the point where the vehicle stops.

Unloaded Test Weight: The weight of the vehicle as built with production parts with 1) a full complement of batteries installed, 2) recommended capacity of fluids necessary for operation of the vehicle, and 3) the weight of the driver and instrumentation.

Unloaded Vehicle Weight: The weight of the vehicle as built with production parts with 1) a full complement of batteries installed and 2) recommended capacity of fluids necessary for operation of the vehicle.

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3.0 METHOD

The braking test procedures were based on established automotive and motorcycle test standards and practices (References 1, 2, 3, 4,) and the Energy Technology Innovation Project's test procedures (Reference 10). The braking tests involved straight line braking from various speeds, brake burnishing, fade and recovery, and wet brake fade and recovery.

The acceleration tests were performed to acquire acceleration performance data under specified conditions. The acceleration test procedures were based on established automotive standards and practices (Reference 6, 7) and the Energy Technology Innovation Project's test procedures (Reference 10). The acceleration tests involved standing start and passing acceleration performance.

In all instances, safety was the prime consideration during testing and safety procedures were followed during all activities. Maximum test speeds were governed by the handling characteristics of the test vehicle. Test speeds were limited to the maximum at which the test engineer determined the vehicle to be completely stable and controllable.

4.0 TEST FACILITY

Acceleration and Brake testing was conducted at the Camarillo, California airport located approximately 40 miles northwest of Los Angeles. Approximately 880 meters of asphalt surfaced straight-away roadway was available for use during testing. Of this, 470 meters was wide, in good condition and afforded good adhesion. The remaining 410 meters was narrow (approximately 7 meters) with some undulations and gravel. In addition, another 800 meters of dirt road was available for coasting and extended runs. The tests for Taxi 2 and Cargo 3 were conducted June 22 through July 1, 1995. Taxi 1 tests were conducted during April 1996.

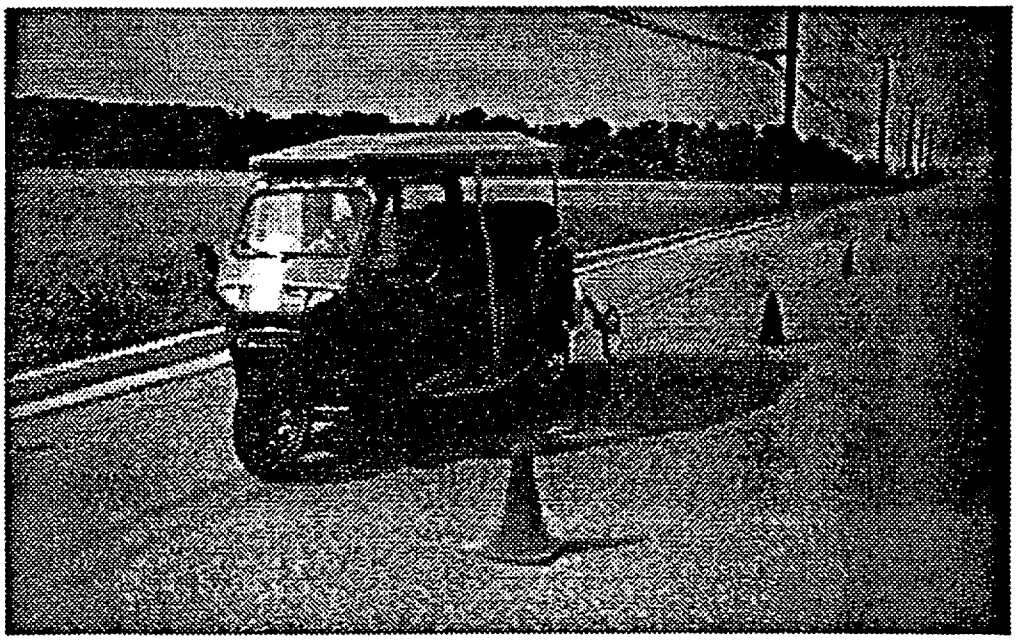

Figure 4. Camarillo, California Test Facility

Additional controlled testing of the Cargo 3 vehicle was conducted at the Ministry of Science, Technology and Enviornment (MOSTE) facility located approximately 20 miles northeast of Bangkok, Thailand. A smooth, wide concrete road approximately 1100 meters long was used for testing. The tests were conducted October 19 - 29, 1995.

Using a Dynamometer, the motor performance of Taxi 1 was evaluated. The Dynamometer is a stationary, computer controlled test facility capable of evaluatimg tuk-tuk performance while the vehicle is "run in-place." With the vehicle weight entered into the computer, motor performance such as torque, hoursepower, etc. can be evaluated for different speeds. The testing was conducted at Advanced Electric Car Technology's facilities in California. Figure 5 shows the Dynamomenter test setup.

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Figure 5. Tuk-Tuk on Dynamometer

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5.0 INSTRUMENTATION

A lightweight, on-board, vehicle instrumentation package was used for data acquisition during the tests. All instrumentation was calibrated in accordance with the manufactures specifications.The package contained a digital data recorder, power supplies and sensors. The instrumentation used for each type of testing is described in the following sections. Appendix A contains a complete instrumentation list.

The digital data recorder consisted of a Fluke Hydra Data Bucket into which were wired the following inputs:

Channel Number	Input
1	Battery Voltage
2	Motor Voltage
3	Battery Current
5	Motor Current
6	Right Brake Temp.
7	Left Brake Temp.
8	Front Brake Temp.
9	Right Vertical Displacement
10	Left Vertical Displacement
11	Front Wheel Magnetic pickup (Hz)
12	Front Wheel Speed (kph)
13	Fifth Wheel Speed (Hz)
Totalizer	Fifth Wheel Optical encoder

6.0 BRAKING TESTS

Distance was measured by a trailing wheel device commonly known as a fifth wheel. The fifth wheel is a custom fabricated assembly that was attached to the rear bumper of the vehicles. A damper installed at the hinge point of the trailing arm controlled the bouncing. The diameter of the tire is about 43.2 cm when inflated to 70 psi. A 20 pulse per revolution optical encoder was connected to the wheel via a

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toothed belt at a one to one ratio, thus one revolution of the wheel produces a 20 pulse output (one pulse equals 0.2231 feet). The pulse output of the fifth wheel is connected to channel twelve of the data recorder. No filtering was applied to the data collected. A typical speed vs. time plot is show in Figure 6.

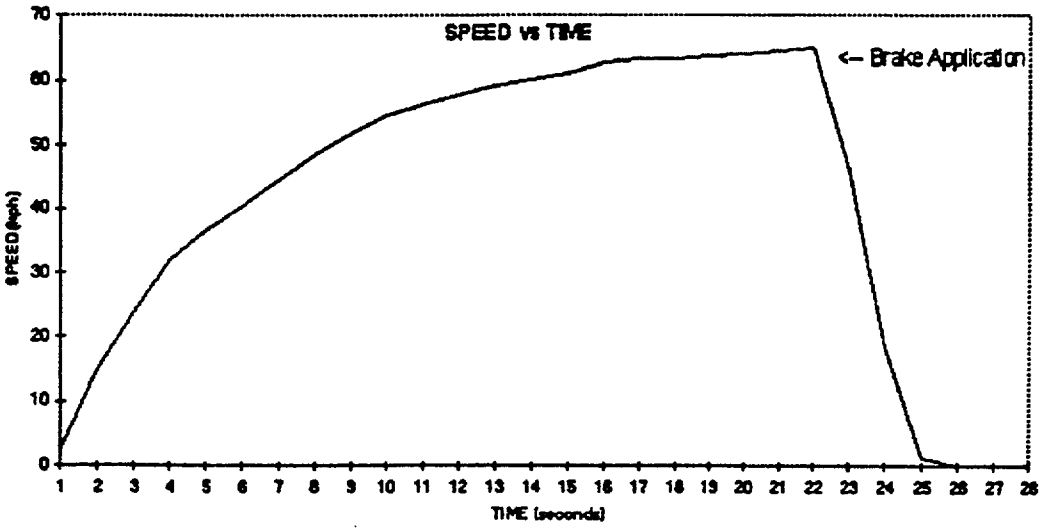

Figure 6. Typical Speed vs. Time Plot

Due to problems with the data acquisition equipment, some of the data collected during the unloaded effectiveness tests for Taxi 2 was unusable. Even though the data for this particular test was lost, there is enough similarity between the other test results of the two vehicles that additional testing is not required. The tests will also be reperformed in Thailand by MOSTE.

Brake Temperatures were measured by installing thermocouples in the brake pad of each brake. Type "K" thermocouples were connected to the data recorder as analog inputs. The data recorder had been calibrated for type K thermocouples by the manufacturer. The thermocouples were attached using silicon epoxy to the backside of the brake pads, through one of several holes existing in each brake pad support assembly. Each thermocouple was mounted in the same respective hole of each brake pad assembly. Because of the wiring length limitations, the thermocouple wiring had to be terminated on a terminal block before being connected to the data recorder. Because

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this procedure may affect the signals seen by the data recorder, a comparison was made with a thermocouple wired directly to the data recorder vs. wired via the terminal block.

Two thermocouples were bound, 1 mm apart, to a piece of metal. The metal was heated to temperatures exceeding 200°C and then cooled back to ambient. By comparing the two signals, it was determined that there was always approximately +2°C (less than 3%) bias between the terminal block mounted thermocouple and the direct wired thermocouple. This bias increased to about +30°C (15%) as the temperatures increased to the maximum 240°C test temperature. The major effect of the terminal block seems to be the introduction of a "time delay" to the signal. It can be inferred from the thermocouple calibration curves that, if the high temperatures were maintained for a longer duration, the difference in temperatures measured would return to the constant +2°C bias. For the purposes of the Controlled Testing, this bias is acceptable.

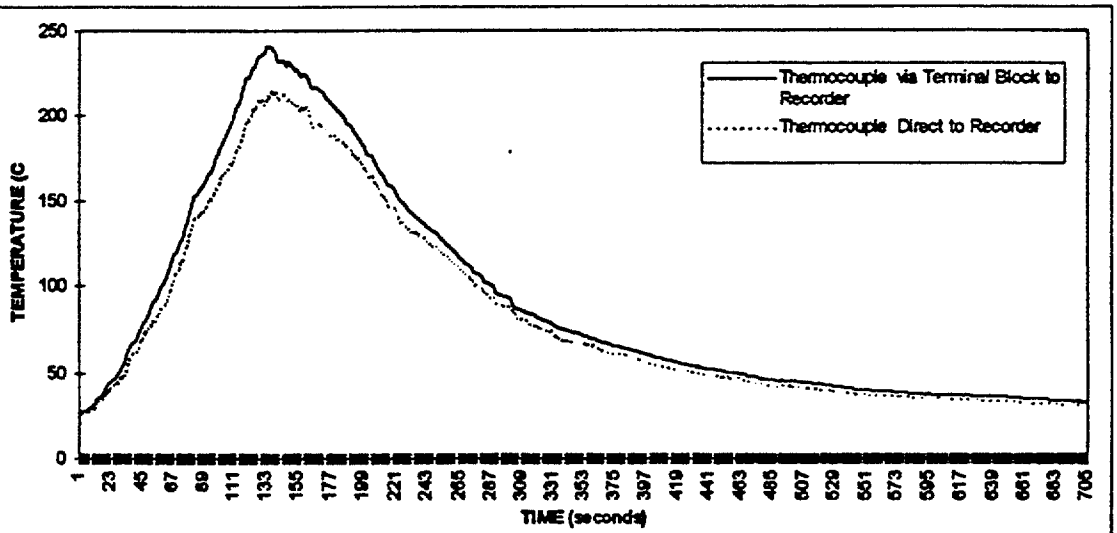

Figure 3. Thermocouple Calibration

In the Fade and Recovery test, the ETT Taxis and CTT Taxi have similar stopping distances but the brake temperatures of the CTT are substantially higher than those of the ETTs. In the Cargo configurations, the ETT vehicle displayed better stopping distances and brake temperatures were similar. In the Final Effectiveness test,

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both the Taxis and Cargo ETT configurations displayed less stopping distances than the CTT. Brake temperatures for both were similar.

A summary of the final effectiveness tests and its comparison to the Conventional Tuk-Tuk is detailed in Figure 8. A complete listing of all the test data obtained is in Appendix B.

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FIGURE 8

FINAL EFFECTIVENESS SUMMARY

Unloaded @ 50 kph

	TAXI 1 (RETT)	TAXI 2	CARGO 3	CTT Taxi	CTT Cargo
Stopping Distance, meters	14.30	14.40	17.86	20.80	25.56
Avg. Deceleration, m/s/s	7.00	6.50	6.91	4.60	3.66
Brake Temp., celsius (LR/RR/F)	59/69/29	66/65/68	67/68/50	65/62	58/64

Loaded @ 50 kph

	TAXI 1 (RETT)	Taxi 2	CARGO 3	CTT Taxi	CTT Cargo
Stopping Distance, meters	13.50	13.60	28.60	21.20	41.33
Avg. Deceleration, m/s/s	7.40	6.00	2.56	4.50	2.21
Brake Temp., celsius	63/66/29	67/68/69	55/71/56	65/61	61/64

Unloaded @ 65 kph

	TAXI 1 (RETT)	TAXI 2	CARGO 3	CTT Taxi	CTT Cargo
Stopping Distance, meters	18.60	16.50	23.53	21.17	46.23
Avg. Deceleration, m/s/s	5.50	8.14	6.33	4.53	3.38
Brake Temp., celsius	69/76/30	61/65/65	46/57/42	64/60	62/65

Loaded @ 65 kph

	TAXI 1 (RETT)	TAXI 2	CARGO 3	CTT Taxi	CTT Cargo
Stopping Distance, meters	15.70	18.56	34.00	37.83	86.60
Avg. Deceleration, m/s/s	6.05	5.48	3.91	4.23	1.76
Brake Temp., celsius	69/77/32	64/69/69	62/71/58	64/58	67/69

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7.0 ACCELERATION TESTS

The acceleration tests involved standing start and passing acceleration performance. A fifth wheel was installed on the vehicles to measure distance and a digital data recorder was programmed to record distance versus time. Speed and acceleration were calculated from the distance versus time data.

Standing Start Acceleration. From a standing start, the vehicle was operated to achieve maximum acceleration. Speed and elapsed time data were recorded for the following:

0 to 50 kph	speed vs elapsed time
0 to 65 kph	speed vs elapsed time
0.4 km	terminal speed & elapsed time
0 to 5 sec.	speed & distance traveled

For each of three SOCs, 100%, 60%, 20%, a minimum of six individual runs were conducted, three in each direction at the Unloaded Test Weight condition. This procedure was repeated for the Loaded Test Weight condition. The battery SOC tolerances used are:

SOC	Range
100	90 -100%
60	55 - 65%
20	15 - 30%

The test results are summarized in Figure 9.

Passing Acceleration. From a stabilized 40 kph, the vehicle was accelerated with wide open throttle to 65 kph. This procedure was conducted for each of the three SOCs, 100%, 60%, 20%. Elapsed time and distance data were recorded. The results are shown in Figure 10. The data for the Cargo 3 Unloaded 20% SOC test was lost, resulting in no data being included in the summary table for that particular test.

While it might be expected that vehicle performance for a given SOC would be equal to or greater than that of a lesser SOC, the resulting data does not always support this. Due to the resolution of the data

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recorder, variance of drivers, loaded vs. unloaded, and day-to-day test differences, some vehicle performance at low SOC was superior to that at a higher SOC.

The ETT Taxis consistently outperformed the CTT Taxi in both the loaded and unloaded configurations of the Standing Start Acceleration tests. In the Cargo configuration however, the ETT outperformed the CTT only in the loaded conditions. In those instances when the Cargo was unloaded, the CTT performed better.

During the Passing Acceleration tests, the CTT Taxi and Cargo was observed to consistently outperform the ETT vehicles in the unloaded configurations. In the loaded configurations the Taxis were similar in performance, but the ETT Cargo displayed performance superior to the CTT Cargo.

A complete compilation of all the acceleration test data is shown in Appendix C.

FIGURE 9

STANDING START ACCELERATION TEST SUMMARY

ETT @ 100% SOC vs. CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 0 to 50 kph, unloaded	10.25	10.60	11.60	14.90	16.80	11.20
Elapsed Time, sec. 0 to 65 kph, unloaded	21.60	18.40	21.50	20.00	26.90	16.60
Elapsed Time, sec. 0 to 50 kph, loaded	10.00	9.60	15.20	19.60	17.50	18.20
Elapsed Time, sec. 0 to 65 kph, loaded	18.22	17.50	29.70	26.80	27.30	29.20

ETT @ 60% SOC vs. CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 0 to 50 kph, unloaded	10.20	7.40	11.60	15.90	16.20	11.20
Elapsed Time, sec. 0 to 65 kph, unloaded	19.67	14.60	21.50	21.60	23.40	16.60
Elapsed Time, sec. 0 to 50 kph, loaded	10.27	8.60	15.20	18.70	19.30	18.20
Elapsed Time, sec. 0 to 65 kph, loaded	20.43	14.60	29.70	25.60	26.10	29.20

ETT @ 20% SOC vs.CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 0 to 50 kph, unloaded	12.43	7.50	11.60	13.40	15.60	11.20
Elapsed Time, sec. 0 to 65 kph, unloaded	25.75	11.00	21.50	18.00	23.20	16.60
Elapsed Time, sec. 0 to 50 kph, loaded	13.93	8.10	15.20	15.00	17.90	18.20
Elapsed Time, sec. 0 to 65 kph, loaded	27.97	12.50	29.70	20.70	23.70	29.20

FIGURE 10

PASSING ACCELERATION TEST SUMMARY

ETT @ 100% SOC vs. CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 40 to 65 kph, unloaded	14.21	15.60	9.95	9.30	11.20	7.10
Elapsed Time, sec. 40 to 65 kph, loaded	15.37	16.20	15.20	11.60	12.90	17.40

ETT @ 60% SOC vs. CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 40 to 65 kph, unloaded	14.69	13.60	9.95	11.30	12.10	7.10
Elapsed Time, sec. 40 to 65 kph, loaded	17.56	13.70	15.20	13.00	13.90	17.40

ETT @ 20% SOC vs. CTT

	ETT TAXI 1 (RETT)	ETT TAXI 2 Horizon	CTT TAXI	ETT CARGO Horizon	ETT CARGO Yuasa	CTT CARGO
Elapsed Time, sec. 40 to 65 kph, unloaded	17.07	13.40	9.95	-	12.60	7.10
Elapsed Time, sec. 40 to 65 kph, loaded	19.05	17.10	15.20	11.90	14.30	17.40

note: data omission due to instrumentation error

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7. Test Plan for Acceleration Performance Tests, September, 1994, Thomas J. Carter, Carter Engineering.

8. SAE J1506 - APR 93, Emission Test Driving Schedules, SAE Information Report.

9. An On-Board Data Acquisition System for Vehicle Brake Testing, Thomas J. Carter and W. D. Perry, Society of Automotive Engineers, SAE No. 920259.

10. Procedures for Performance, Braking, Acceleration and Urban In-Service Testing, Energy Technology Innovation Project.

11. Energy Technology Innovation Report, CE-94-TT01, Baseline Braking and Performance of Conventional Taxi.

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APPENDIX A

INSTRUMENTATION LIST

1. Vehicle Fifth Wheel
   Custom built by Carter Engineering.
   Tire circumference: 1.3604 m ±0.227%
   Tire circumference divided into 20 pulses with BEI H25 optical encoder.

2. Friction Material Thermocouples
   Omega Iron-Constantan Thermocouples, Type "K"

3. Linear Displacement Transducer
   Lucas-Schaevitz model 3000 DC-E

4. Fiber Optic Photosensor - for RPM
   Pulnix-Seeka
   F5H

5. Proximity Sensor
   Effector model 1E2002FROG

6. Frequency to Voltage Converter
   Burr-Brown model VFC32KP

7. Current Transducers
   LEM-HAL series

8. Power Supplies
   MF 330 series
   15 VDC output

APPENDIX A

9. On-Site FAA Weather Station
   - Ambient temperature
   - Wind speed and direction

10. Continuous Data Recorder
    - Fluke Hydra Data Bucket model 2635A

11. Portable Computer
    - Compaq model Notebook
    - 486 - 75mhz; 12MB RAM; 510 MBHD

APPENDIX B

EFFECTIVENESS TEST

TAXI 1
(RETT)

Date: 21 Apr 1996
Breeze
Driver: Eric (145 lbs)

Temperature: 60s °F
Wind: Lt. Easterly

Road: Dry

Unloaded

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	52.7	51.7	15.1	22.6	7.04	4.55	73.21	61.13	26.29	51.1	56.9
2	52.6	51.5	14.4	28.7	7.37	3.56	74.94	62.10	25.97	58	57.3
3	49.4	50.9	14.7	23.8	6.37	4.19	73.44	62.38	25.34	58.3	63
4	50.6	52.3	15.1	23.3	6.49	4.54	76.15	63.04	26.06	61.8	67.3
5	51.3	50.4	14.4	23.4	7.03	4.19	69.14	63.37	22.13	64	63.4
6	50.9	50.4	14.5	22.1	6.85	4.43	74.77	60.80	26.54	61.6	63.9

Date: 21 Apr 1996
Breeze
Driver: Eric (145 lbs)

Temperature: 60s °F
Wind: Lt. Easterly

Road: Dry

Loaded

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	49.4	51.7	16.38	23.6	5.72	4.37	75.60	62.32	25.47	52.9	59.9
2	50.2	51.2	17.62	23.6	5.48	4.34	81.30	62.34	28.55	63.5	65.8
3	50.8	50.1	15.14	21.8	6.54	4.43	79.00	59.49	26.87	65.8	63.5
4	51.2	49.3	15.08	20.4	6.67	4.6	77.21	59.09	26.71	64.6	64.9
5	50.3	48.3	15.13	21.1	6.42	4.26	76.62	60.50	27.80	62.9	63.9
6	49.5	49.1	14.98	21.5	6.28	4.33	82.42	73.80	26.31	63.8	64.8

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APPENDIX B

FADE and RECOVERY TEST

TAXI 1
(RETT)

Date: 21 Apr 1996
Breeze
Driver: Eric (145 lbs)

Temperature: 60s °F
Wind: Lt. Easterly

Road: Dry

Loaded Baseline

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	50.3	48.6	32.8	29.5	2.96	3.09	77.78	62.65	26.55	64.9	63.3
2	49.8	48.9	31.6	30.1	3.010	3.07	78.44	67.22	25.92	64.5	64.9
3	49.7	47.7	32.4	30.8	2.92	2.84	72.72	70.68	22.67	63.8	64.2

Date: 21 Apr 1996
Breeze
Driver: Eric (145 lbs)

Temperature: 60s °F
Wind: Lt. Easterly

Road: Dry

Loaded Fade

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	58.3	57.5	26.3	36.3	4.96	3.51	74.98	65.14	24.94	60.6	59.6
2	57.6	58.1	27.5	37	4.63	3.52	90.06	80.71	26.91	84.3	86.0
3	59.3	57.6	26.9	37.2	5.02	3.44	107.14	95.29	32.16	108.1	111.6
4	58.7	58.3	25.8	38	5.12	3.45	110.40	95.42	32.09	125.1	130.6
5	60.8	54.6	27.2	38.3	5.21	3.00	111.41	96.03	33.88	136.0	145.4
6	59.2	56.4	26.4	35.8	5.09	3.42	115.68	104.37	31.40	144.0	155.0
7	61.1	56.5	27.3	40.1	5.25	3.07	123.98	113.55	32.52	147.5	160.4
8	59.6	57.0	26.6	37.2	5.12	3.36	126.22	113.36	33.08	150.3	164.2
9	58.9	55.4	27.1	38.4	4.91	3.08	122.04	107.37	31.15	152.6	166.5
10	59.7	57.5	26.7	39.3	5.12	3.24	116.28	115.18	24.91	156.1	170.0

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APPENDIX B

FADE and RECOVERY TEST

TAXI 1
(RETT)

Date: 21 Apr 1996
Breeze
Driver: Eric (145 lbs)

Temperature: 60s °F
Wind: Lt. Easterly

Road: Dry

Loaded Recovery

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	49.7	48.6	31.6	34.4	3.00	2.65	113.6	108.6	27.4	155.0	166.4
2	51.1	48.9	31.9	33.4	3.14	2.77	119.5	116.1	28.0	148.5	154.0
3	50.8	50.4	32.2	34	3.07	2.87	125.1	123.1	28.6	147.8	150.4
4	51.9	50.9	31.1	32.1	3.32	3.11	130.4	128.8	29.1	137.9	138.6
5	50.4	50.6	32.3	33.4	3.02	2.94	111.7	96.1	34.2	136.0	135.7
6	50.6		31.7		3.10		115.2	115.4	31.8		

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APPENDIX B

FINAL EFFECTIVENESS TEST

TAXI 1
(RETT)

Date: 26 Apr 1996
Breeze
Driver: Eric (145 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Unloaded @ 50 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	51.3	50.7	13.2	21.5	7.6	4.6	58.3	66.8	29.7	63.6	57.5
2	50.8	49.6	15.2	21.0	6.5	4.5	59.8	68.9	29.4	65.2	61.0
3	51.1	48.9	14.5	20.0	6.9	4.6	61.4	70.1	30.0	65.1	62.2

Date: 26 Apr 1996
Breeze
Driver: Eric (145 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Loaded @ 50 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	51.3	49.1	13.7	21.0	7.37	4.43	62.0	67.8	28.6	65.3	63.7
2	51.6	48.9	13.4	19.1	7.62	4.82	64.0	69.5	28.7	64.9	60.4
3	49.9	51.4	13.3	23.4	7.18	4.34	63.9	66.8	29.0	65.1	59.0

APPENDIX B

FINAL EFFECTIVENESS TEST

TAXI 1
(RETT)

Date: 26 Apr 1996
Breeze
Driver: Eric (145 lbs)

Temperature: 70s °F
Wind: Lt. Easterly
Road: Dry

Unloaded @ 65 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	64.1	64.2	28.5	34.6	5.53	4.6	69.3	69.4	31.8	63.3	62.0
2	64.3	64.2	28.3	33.3	5.60	4.7	74.8	76.7	32.1	65.4	62.2
3	63.8	65.2	29.1	35.1	5.36	4.6	63.9	84.3	27.7	64.6	58.2

Date: 26 Apr 1996
Breeze
Driver: Eric (145 lbs)

Temperature: 70s °F
Wind: Lt. Easterly
Road: Dry

Loaded @ 65 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	64.2	65.8	26.4	37.8	5.99	4.42	67.9	73.8	31.5	65.3	59.2
2	63.6	62.2	25.5	37.0	6.09	4.02	69.4	78.8	31.7	63.8	56.8
3	63.1	65.2	25.1	38.7	6.09	4.24	70.8	81.0	33.7	64.7	58.3

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APPENDIX B

WATER RECOVERY TEST

TAXI 1
(RETT)

Date: 26 Apr 1996
Breeze
Driver: Eric (145 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Loaded Baseline

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	51.6	48.1	32.3	29.5	3.16	3.03	52.6	51.1	25.4	62.5	57.7
2	50.9	49.1	31.8	31.0	3.13	3.00	66.8	65.0	26.6	64.8	63.5
3	51.3	49.4	32.1	30.3	3.15	3.11	72.8	77.1	28.7	62.4	60.8

Date: 26 Apr 1996
Breeze
Driver: Eric (145 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Loaded Recovery

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	52.2	42.3	30.6	31.5	3.42	2.19	37.8	40.1	28.0	32.1	33.1
2	51.3	45.5	31.9	32.8	3.16	2.12	41.4	49.3	30.1	39.2	38.5
3	50.9	43.6	31.4	32.1	3.17	2.29	47.8	59.6	31.6	49.8	46.9
4	51.4	38.6	31.7	30.2	3.20	1.91	54.2	70.3	33.3	59.2	57.2
5	51.7	43.5	32.2	30.7	3.18	2.37	59.6	85.7	33.9	71.1	62.0
6	50.6		31.8		3.09		61.7	86.2	34.4		

APPENDIX B

EFFECTIVENESS TEST

TAXI 2

Date: 23 Jun 1995
Breeze
Driver: Rich (170 lbs)

Temperature: 70s °F
Wind: Lt. Easterly
Road: Dry

Unloaded

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	37.4	51.7		22.6		4.55	46.2	49.8	49.2	51.1	56.9
2	40.1	51.5		28.7		3.56	54.5	61.1	54.5	58.0	57.3
3	38.2	50.9		23.8		4.19	62.6	69.2	63.9	58.3	63.0
4	39.0	52.3		23.3		4.54	71.5	80.4	75.5	61.8	67.3
5	40.3	50.4		23.4		4.19	79.5	89.0	84.1	64.0	63.4
6	38.2	50.4		22.1		4.43	79.5	89.0	84.1	61.6	63.9

Date: 23 Jun 1995
Breeze
Driver: Sean (135 lbs)

Temperature: 70s °F
Wind: Lt. Easterly
Road: Dry

Loaded

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	40.6	51.7		23.6		4.37	89.2	94.9	97.9	52.9	59.9
2	40.0	51.2		23.6		4.34	91.2	96.6	98.4	63.5	65.8
3	38.4	50.1		21.8		4.43	95.4	101.0	102.4	65.8	63.5
4	37.6	49.3		20.4		4.60	99.9	106.1	105.3	64.6	64.9
5	39.2	48.3		21.1		4.26	105.6	111.4	108.5	62.9	63.9
6	42.0	49.1		21.5		4.33	110.4	115.6	113.6	63.8	64.8

note: data ommission due to instrumentation error

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APPENDIX B

FADE and RECOVERY TEST

TAXI 2

Date: 24 Jun 1995
Driver: Eric (145 lbs)

Temperature: 70s °F
Wind: Calm
Road: Dry

Loaded Baseline

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	46.1	48.6	32.7	29.5	2.49	3.09	45.5	89.5	63.2	64.9	63.3
2	47.3	48.9	32.0	30.1	2.68	3.07	64.4	85.1	67.7	64.5	64.9
3	48.3	47.7	32.2	30.8	2.78	2.84	47.9	68.9	50.7	63.8	64.2

Date: 24 Jun 1995
Driver: Eric (145 lbs)

Temperature: 70s °F
Wind: Calm
Road: Dry

Loaded Fade

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	53.7	57.5	45	36.3	2.45	3.51	52.6	53.4	59.3	60.6	59.6
2	58.7	58.1	45	37.0	2.93	3.52	59.6	58.0	60.7	84.3	86.0
3	51.2	57.6	45	37.2	2.23	3.44	63.6	59.5	64.0	108.1	111.6
4	50.7	58.3	45	38.0	2.19	3.45	68.3	62.1	67.5	125.1	130.6
5	55.0	54.6	45	38.3	2.57	3.00	48.6	45.2	50.9	136.0	145.4
6	55.5	56.4	45	35.8	2.62	3.42	56.8	53.1	59.1	144.0	155.0
7	53.3	56.5	45	40.1	2.42	3.07	60.4	56.4	63.7	147.5	160.4
8	59.1	57.0	45	37.2	2.97	3.36	67.4	61.1	70.6	150.3	164.2
9	52.9	55.4	45	38.4	2.38	3.08	69.2	58.9	69.7	152.6	166.5
10	54.0	57.5	45	39.3	2.48	3.24	70.8	59.4	72.8	156.1	170.0

APPENDIX B

FADE and RECOVERY TEST

TAXI 2

Date: 24 Jun 1995
Driver: Eric (145 lbs)

Temperature: 70s °F
Wind: Calm
Road: Dry

Loaded Recovery

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	47.7	48.6	32	34.4	2.72	2.65	54.2	49.4	57.4	155.0	166.4
2	48.3	48.9	32	33.4	2.79	2.77	59.5	55.2	60.9	148.5	154.0
3	49.7	50.4	32	34	2.96	2.87	65.6	63.2	65.4	147.8	150.4
4	49.3	50.9	32	32.1	2.91	3.11	70.6	66.8	71.2	137.9	138.6
5	42.4	50.6	32	33.4	2.15	2.94	74.7	71.3	76.0	136.0	135.7
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APPENDIX B

FINAL EFFECTIVENESS TEST

TAXI 2

Date: 25 Jun 1995
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Calm
Road: Dry

Unloaded @ 50 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	40.5	50.7	14.3	21.5	4.4	4.6	62.3	61.3	64.3	63.6	57.5
2	51.1	49.6	13.9	21.0	7.2	4.5	65.4	64.2	65.6	65.2	61.0
3	56.1	48.9	15.1	20.0	7.9	4.6	66.8	65.9	68.4	65.1	62.2

Date: 25 Jun 1995
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Calm
Road: Dry

Loaded @ 50 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	46.0	49.1	17.4	21.0	4.66	4.43	52.2	55.1	56.8	65.3	63.7
2	45.7	48.9	13.4	19.1	5.97	4.82	62.2	65.7	63.8	64.9	60.4
3	44.4	51.4	10.0	23.4	7.56	4.34	67.6	68.7	69.6	65.1	59.0

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APPENDIX B

FINAL EFFECTIVENESS TEST

TAXI 2

Date: 25 Jun 1995
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Calm
Road: Dry

Unloaded @ 65 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	52.3	64.2	19.2	34.6	5.46	4.6	48.9	53.2	50.5	63.3	62.0
2	46.8	64.2	15.3	33.3	5.49	4.7	54.1	58.4	57.8	65.4	62.2
3	72.6	65.2	15.0	35.1	13.48	4.6	61.6	65.8	65.5	64.6	58.2

Date: 25 Jun 1995
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Calm
Road: Dry

Loaded @ 65 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	45.3	65.8	18.7	37.8	4.21	4.42	54.1	58.2	63.6	65.3	59.2
2	55.1	62.2	18.5	37.0	6.29	4.02	52.8	56.9	61.5	63.8	56.8
3	53.6	65.2	18.5	38.7	5.95	4.24	64.6	69.0	69.9	64.7	58.3

APPENDIX B

WATER RECOVERY TEST

TAXI 2

Date: 25 Jun 1995
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Calm
Road: Dry

Loaded Baseline

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	36.6	48.1	32	29.5	1.60	3.03	46.5	49.2	46.2	62.5	57.7
2	43.4	49.1	32	31.0	2.26	3.00	49.7	54.5	47.3	64.8	63.5
3	46.0	49.4	32	30.3	2.54	3.11	57.1	63.4	51.5	62.4	60.8

Date: 25 Jun 1995
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Calm
Road: Dry

Loaded Recovery

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	44.9	42.3	32	31.5	2.42	2.19	35.6	28.7	33.4	32.1	33.1
2	49.4	45.5	32	32.8	2.92	2.12	54.4	52.5	43.4	39.2	38.5
3	46.5	43.6	32	32.1	2.59	2.29	65.4	65.5	51.5	49.8	46.9
4	36.3	38.6	32	30.2	1.58	1.91	81.6	82.8	69.4	59.2	57.2
5	38.7	43.5	32	30.7	1.79	2.37	89.1	90.8	79.6	71.1	62.0
6	38.0		32		1.73		93.8	97.9	89.2		

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APPENDIX B

EFFECTIVENESS TEST

CARGO 3

Date: 29 Jun 1995
Breeze
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Unloaded

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	40.4	49.1	18.7	28.0	3.34	3.32	59.4	65.3	62.0	55.5	65.3
2	25.5	48.6	20.1	26.4	1.24	3.46	58.4	86.4	67.1	57.2	61.5
3	46.8	50.4	19.0	24.9	4.42	3.93	61.2	99.5	73.7	55.2	65.4
4	24.8	49.4	18.4	25.8	1.28	3.65	55.7	84.0	77.0	55.0	60.6
5	41.0	48.1	19.7	24.5	3.27	3.65	55.3	99.8	83.2	63.1	65.2
6	45.5	49.4	20.9	25.6	3.80	3.68	65.9	94.6	86.1	62.2	64.6

Date: 29 Jun 1995
Breeze
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Loaded

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	49.3	48.6	21.1	42.4	4.41	2.15	48.8	63.6	80.8	65.3	63.6
2	49.9	49.9	21.6	44.7	4.42	2.15	53.3	95.5	85.5	63.3	60.7
3	51.2	48.6	22.3	32.8	4.51	2.78	50.3	93.8	77.6	63.5	58.0
4	47.8	49.4	19.8	29.4	4.43	3.21	49.1	85.3	82.3	65.8	59.8
5	46.3	49.4	19.4	28.1	4.24	3.36	53.6	80.8	76.4	64.5	56.8
6	47.4	50.1	21.0	29.2	4.10	3.31	49.3	81.0	72.2	65.5	59.2

APPENDIX B

FADE and RECOVERY TEST

CARGO 3

Date: 29 Jun 1995
Breeze
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Loaded Baseline

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	46.1	45.7	32.7	40.3	2.49	2.00	45.5	89.5	63.2	60.1	65.3
2	47.3	49.4	32.0	51.4	2.68	1.83	64.4	85.1	67.7	58.8	65.5
3	48.3	48.9	32.2	54.5	2.77	1.69	47.9	68.9	50.7	59.8	64.3

Date: 29 Jun 1995
Breeze
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Loaded Fade

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	49.2	49.9	32	56.5	2.90	1.70	47.0	68.5	58.9	57.8	65.5
2	50.5	49.6	32	56.6	3.05	1.67	41.6	69.1	59.7	110.3	81.3
3	51.2	49.9	32	55.5	3.14	1.73	60.4	82.2	67.6	86.3	96.4
4	50.7	48.9	32	57.4	3.08	1.61	62.9	81.4	66.6	97.5	108.5
5	50.9	48.5	32	56.8	3.10	1.59	58.4	90.7	71.0	106.0	118.0
6	47.4	49.4	32	57.7	2.69	1.63	54.6	74.3	69.4	115.9	125.7
7	48.4	49.7	32	54.7	2.80	1.75	48.1	78.2	63.5	119.7	130.0
8	51.6	49.9	32	58.5	3.19	1.64	55.1	81.8	67.8	123.7	133.2
9	50.8	46.7	32	56.1	3.09	1.50	62.7	77.8	67.6	125.2	135.2
10	50.8	48.5	32	55.6	3.09	1.63	63.7	82.4	72.7	123.9	132.7

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APPENDIX B

FADE and RECOVERY TEST

CARGO 3

Temperature: 70s °F
Date: 29 Jun 1995 Wind: Lt. Easterly
Breeze
Driver: George (200 lbs) Road: Dry

Loaded Recovery

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	50.4	49.9	32.2	62.0	3.02	1.55	53.9	88.9	72.5	113.7	120.2
2	52.1	49.8	32.2	58.6	3.23	1.62	67.7	108.1	91.3	106.1	109.4
3	50.8	48.6	32.1	56.7	3.08	1.61	74.9	121.2	95.2	100.7	102.4
4	51.3	50.4	32.0	56.1	3.15	1.74	75.0	134.2	102.5	98.1	98.7
5	45.8	50.1	32.0	58.6	2.51	1.65	70.4	126.6	113.6	97.3	96.6
6	50.5		32.1		3.04		69.4	148.6	107.1		

APPENDIX B

FINAL EFFECTIVENESS TEST

CARGO 3

Date: 29 Jun 1995
Breeze
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Unloaded @ 50 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	57.2	50.2	17.2	25.2	7.29	3.86	61.4	65.2	48.5	56.5	65.2
2	56.1	50.1	17.9	26.7	6.74	3.62	69.4	72.2	52.4	59.5	64.9
3	56.9	47.5	18.5	24.8	6.71	3.51	70.7	69.1	50.6	59.4	64.8

Date: 29 Jun 1995
Breeze
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Loaded @ 50 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	45.2	47.7	28.4	38.0	2.75	2.31	52.6	62.2	53.5	58.0	62.5
2	44.9	49.6	26.9	39.9	2.87	2.38	53.0	73.7	57.8	62.2	64.4
3	40.5	48.1	30.5	46.1	2.06	1.94	62.0	78.8	58.1	63.4	65.6

APPENDIX B

FINAL EFFECTIVENESS TEST

CARGO 3

Date: 29 Jun 1995
Breeze
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Lt. Easterly
Road: Dry

Unloaded @ 65 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	64.3	63.1	28.2	44.9	5.62	3.42	43.1	49.4	37.6	63.8	66.0
2	66.2	63.6	21.8	45.3	7.71	3.44	46.8	61.6	44.5	62.3	65.2
3	55.2	64.4	20.6	48.5	5.67	3.30	49.5	61.7	43.9	62.2	65.1

Date: 29 Jun 1995
Breeze
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Lt. Easterly
Road: Dry

Loaded @ 65 kph

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	55.8	63.6	33.3	86.2	3.58	1.81	61.0	77.6	55.9	68.5	72.0
2	55.6	62.6	34.7	86.8	3.41	1.74	60.1	65.4	56.7	66.7	69.9
3	65.0	62.5	34.0	86.8	4.76	1.73	66.8	72.3	63.6	67.9	67.9

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APPENDIX B

WATER RECOVERY TEST

CARGO 3

Date: 29 Jun 1995
Breeze
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Loaded Baseline

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	52.2	49.4	32.0	59.4	3.26	1.58	45.2	55.3	47.1	56.0	63.0
2	57.4	50.2	32.0	54.1	3.95	1.80	49.9	61.2	52.4	61.0	65.8
3	63.6	46.5	332.0	54.2	4.84	1.54	56.3	72.3	60.3	60.9	65.0

Date: 29 Jun 1995
Breeze
Driver: George (200 lbs)

Temperature: 70s °F
Wind: Lt. Easterly

Road: Dry

Loaded Recovery

Run	Speed kph		Stopping Distance meters		Average Deceleration m/s/s		ETT Brake Temperature celsius			CTT Brake Temp. celsius	
	ETT	CTT	ETT	CTT	ETT	CTT	LR	RR	F	LR	RR
1	58.9	41.1	32.0	57.5	4.15	1.13	34.7	47.4	31.1	32.2	38.4
2	37.8	41.2	32.0	55.8	1.71	1.17	34.5	57.7	37.4	42.9	55.4
3	57.4	40.9	32.0	53.3	3.95	1.21	39.8	64.5	43.0	53.5	66.7
4	53.7	43.0	32.0	53.5	3.45	1.33	44.9	68.3	45.0	60.4	73.5
5	58.9	41.5	32.0	56.4	4.15	1.18	43.3	79.8	54.2	71.1	76.9
6	54.4		32.0		3.54		58.4	73.3	55.7		

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APPENDIX C

STANDING START ACCELERATION TESTS

TAXI 1
(RETT)

Run	% of Charge	Loading	Elapsed Time (sec)			Terminal Speed (kph)		Dist, m
			0 to 50 kph	0 to 65 kph	0 to 0.4 km	0 to 0.4 km	0 to 5 sec.	0 to 5 sec.
1	100%	Unloaded	11.7	20.1	23.6	66	39	52
2	100%	Unloaded	9.2	20.5	23.7	66	37	49
3	100%	Unloaded	9.6	21.8	23.2	68	36	53
4	100%	Unloaded	10.3	23.1	23.5	66	35	50
5	100%	Unloaded	9.9	22.2	23.3	68	37	48
6	100%	Unloaded	10.8	21.9	23.6	67	35	44
1	100%	Loaded	8.4	17.6	23.8	66	39	51
2	100%	Loaded	10.6	19.3	24.1	66	38	49
3	100%	Loaded	9.3	15.9	23.5	68	40	50
4	100%	Loaded	11.7	17.9	23.9	67	37	48
5	100%	Loaded	10.2	18.5	23.6	66	39	49
6	100%	Loaded	9.8	20.1	24.1	66	41	51
1	60%	Unloaded	9.4	18.7	24	67	39	50
2	60%	Unloaded	11.1	21.2	26.1	66	36	47
3	60%	Unloaded	10.7	18.5	25.9	66	37	48
4	60%	Unloaded	9.6	20.2	26.4	67	40	49
5	60%	Unloaded	9.1	18.4	26.3	68	39	51
6	60%	Unloaded	11.3	21	26.5	66	36	49
1	60%	Loaded	10.4	21.6	26.6	66	38	49
2	60%	Loaded	9.6	19.7	26	68	40	52
3	60%	Loaded	11.2	20.9	26.2	66	36	47
4	60%	Loaded	10.7	20	26.2	65	38	48
5	60%	Loaded	9.6	19.5	26.5	67	39	50
6	60%	Loaded	10.1	20.9	26.4	66	37	48
1	30%	Unloaded	11.7	25.3	27.2	67	36	37
2	30%	Unloaded	12.4	25.7	27.5	67	35	36
3	30%	Unloaded	12.8	26.1	27.9	66	34	36
4	30%	Unloaded	11.9	25.9	27.8	66	36	37
5	30%	Unloaded	13.1	63kph*	28.4	63	33	33
6	30%	Unloaded	12.7	63kph*	28.4	63	34	32
1	30%	Loaded	13.4	27.6	29.3	66	35	36
2	30%	Loaded	12.5	27.9	29.8	65	36	37
3	30%	Loaded	14.7	28.4	30.3	66	34	33
4	30%	Loaded	13.9	63kph*	31.1	63	36	35
5	30%	Loaded	14.3	62kph*	31.3	62	34	33
6	30%	Loaded	14.8	61kph*	33.8	61	33	32

note: * = maximum attainable speed

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APPENDIX C

STANDING START ACCELERATION TESTS

TAXI 2

			Elapsed Time (sec)			Terminal Speed (kph)		Dist, m
Run	% of Charge	Loading	0 to 50 kph	0 to 65 kph	0 to 0.4 km	0 to 0.4 km	0 to 5 sec.	0 to 5 sec.
1	100%	Unloaded	9.2	14.1	27.2	66	25	31.0
2	100%	Unloaded	10.3	15.2	29.9	67	22	15.7
3	100%	Unloaded	10.2	18.1	30.5	62	26	19.6
4	100%	Unloaded	12.0	23.8	31.5	62	21	16.0
5	100%	Unloaded	10.8	17.9	26.4	60	19	14.6
6	100%	Unloaded	11.6	21.5	31.9	63	24	18.9
1	100%	Loaded	7.7	13.5	28.1	68	26	18.9
2	100%	Loaded	11.7	18.8	30.7	65	21	13.7
3	100%	Loaded	7.7	15.6	29.7	69	28	21.4
4	100%	Loaded	9.9	17.8	29.8	68	23	16.7
5	100%	Loaded	9.8	18.6	29.1	66	19	11.7
6	100%	Loaded	11.2	21.0	28.8	67	26	20.5
1	60%	Unloaded	8.0	14.1	26.2	66	33	25.8
2	60%	Unloaded	8.5	18.2	29.4	65	32	23.1
3	60%	Unloaded	7.9	13.5	28.1	67	27	18.7
4	60%	Unloaded	5.0	15.2	30.3	67	29	20.9
5	60%	Unloaded	7.9	12.8	28.9	66	20	21.6
6	60%	Unloaded	7.6	14.0	25.3	66	32	24.3
1	60%	Loaded	8.8	14.9	29.7	68	26	19.5
2	60%	Loaded	8.4	14.0	29.1	70	30	15.6
3	60%	Loaded	8.7	12.9	28.1	67	27	20.2
4	60%	Loaded	8.2	15.6	28.6	68	31	16.1
5	60%	Loaded	9.7	18.1	31.1	69	27	19.1
6	60%	Loaded	8.2	12.6	26.8	68	28	21.6
1	30%	Unloaded	7.2	11.3	28.4	68	33	25.9
2	30%	Unloaded	8.1	10.5	22.2	72	38	27.6
3	30%	Unloaded	6.5	9.9	27.0	68	37	30.1
4	30%	Unloaded	7.6	11.89	24.4	70	33	25.9
5	30%	Unloaded	9.0	12.9	24.9	69	24	16.8
6	30%	Unloaded	6.9	10.0	23.8	70	32	24.9
1	30%	Loaded	7.8	12.5	28.9	68	32	10.2
2	30%	Loaded	8.4	12.4	28.9	71	26	19.2
3	30%	Loaded	8.2	13.0	29.2	69	28	21.1
4	30%	Loaded	8.1	12.5	24.1	69	30	22.8
5	30%	Loaded	7.6	12.2	28.7	69	35	29.1
6	30%	Loaded	8.8	12.9	26.5	68	24	17.2

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APPENDIX C

STANDING START ACCELERATION TESTS

CARGO 3
(Horizon Batteries)

			Elapsed Time (sec)			Terminal Speed (kph)		Dist, m
Run	% of Charge	Loading	0 to 50 kph	0 to 65 kph	0 to 0.4 km	0 to 0.4 km	0 to 5 sec.	0 to 5 sec.
1	100%	Unloaded	14.1	19.0	27.2	64	15	17
2	100%	Unloaded	15.5	21.8	31.0	63	16	17
3	100%	Unloaded	15.7	19.8	32.0	61	15	15
4	100%	Unloaded	14.8	19.3	28.1	60	18	20
5	100%	Unloaded	14.3	19.5	29.3	61	17	19
6	100%	Unloaded	15.4	20.6	31.4	62	16	17
1	100%	Loaded	18.3	26.4	31.0	62	11	20
2	100%	Loaded	20.6	27.3	31.5	60	13	15
3	100%	Loaded	19.2	25.4	29.7	61	14	17
4	100%	Loaded	19.9	28.1	30.8	61	12	13
5	100%	Loaded	20.0	27.2	32.1	62	9	10
6	100%	Loaded	19.7	26.9	30.3	61	11	12
1	60%	Unloaded	18.9	26.7	35.2	61	12	13
2	60%	Unloaded	14.8	21.1	31.6	62	13	14
3	60%	Unloaded	14.3	21.6	29.3	61	13	13
4	60%	Unloaded	16.1	20.4	29.2	61	14	15
5	60%	Unloaded	15.8	19.9	28.9	62	15	17
6	60%	Unloaded	15.6	20.3	28.1	61	13	14
1	60%	Loaded	18.2	25.1	29.7	62	13	13
2	60%	Loaded	18.7	24.4	29.6	61	12	13
3	60%	Loaded	18.3	25.6	30.3	60	14	15
4	60%	Loaded	18.9	25.9	33.1	61	13	14
5	60%	Loaded	19.0	26.1	30.6	60	11	12
6	60%	Loaded	19.3	26.7	29.8	60	10	13
1	30%	Unloaded	14.6	18.9	30.4	69	16	16
2	30%	Unloaded	13.2	18.1	29.8	68	15	14
3	30%	Unloaded	12.9	17.8	28.9	69	17	16
4	30%	Unloaded	12.3	16.7	28.5	69	19	19
5	30%	Unloaded	14.9	18.6	30.6	70	14	12
6	30%	Unloaded	12.9	17.9	30.2	71	20	21
1	30%	Loaded	14.8	20.3	30.6	70	16	17
2	30%	Loaded	15.2	21.6	31.1	70	16	17
3	30%	Loaded	14.7	20.2	29.8	70	15	16
4	30%	Loaded	14.9	20.4	30.2	71	20	17
5	30%	Loaded	14.1	21.3	29.9	70	15	16
6	30%	Loaded	15.7	20.5	29.7	71	17	19

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APPENDIX C

STANDING START ACCELERATION TESTS

CARGO 3
(Yuasa Batteries)

			Elapsed Time (sec)			Terminal Speed (kph)		Dist, m
Run	% of Charge	Loading	0 to 50 kph	0 to 65 kph	0 to 0.4 km	0 to 0.4 km	0 to 5 sec.	0 to 5 sec.
1	100%	Unloaded	18.3	27.5	33.6	68	13	18
2	100%	Unloaded	17.6	26.9	29.5	66	15	16
3	100%	Unloaded	17.1	27.7	31.2	70	14	17
4	100%	Unloaded	15.4	26.2	32.3	69	16	15
5	100%	Unloaded	16.8	27.3	36.1	68	13	16
6	100%	Unloaded	15.6	25.8	29.9	69	12	17
1	100%	Loaded	17.6	27.9	33.1	71	16	20
2	100%	Loaded	17.1	26.8	32.7	68	11	16
3	100%	Loaded	17.5	27.9	33.9	69	14	18
4	100%	Loaded	17.3	26.8	33.4	70	16	21
5	100%	Loaded	18.1	27.7	34.5	68	13	19
6	100%	Loaded	17.4	26.7	32.8	69	14	17
1	60%	Unloaded	17.1	24.7	33.7	67	14	14
2	60%	Unloaded	16.7	23.3	32.4	70	15	14
3	60%	Unloaded	14.6	22.1	30.9	68	11	17
4	60%	Unloaded	16.5	24.7	32.7	68	13	13
5	60%	Unloaded	14.8	22.4	30.8	67	9	14
6	60%	Unloaded	16.9	23.2	32.2	69	14	15
1	60%	Loaded	20.2	26.8	33.9	70	15	13
2	60%	Loaded	19.6	26.4	32.8	69	12	16
3	60%	Loaded	18.2	25.3	32.0	69	11	10
4	60%	Loaded	21.1	27.8	34.6	67	13	14
5	60%	Loaded	18.6	25.1	30.7	68	9	13
6	60%	Loaded	18.1	25.4	32.3	69	10	15
1	30%	Unloaded	15.7	23.1	34.1	69	14	18
2	30%	Unloaded	16.8	24.7	35.2	71	13	16
3	30%	Unloaded	14.5	22.3	32.8	69	15	17
4	30%	Unloaded	16.2	23.7	33.9	68	12	16
5	30%	Unloaded	14.9	22.6	32.5	69	14	18
6	30%	Unloaded	15.5	22.9	33.1	67	13	21
1	30%	Loaded	16.9	22.7	34.5	68	16	19
2	30%	Loaded	18.2	23.2	35.2	68	11	15
3	30%	Loaded	16.6	22.6	33.7	67	13	18
4	30%	Loaded	18.7	24.3	34.3	67	14	14
5	30%	Loaded	16.8	22.9	33.9	68	10	18
6	30%	Loaded	20.2	26.5	35.4	68	13	19

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APPENDIX C

PASSING ACCELERATION TESTS

TAXI 1
(RETT)

% of Charge	Run	Loading	Time (sec) 40 to 65 kph	Distance (m)	Run	Loading	Time (sec) 40 to 65 kph	Distance (m)
100%	1	Unloaded	14.3	211	1	Loaded	15.85	157
100%	2	Unloaded	14.16	209	2	Loaded	17.32	192
100%	3	Unloaded	13.7	132	3	Loaded	14.67	163
100%	4	Unloaded	13.82	153	4	Loaded	16.43	182
100%	5	Unloaded	14.01	138	5	Loaded	13.06	168
100%	6	Unloaded	13.64	127	6	Loaded	17.54	171
100%	7	Unloaded	15.29	237	7	Loaded	13.68	152
100%	8	Unloaded	14.72	224	8	Loaded	14.37	159
100%	9	Unloaded	14.34	219	9	Loaded	15.06	167
100%	10	Unloaded	13.84	171	10	Loaded	15.28	186
100%	11	Unloaded	13.26	118	11	Loaded	16.03	169
100%	12	Unloaded	15.48	241	12	Loaded	15.17	174
60%	1	Unloaded	14.32	186	1	Loaded	17.53	219
60%	2	Unloaded	14.47	177	2	Loaded	19.36	239
60%	3	Unloaded	14.61	190	3	Loaded	15.83	183
60%	4	Unloaded	15.27	193	4	Loaded	17.94	206
60%	5	Unloaded	12.79	172	5	Loaded	18.17	213
60%	6	Unloaded	14.36	181	6	Loaded	15.38	179
60%	7	Unloaded	14.53	175	7	Loaded	17.23	199
60%	8	Unloaded	15.07	184	8	Loaded	16.06	194
60%	9	Unloaded	14.31	176	9	Loaded	19.67	246
60%	10	Unloaded	16.43	211	10	Loaded	17.19	201
60%	11	Unloaded	14.75	183	11	Loaded	18.61	227
60%	12	Unloaded	15.48	203	12	Loaded	17.82	213
30%	1	Unloaded	14.72	168	1	Loaded	14.01	177
30%	2	Unloaded	15.84	189	2	Loaded	15.23	181
30%	3	Unloaded	15.02	177	3	Loaded	15.94	199
30%	4	Unloaded	16.86	186	4	Loaded	18.27	187
30%	5	Unloaded	15.32	174	5	Loaded	16.64	193
30%	6	Unloaded	14.88	178	6	Loaded	21.06	209
30%	7	Unloaded	16.73	181	7	Loaded	18.72	192
30%	8	Unloaded	18.59	194	8	Loaded	20.14	211
30%	9	Unloaded	17.05	187	9	Loaded	19.08	194
30%	10	Unloaded	18.37	179	10	Loaded	22.35	218
30%	11	Unloaded	18.29	183	11	Loaded	23.17	232
30%	12	Unloaded	23.17	237	12	Loaded	24.06	241

APPENDIX C

PASSING ACCELERATION TESTS

TAXI 2

% of Charge	Run	Loading	Time (sec) 40 to 65 kph	Distance (m)	Run	Loading	Time (sec) 40 to 65 kph	Distance (m)
100%	1	Unloaded	15.7	219	1	Loaded	17.2	174
100%	2	Unloaded	13.6	209	2	Loaded	16.8	204
100%	3	Unloaded	10.5	198	3	Loaded	15.3	178
100%	4	Unloaded	12.0	164	4	Loaded	14.1	209
100%	5	Unloaded	19.1	252	5	Loaded	14.3	187
100%	6	Unloaded	19.7	118	6	Loaded	19.1	211
100%	7	Unloaded	15.7	119	7	Loaded	16.8	179
100%	8	Unloaded	13.7	122	8	Loaded	17.3	206
100%	9	Unloaded	16.3	132	9	Loaded	15.3	163
100%	10	Unloaded	18.0	107	10	Loaded	18.5	190
100%	11	Unloaded	13.1	154	11	Loaded	14.7	151
100%	12	Unloaded	19.1	108	12	Loaded	16.1	198
60%	1	Unloaded	11.3	125	1	Loaded	14.3	158
60%	2	Unloaded	13.7	203	2	Loaded	13.6	185
60%	3	Unloaded	16.1	173	3	Loaded	12.1	237
60%	4	Unloaded	15.7	216	4	Loaded	12.3	167
60%	5	Unloaded	15.2	152	5	Loaded	13.1	248
60%	6	Unloaded	15.8	193	6	Loaded	15.2	204
60%	7	Unloaded	11.3	170	7	Loaded	13.9	211
60%	8	Unloaded	12.8	183	8	Loaded	14.6	199
60%	9	Unloaded	13.1	198	9	Loaded	12.7	173
60%	10	Unloaded	12.6	189	10	Loaded	15.7	208
60%	11	Unloaded	11.8	191	11	Loaded	13.3	258
60%	12	Unloaded	14.3	211	12	Loaded	14.2	171
30%	1	Unloaded	11.8	126	1	Loaded	16.7	192
30%	2	Unloaded	12.9	156	2	Loaded	16.9	189
30%	3	Unloaded	14.2	139	3	Loaded	17.5	196
30%	4	Unloaded	15.1	196	4	Loaded	16.9	193
30%	5	Unloaded	12.4	132	5	Loaded	17.8	194
30%	6	Unloaded	13.0	192	6	Loaded	17.6	189
30%	7	Unloaded	14.3	141	7	Loaded	17.7	180
30%	8	Unloaded	12.9	171	8	Loaded	16.8	197
30%	9	Unloaded	11.9	136	9	Loaded	16.6	174
30%	10	Unloaded	13.9	187	10	Loaded	17.1	183
30%	11	Unloaded	14.6	173	11	Loaded	16.7	178
30%	12	Unloaded	14.1	158	12	Loaded	17.7	189

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APPENDIX C

PASSING ACCELERATION TESTS

CARGO 3

(Horizon Batteries)

% of Charge	Run	Loading	Time (sec) 40 to 65 kph	Distance (m)	Run	Loading	Time (sec) 40 to 65 kph	Distance (m)
100%	1	Unloaded	9.7	164	1	Loaded	14.8	255
100%	2	Unloaded	10.1	166	2	Loaded	11.3	177
100%	3	Unloaded	11.3	186	3	Loaded	11.7	195
100%	4	Unloaded	7.7	137	4	Loaded	10.9	166
100%	5	Unloaded	8.3	139	5	Loaded	11.8	201
100%	6	Unloaded	9.6	145	6	Loaded	12.3	207
100%	7	Unloaded	7.8	131	7	Loaded	11.4	189
100%	8	Unloaded	10.2	164	8	Loaded	9.7	152
100%	9	Unloaded	9.9	156	9	Loaded	11.6	211
100%	10	Unloaded	9.2	148	10	Loaded	11.2	186
100%	11	Unloaded	9.4	158	11	Loaded	12.4	193
100%	12	Unloaded	9.3	164	12	Loaded	11.2	181
60%	1	Unloaded	11.3	192	1	Loaded	12.4	209
60%	2	Unloaded	9.8	168	2	Loaded	13.2	220
60%	3	Unloaded	13.8	256	3	Loaded	12.6	193
60%	4	Unloaded	11.6	211	4	Loaded	12.9	223
60%	5	Unloaded	11.2	193	5	Loaded	13.6	218
60%	6	Unloaded	10.7	182	6	Loaded	12.1	196
60%	7	Unloaded	11.6	206	7	Loaded	13.4	220
60%	8	Unloaded	11.5	192	8	Loaded	11.5	186
60%	9	Unloaded	11.9	213	9	Loaded	12.8	204
60%	10	Unloaded	12.3	222	10	Loaded	11.7	197
60%	11	Unloaded	11.4	198	11	Loaded	17.7	281
60%	12	Unloaded	11.6	207	12	Loaded	12.2	211
30%	1	Unloaded			1	Loaded	12.3	228
30%	2	Unloaded			2	Loaded	11.1	169
30%	3	Unloaded			3	Loaded	11.8	194
30%	4	Unloaded			4	Loaded	11.6	206
30%	5	Unloaded			5	Loaded	12.4	222
30%	6	Unloaded			6	Loaded	11.0	195
30%	7	Unloaded			7	Loaded	12.4	198
30%	8	Unloaded			8	Loaded	11.3	192
30%	9	Unloaded			9	Loaded	13.2	228
30%	10	Unloaded			10	Loaded	11.7	186
30%	11	Unloaded			11	Loaded	12.1	211
30%	12	Unloaded			12	Loaded	12.8	217

note: data ommission due to instrumentation error

APPENDIX C

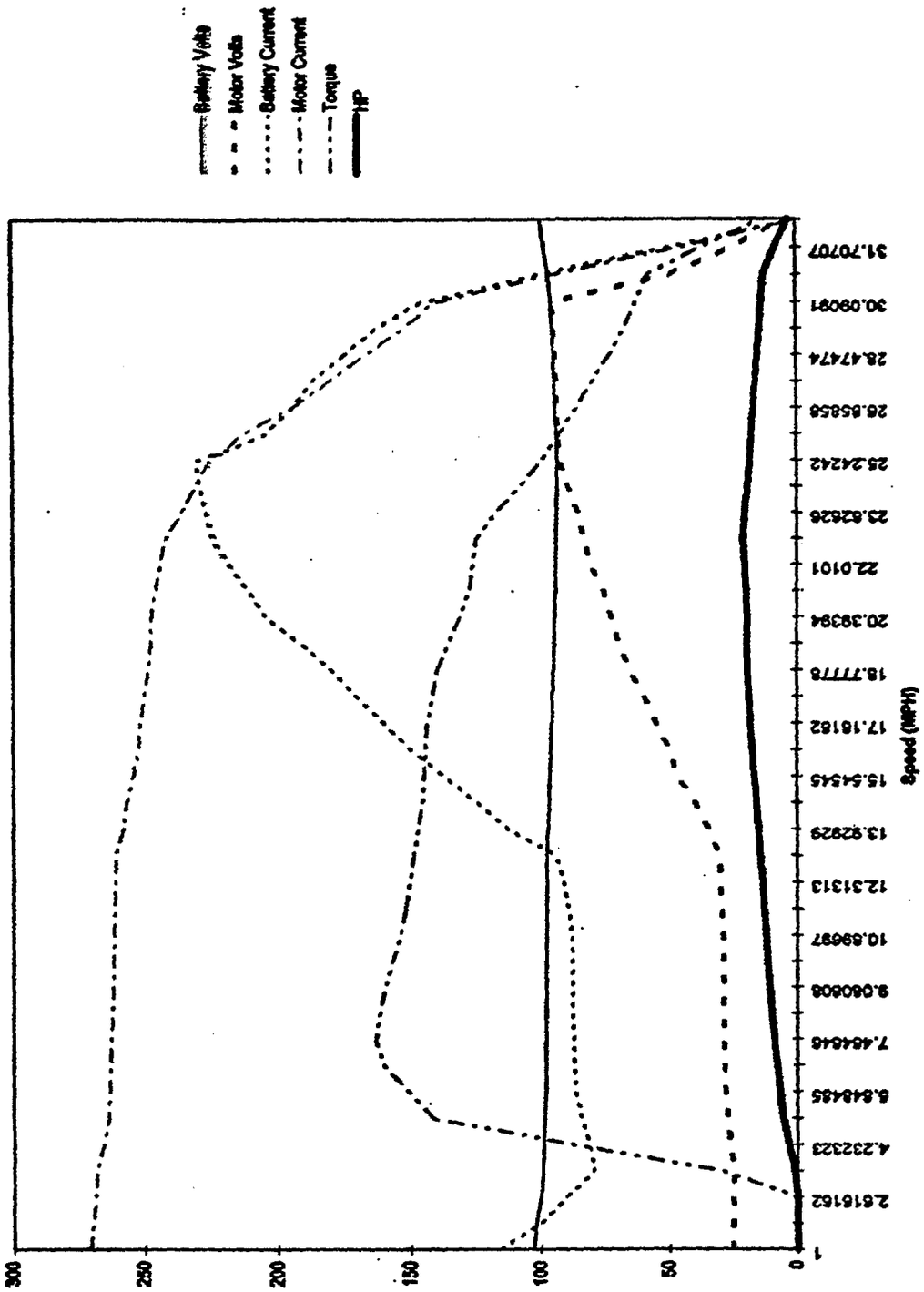
PASSING ACCELERATION TESTS

CARGO 3
(Yuasa Batteries)

% of Charge	Run	Loading	Time (sec) 40 to 65 kph	Distance (m)	Run	Loading	Time (sec) 40 to 65 kph	Distance (m)
100%	1	Unloaded	11.7	169	1	Loaded	11.8	189
100%	2	Unloaded	11.9	171	2	Loaded	13.7	217
100%	3	Unloaded	10.5	151	3	Loaded	12.6	197
100%	4	Unloaded	10.9	161	4	Loaded	13.2	220
100%	5	Unloaded	11.3	167	5	Loaded	12.7	204
100%	6	Unloaded	11.4	169	6	Loaded	13.6	219
100%	7	Unloaded	10.9	157	7	Loaded	12.5	193
100%	8	Unloaded	11.6	177	8	Loaded	14.1	229
100%	9	Unloaded	10.8	158	9	Loaded	13.8	217
100%	10	Unloaded	11.5	167	10	Loaded	12.4	189
100%	11	Unloaded	10.6	154	11	Loaded	11.9	176
100%	12	Unloaded	11.3	163	12	Loaded	12.4	193
60%	1	Unloaded	12.7	201	1	Loaded	13.7	216
60%	2	Unloaded	11.7	189	2	Loaded	13.2	204
60%	3	Unloaded	12.3	213	3	Loaded	14.3	243
60%	4	Unloaded	11.8	197	4	Loaded	13.9	221
60%	5	Unloaded	12.1	215	5	Loaded	14.7	248
60%	6	Unloaded	12.5	221	6	Loaded	13.1	214
60%	7	Unloaded	11.9	214	7	Loaded	13.7	217
60%	8	Unloaded	12.5	232	8	Loaded	14.8	231
60%	9	Unloaded	11.6	194	9	Loaded	13.6	202
60%	10	Unloaded	11.8	217	10	Loaded	14.1	226
60%	11	Unloaded	12.1	226	11	Loaded	13.8	203
60%	12	Unloaded	12.2	233	12	Loaded	13.9	209
30%	1	Unloaded	12.7	236	1	Loaded	14.2	218
30%	2	Unloaded	13.5	228	2	Loaded	13.9	247
30%	3	Unloaded	12.4	203	3	Loaded	13.8	238
30%	4	Unloaded	12.5	209	4	Loaded	14.9	244
30%	5	Unloaded	11.8	197	5	Loaded	14.7	229
30%	6	Unloaded	12.9	224	6	Loaded	14.3	241
30%	7	Unloaded	13.3	242	7	Loaded	15.1	253
30%	8	Unloaded	12.6	221	8	Loaded		
30%	9	Unloaded	13.2	238	9	Loaded		
30%	10	Unloaded	12.3	214	10	Loaded		
30%	11	Unloaded	11.6	193	11	Loaded		
30%	12	Unloaded	12.4	204	12	Loaded		

APPENDIX D

TAXI 1 MOTOR PERFORMANCE



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APPENDIX E

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
Bureau for Global Programs, Field Support and Research
Center for Environment
Office of Energy, Environment, and Technology

THAILAND TUK-TUK ELECTRIC VEHICLE DEMONSTRATION PROJECT

COMPUTER SIMULATION PROGRAM FOR A FUEL CELL/BATTERY POWERED VEHICLE OPERATIONS MANUAL

Research, Development and Demonstration
of a
Fuel Cell/Battery Powered Bus System

September 1992

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S. Romano and J. Thelmo of Georgetown University's Advanced Vehicle Development initiated the development of the HYBRID program. The following organizations supported the development of the program:

OpSearch, Sedona, AZ -- Dr. R. McKenzie, R. Schwartz
University of Florida, Gainesville, FL -- Dr. V. Roan, J. Fletcher
Pavlics Engineering, Santa Barbara, CA -- F. Pavlics

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INTRODUCTION

Purpose: HYBRID is a hybrid bus simulation program and is a practical tool for advanced electric vehicle evaluation studies for use on a PC machine. It simulates the behavior of a phosphoric acid fuel cell/battery electric drive powered bus operation over any user inputted transit route cycle. HYBRID evaluates component sizing and provides performance criteria through user specifications for preliminary design considerations. Both simulation novice and expert will find it effective.

Description: HYBRID program allows for flexibility in user performance analysis. It takes a fuel cell model and battery model to provide the energy prediction both as kW hrs/mile and kW hrs/route. Any transit route or driving cycle can be inputted to establish the energy used and the speed profile of each segment traveled. The vehicle is modeled with respect to propulsion system characteristics and components. The program accepts a vehicle data file with pertinent vehicular characteristics and a route data file. The vehicle proceeds over the route and the program plots pertinent data as a function of time. This time interval can be varied for computation and route segment analysis. The program can be used for trade-off analysis with respect to a wide range of component and subsystem characteristics. The program is written in Fortran, is easy to use, and is optimized for engineering design studies. The software was developed by Georgetown University to support the Fuel Cell Bus program and bus operation applications.

Hardware and Software Requirements: HYBRID runs on IBM PC-AT or IBM PS/2 and compatible microcomputers. It requires at least 512K RAM and a hard disk with at least 3M bytes of free disk space. A math coprocessor chip is also required.

Installation: Before installing the HYBRID program, it is suggested that backup copies of the Hybrid program be made first. Please consult your DOS user manual for disk backup.

> To install HYBRID onto a hard disk, type MD HYBRID <Enter> to create a directory named "hybrid". Then type cd\HYBRID <Enter>. Insert HYBRID diskette #1 into drive A and type copy A:*.* to transfer files from the floppy disk onto the hard disk. Repeat the above copy command with each of the other HYBRID diskettes.

Running HYBRID: To run HYBRID, type cd\HYBRID <Enter> to go into the hybrid directory first, then type HYBR30 <Enter>. See Appendix A.

Inputs: Vehicle configuration, battery, fuel cell, and driving route parameters.

Output: Battery and fuel cell energy output and total power profile, motor armature and field current, average current for the route, battery state-of-charge, battery energy output, fuel cell energy output, battery IR heating and average battery heat loss, total distance traveled, dwell time during the route, energy rate of consumption, speed, and profile throughout the route.

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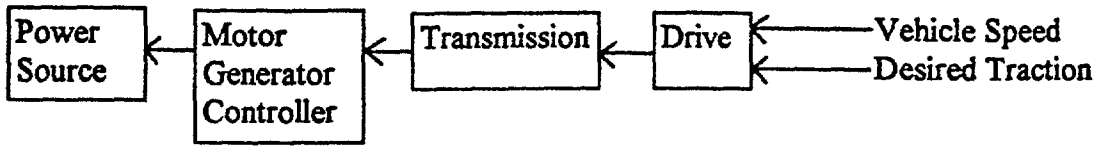
PROGRAM ORGANIZATION

The gross computational flow of the program is shown in Figure 1. At any given time in a simulation the vehicle position and speed are checked against the route segment description to determine the desired vehicle acceleration during the next time interval. The tractive effort needed at the road is computed which uniquely fixes the required output from the drive system, the output speed and torque. All losses in the drive are accounted for in determining the drive input speed and torque to produce the necessary output. These losses include fixed, viscous, differential, gear, and inertia losses.

Figure 1: Basic Computation Flow



Proceeding backwards through the transmission, it is necessary to compute the motor/generator/controller output power which as input to the transmission results in the appropriate input to the drive. Transmission losses are fixed, viscous, and gear losses.

The power losses in the motor/generator/controller accounted for are torque, windage, field and armature resistance, and brush losses. The armature current and voltage are computed which satisfy the desired motor output power. The power source, battery and fuel cell combination must provide this power, accounting for the DC/DC converter efficiency, and that required by the accessories.

The main program logic is shown in Figure 2 giving a detailed view of the computational flow of the computer simulation. The program is initiated by typing the program name, HYBR30, and the user is asked for the filenames of the four required INPUT data files (see APPENDIX A), vehicle, battery, fuel cell and route files. These data are read in and stored in memory for subsequent use. INIT is a subroutine which performs some necessary variable initialization. The first variable check and decision is the comparison of the actual route pass, IPASS, with the number of route passes the user has inputted, NPASS. While IPASS is less than NPASS the simulation proceeds to compare the actual segment number, ISEG, with the total number of segments in the route data file, NSEG. NSEG is determined as the route file is read into memory. If the segment being processed exceeds the last segment the program prints a SUMMARY of pertinent statistics relative to the entire route, the pass is incremented and the program begins again with a check and decision, IPASS vs. NPASS.

The beginning of each segment requires some reinitialization of variables which is performed in the subroutine REINIT. The principal processing is done in the loop after resetting the segment counter and reinitializing. At this point the vehicle position, speed, and desired

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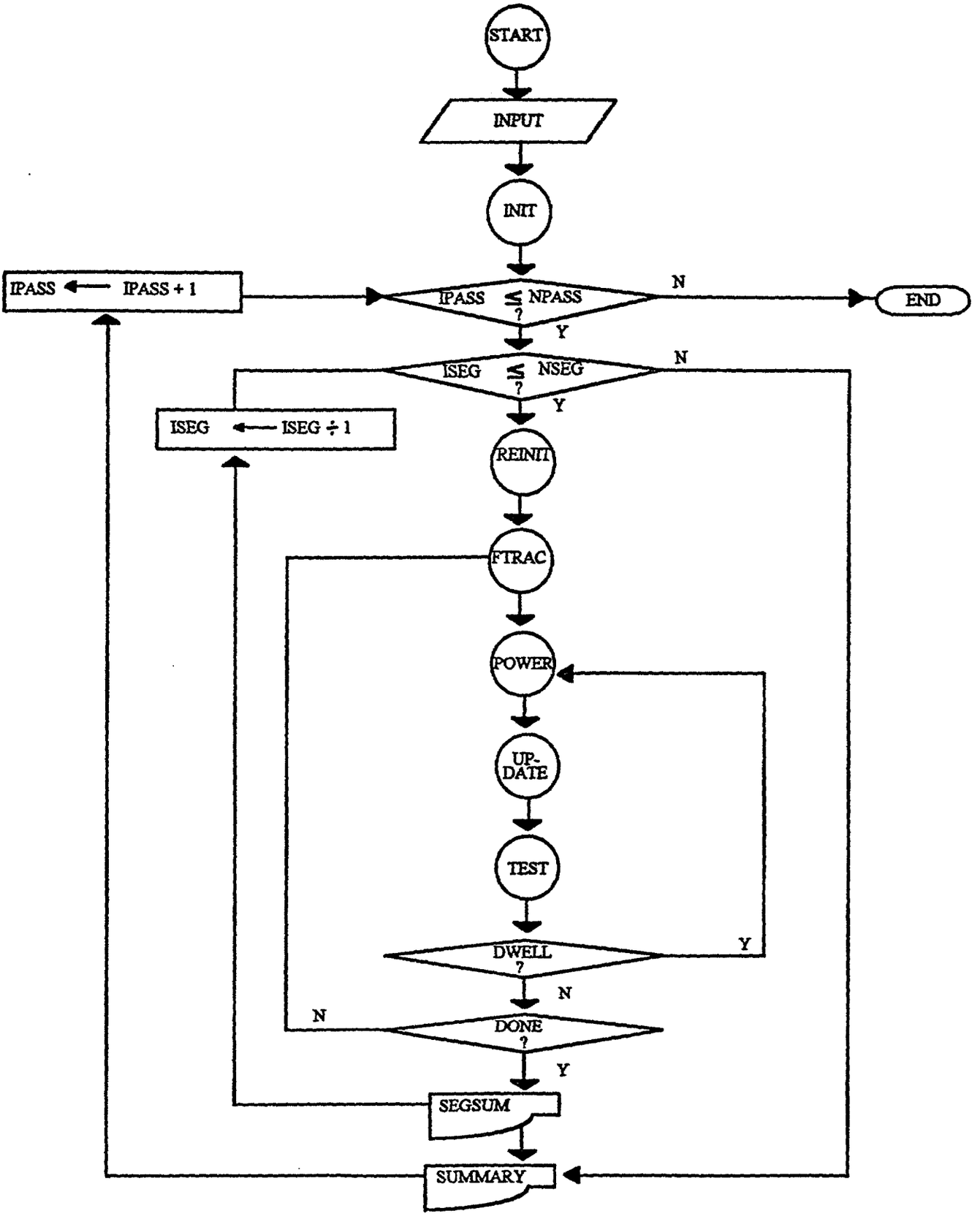
FIGURE 2: MAIN PROGRAM LOGIC



acceleration is known and thus the tractive effort required is computed in the subroutine FTRAC. The subroutine POWER is called next to perform all of the calculations discussed above relative to Figure 1. The power required by the power source together with the power split between the battery and fuel cell is computed. When the power required to produce the desired vehicle acceleration exceeds the limit of the source, the system variables must be recomputed for the power available. At this point in the simulation, an update of the system variables is performed in UPDATE. A fourth-order Runge Kutta integration routine is used to carry out the necessary integration of system variables.

Following the update, a check is made on the vehicle position and speed. This comparison with the input route profile indicates the setting for the desired vehicle acceleration over the next time interval. If the vehicle is in dwell at the end of a segment, a loop is made back to the subroutine power for a computation of power requirements during the dwell time. If the vehicle is not in dwell and the segment not complete, the program loops back to the subroutine FTRAC to calculate the tractive effort. At the end of each segment the subroutine SEGSUM is entered and a summary of statistics for the segment is outputted to the designated output file. The name to be given to the output file is specified by the user at entry.

MATHEMATICAL MODELING

Vehicle

The vehicle model is essentially an expression for the tractive effort required for a given vehicle acceleration with explicit dependence on all vehicle and road parameters. In the simplest form this expression is a statement of Newton's 2nd law:

$$FT = FRL + XMASS\ (J) \times A \tag{1}$$

where

FT = Tractive Force
FRL = Road Load
J = Gear Position
XMASS(J) = Effective Vehicle Mass (a function of gear position)
A = Vehicle Acceleration

$$FRL = \left(f + \frac{G}{100}\right) \times (WC + WPL) + \rho \times CDA \times \frac{V^2}{2} \tag{2}$$

The total vehicle weight, W, is the sum of the vehicle curb weight, WC, and the vehicle payload, WPL. The rolling resistance is the product of the coefficient of rolling resistance, f, and the total

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vehicle weight. The grade resistance is $\frac{G}{100} \times W$ with G as the road slope or gradient in percent. The air resistance is one-half the product of the air density at standard sea level conditions, rho(ρ), the drag coefficient times the vehicle frontal area, CDA, and the vehicle velocity squared.

The effective mass of the vehicle as a function of the gear selected is written as:

$$XMASS\ (J) = \frac{1}{g} \times (WC + WPL + \frac{1}{R^2} \times [IOMEGA + RD^2 \times IDL + (RD \times RT(J))^2 \times IM]) \tag{3}$$

where

W = WC + WPL
IOMEGA = Rotational inertia of wheels, tires, brake drums, etc.
RD = Final drive ratio
IDL = Rotational inertia of drive shaft, pinion, etc.
RT(J) = Transmission ratio
IM = Rotational inertia of motor armature, transmission, etc.
R = Rolling radius
g = Acceleration of gravity

Drive and Transmission

The equations relating the motor output speed and torque to the drive output speed and torque recognize the former as the input to the transmission with the transmission output equal to the drive input, a linear system.

The drive output speed, NDO, is related to the vehicle velocity, V, and the rolling radius, R, by the expression:

$$NDO = \left(\frac{V}{R}\right) \times fps2rpm \tag{4}$$

where fps2rpm is the conversion from feet per second to rpm. The drive output torque, TDO, is the product of the tractive force, FT, and the rolling radius, R:

$$TDO = FT \times R \tag{5}$$

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The transmission output speed, NTO, is linearly related to the drive output speed thru the constant final drive ratio, RD,

$$NTO = RD \times NDO \tag{6}$$

The expression for the transmission output torque, TTO, equal to the drive input torque, accounts for the fixed torque loss measured at the input, TDF, and viscous torque losses.

$$TTO = CUD \times \frac{TDO}{RD} + TDF + CDV \times NTO \tag{7}$$

The last term, the product of the viscous torque loss coefficient measured at input, CDV, and the transmission output torque, together with the fixed torque loss term, is the "spin loss". CUD is a constant which is related to the differential torque efficiency, UD by:

$$\begin{aligned} CUD &= \frac{1}{UD} \quad \text{TDO} \geq 0 \\ &= UD \quad \text{TDO} < 0 \end{aligned} \tag{8}$$

The motor output speed NMO, and torque TMO, inputs to the transmission, are expressed:

$$NMO = RT(J) \times NTO \tag{9}$$

$$TMO = CUT \times \frac{TTO}{RT(J)} + TTF(J) \times \frac{NMO}{(NMO+1)} + CTV(J) \times NMO \tag{10}$$

where RT(J) is the transmission ratio as a function of the gear J and TTF(J), CTV(J) are defined analogously to TDF and CDV, with:

$$\begin{aligned} CUT &= \frac{1}{UT(J)} \qquad TTO \geq 0 \\ &= UT(J) \qquad TTO < 0 \end{aligned} \tag{11}$$

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Motor/Generator/Controller

The motor model assumes a separately excited DC motor operating in either the armature chopping mode or field weakening mode. The former is characterized by the motor output speed, NMO, being less than or equal to the motor base speed, NMB. The base speed is linearly related to the battery voltage output, VB, by the expression:

$$NMB = \left(\frac{NMBO}{VBO}\right) \times VB \tag{12}$$

where NMBO is the motor base speed at the nominal power source voltage, VBO.

In the armature chopping mode (NMO ≤ NMB) the equations for the motor armature current, IA, and armature voltage, VA, have to be solved iteratively to allow the armature current and voltage, and battery output voltage to converge to values consistent with the motor output speed and torque. The armature current is expressed in terms of the motor output speed, NMO, and motor output torque, TMO, by:

$$IA = \frac{\left(TMO + \frac{KV \times NMO}{K}\right)}{KT} \tag{13}$$

where

KV = Windage loss constant (watt/rpm^2)
K = Conversion factor from ft.lb × rpm to watt
KT = Motor torque constant (lb-ft/amp)

The armature power loss, PL, in terms of the armature current:

$$PL = IA^2 \times RA + VBR \times IA + KV \times NMO^2 \tag{14}$$

where

RA = Armature circuit resistance (ohm)
VBR = Brush drop (volt)

and finally, the armature voltage VA, is given by:

$$VA = \frac{(PMO + PL)}{IA} \tag{15}$$

where

PMO = Motor output power (watt)

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The field power loss, PFL, depends on the battery output voltage:

$$PFL = \frac{VB^2}{RF} \tag{16}$$

where RF is the hot field resistance.

In the field weakening mode, the computations for the armature current are carried out with slight modification to the above chopping mode. For this case the armature current is expressed:

$$IA = \frac{(PMO + PL)}{VB} \tag{17}$$

with the armature power loss being given as above. Note the armature voltage is set equal to the battery voltage. The field power loss is, PFL:

$$PFL = IFF^2 \times RF \tag{18}$$

with the field current, IFF, modeled as a function of the ratio of the motor output speed to base speed.

The above equations are written in the output to input direction. If the output conditions yield a value of the armature current greater than the motor armature current limit, IMAX, then IA is set equal to IMAX and motor output torque and ultimately the rest of the drive-train torques are corrected.

The generator model follows from the above. The expression for IÀ applies, the armature voltage is set equal to the battery voltage, with the armature power loss and field power loss determined as in the motor case. If the output conditions yield a value for IA above the regenerative current limit, or a value for VB which is above the gassing point, it is necessary to adjust the generator output to the maximum torque it is capable of absorbing, correct the drive train torques, and take out the difference between the available drive axle decelerating torque and torque required for the vehicle deceleration in friction braking. Above base speed the regenerative current limit is set equal to the minimum of armature current limit in the regen mode and the nominal regenerative current limit. Below base speed the procedure is the same except the nominal regenerative current limit is multiplied by the ratio of the motor speed to the base speed so the "linear" decrease of available power absorption with speed is taken into account.

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Battery

The output voltage, VB, under battery discharge conditions, is given by:

$$VB = VB10(S) - IB1 \times RB1(S) \tag{19}$$

where VB10(S) is the open circuit voltage, IB1 is the current, and RB1(S) the internal resistance. Both the open circuit voltage and resistance are functions of the battery state of charge, S. Under charge conditions the internal resistance is expressed by an alternate function, RB1P(S).

The open circuit voltage, is assumed to be a linear function of the state of charge, S:

$$VB10(S) = V0 + V1 \times S \tag{20}$$

V0 and V1 are battery voltage constants. (Note that the units for the inputs V0 and V1 of Appendix C are volt/cell, conversion to volt is done internally to the program by multiplying these inputs by the number of cells).

From the basic battery power equation:

$$VB \times IB1 = PB1 \tag{21}$$

substituting the expression above for VB, a relationship for the battery current, IB1, is:

$$IB1 = \frac{VB10 - \sqrt{VB10^2 - 4 \times RB1 \times PB1}}{2 \times RB1} \tag{22}$$

in terms of the power demand, PB1, the internal resistance, RB1, and the open circuit voltage.

The battery state of charge, S, is related to the integral of the current over time and the battery capacity, C. The state of charge is given by:

$$S = SO - \int_0^T \frac{IB1(t)dt}{C} \tag{23}$$

where SO is the initial state of charge, and T is the total time. Recognizing that the integral is equal to the product of the average current, IBAR, and the total time, the expression for S can also be written as:

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$$S = \frac{SO - IBAR \times T}{C} \tag{24}$$

The program automatically terminates a run in the event that the state of charge reaches 0.01 or less and prints an inadequate power message.

The hybrid program incorporates two models for the battery capacity, an exponential model and a linear model. The exponential model is found to be consistent with data on the tubular lead acid battery. Data on other battery types such as sodium-sulfur and nickel-cadmium exhibit linear characteristics.

The exponential model for the battery capacity, C, is:

$$C = C0 \times \left(\frac{IBAR}{I0}\right)^{\alpha} \times f\left(\frac{IBAR}{IBMAX}\right) \tag{25}$$

where C0 is the capacity at the constant current, I0, alpha (α) is an exponent which is determined from a log-log plot of capacity vs. discharge current or discharge time vs. discharge current, IBAR, is the average current, IBMAX the maximum value of the current over time T, and B0 and B1 are constants for correcting constant current discharge data to variable current.

The linear battery capacity model is:

$$C = C0 \times \left(B0 + B1 \times \left(\frac{IBAR}{I0}\right)\right) \tag{26}$$

In this case the exponent α is set to zero. Again, the constants B0 and B1 are constants determined from experimental data.

The internal resistance, RB1, is modeled as a cubic function of the state of charge:

$$RB1(S) = R0 \times (R1 + R2 \times S + R3 \times S^2 + R4 \times S^3) \tag{27}$$

with

$$R0 = \left(\frac{RFACTR}{CO}\right) \times NCELL \tag{28}$$

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and NCELL is the number of cells. Thus five constants (RFACTR, R1, R2, R3, and R4) are required input.

The internal resistance in charge is assumed to be an exponential of the state of charge:

$$RB1P(S) = R0 \times R1 \times \exp(0.2303 \times S) \tag{29}$$

Fuel Cell and Reformer[1]

The phosphoric acid fuel cell system, for the ease of analysis has been broken into two parts: the reformer subsystem and the fuel cell subsystem. The reformer subsystem includes the components required to reform the fuel mix, specifically the reformer, vaporizer heat exchanger (hx-01), pumps, blowers and the fuel cell tail gas. The fuel cell sub-system comprises the fuel cell stack, the coolant loop, the step up chopper, start up chopper, start up burner and blower and also the fuel cell blower.

The steady state system has been modeled using the data available from the brass-board test of a 25 kW system and the available data has been scaled up for the 50 kW system. The fuel mix ratio is the ratio of the number of moles of water to that of methanol has been taken as 1.47. The modeling of the vaporizer heat exchanger hx-01 in the steady state case has been based on an energy balance as the flow rates of the coolant and the fuel mix are known and also the approximate inlet and outlet temperatures are known. In the reformer the fuel mix is superheated and steam reformed. The heat for this endothermic reaction is supplied by the fuel cell tail gas which is basically the reformate not consumed by the fuel cell. Also there exists a possibility of adding liquid methanol into the reformer burner based on the necessity. The efficiency of the reformer has been considered to be 90%.

The value of the equilibrium constant has been found as a function of temperature from the JANAF tables. Also assuming that Dalton's las is valid and all gases behave ideally, the composition and quantity of the reformate can be solved for a given flow of the fuel mix using four equations. The following method was used to determine the composition of the reformate leaving the reformer. Assuming that 99% of the methanol is steam reformed, the assumed equation for the reforming process based on one mole of methanol is:

$$CH_3OH + 1.47H_2O \rightarrow 0.01CH_3OH + aCO + bCO_2 + cH_2 + dH_2O \tag{30}$$

The composition of the reformate (a,b,c, and d) is calculated using three mass balance equations:

For Carbon	:	1	=	0.01 + a + b	(31)
For Oxygen	:	1 + 1.47	=	0.01 + a + (2 × b) + d	(32)
For Hydrogen	:	4 + 2.94	=	0.04 + (2 × c) + (2 × d)	(33)

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and the equation for the chemical equilibrium constant, K_p, for the equilibrium chemical equation:

$$cH_2 + bCO_2 \leftrightarrow dH_2O + aCO \tag{34}$$

The equation for K_p is given by:

$$K_p = \log^{-1}(\log_{10} H_2O + \log_{10} CO - \log_{10} H_2 - \log_{10} CO_2) \tag{35}$$

$$= \frac{(a \times d)}{(b \times c)} \tag{36}$$

The value of the equilibrium constant has been found using the $\log_{10}$ values from the JANAF tables. Therefore the assumed equilibrium composition (a,b,c, and d) of the reformate can be found from the equations 31, 32, 33 and 34.

The heat required in the reformer is to superheat and steam reform the fuel mix and also accounts for the losses from the reformer. The heat required to superheat the fuel mix is calculated from:

Q = (mass flow rate of methanol × avg. specific heat of methanol + mass flow rate of water × avg. specific heat of water) × temp. difference

The steam reforming process has been modeled as an isothermal combustion process. The heat required is the change in enthalpies for the reforming equation and is given by the equation:

$$Q_r = \sum_{PROD} (M \times (EOF + C_p \times T_{ref} - 537)) - \sum_{REAC} (M \times (EOF + C_p (T_{ref} - 537))) \tag{37}$$

where:

Q_r	=	heat required to steam reform the fuel mix (Btu/hr)
M	=	molar flow rate (lbmol/hr)
EOF	=	enthalpy of formation at 537.0 °R (Btu/lbmol)
Cp	=	average specific heat (Btu/(lbmol × °R))
T_{ref}	=	temperature of the reforming process (°R)
PROD	=	products of the reforming reaction: $H_2, H_2O, CO, CO_2, CH_3OH$
REAC	=	reactants of the reforming reaction: CH_3OH, H_2O

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The heat loss by convection is modeled as free convection from the top and vertical sides of the reformer. The flue gas which provides for all heat is modeled as a process involving 100% combustion of the unused reformate from the fuel cell. Also the flow rate of air to the reformer burner is adjusted so as to maintain a particular adiabatic combustion temperature. The heat is convectively transferred from the flue gas to the inner walls of the reformer and then conducted through the catalyst bed. This heat transfer is modeled as an energy balance model because the detail reformer design is not yet known. The wall is modeled using a lumped analysis and the convective heat transfer is modeled considering the wall to have a constant surface temperature. Further, the temperature profile of the catalyst bed in the direction of conduction is considered linear. Due to the absence of data on the thermal contact resistance of the pellets in the catalyst bed, it had been assumed that the temperature difference between the wall and the inner catalyst bed is approximately 200°C for the design power output. This assumption is made to determine the conduction and contact resistance. All the above assumptions enable the computer program to calculate the heat transfer coefficient for the given data points. In order to determine the coefficient at all other states, a curve was fitted between the heat transfer coefficient at the given data points and the flow rate of the reformer burner flue gas. In this way the catalyst bed temperature was calculated. The catalyst bed temperature is maintained at the lower limit of 969° R by increasing the fuel mix or the liquid methanol into the reformer burner when the temperature drops down. By bleeding the fuel cell tail gas the upper limit temperature of 1100°R is maintained.

The fuel cell modeling is based on experimentally obtained polarization curve. The relation between the cell voltage and current density for the fuel cell was found by fitting a curve to the available data points. This curve is valid only for a particular stack operating temperature. However, the change in the voltage for different temperatures has been taken into consideration by using the trends of temperature effect on voltage from a technical paper. Another important factor in the fuel cell modeling is the percentage of hydrogen consumed by the cell. Data available on this is a hydrogen gas utilization curve which has been plotted between the fuel cell stack current and the hydrogen used for 25% and 100% power output at 190°C. In order to account for different stack temperatures the following equation has been used:

$$FC_t = FC_{fr} + FC_{temp} \tag{38}$$

where:

FC_t is the maximum consumption of hydrogen gas by the fuel cell stack at the operating temperature.

FC_{fr} is the maximum consumption of hydrogen gas by the fuel cell stack at 190°C.

FC_{temp} is the effect of stack temperature on maximum consumption.

The heat transfer within the fuel cell has been modeled to determine the center of stack temperature. The temperature of all the cells in the stack is assumed to be at the center of stack

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temperature. The theoretical maximum voltage of the cell was calculated by considering the maximum heat generated as 27,583 watts and at 480 amps. The heat generated within the stack for various stack voltages was found using the equation:

$$Q_{gfc} = (1.2525 - \text{stack voltage}) \times \text{cell number} \times \text{current} \tag{39}$$

The heat generated within the fuel cell is removed from the stack by the incoming air, by the coolant and also by radiation and convection losses. The heat required to raise the temperature of air has been modeled by using an energy balance equation by:

$$Q_6 = \text{flow rate} \times \text{average specific heat} \times \text{temperature difference} \tag{40}$$

The convection losses (Q_2) from the sides and the top have been modeled exactly the same way as had been done previously for the reformer. The surface temperature in these cases have been assumed as 10°C less than the center of stack temperature. Most of the heat at higher power output is removed by the coolant, PG-1 mineral oil. This has been modeled by considering the coolant flow to be fully developed and turbulent. The equation used for the heat transfer from the cell to the coolant is:

$$Q_6 = \text{mass flow rate} \times \text{average specific heat} \times (\text{mean outlet temp.} - \text{mean inlet temp.}) \tag{41}$$

The mean inlet temperature is the temperature of coolant leaving the heat exchanger hx-03. The mean outlet temperature is found by assuming a constant surface temperature. From the test data, it was determined that the approximate temperature of the cooing channel surface is equal to 2/3 the temperature difference between the stack and the inlet temperatures.

By adjusting the center of stack temperature Temp(30), the values of Q_2, Q_3 and Q_6 are controlled. Therefore the strategy involved in the modeling has been to first calculate the heat generated, Q_{gfp}, and then adjusting Temp(30) such that:

$$Q_{gfp} = Q_2 + Q_3 + Q_6 \tag{42}$$

The coolant after passing through the cell goes through the heat exchanger hx-01 where the heat is transferred to the incoming fuel mix. This has been modeled and has been described before. Then the coolant passes through hx-03 where heat is either added to or taken away from the coolant in order to control the temperature of the stack. The heat transfer within the hx-03 has to be modeled. For the steady sate, a simple model is used to determine the approximate constant flow rate of methanol into the burner. For this purpose the outlet temperature of the coolant is assumed to be a constant and the required heat transfer (Q_{hx-03}) within the hx-03 is found. If

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Q_{hx-03} is greater than zero, heat is added to the coolant by adding liquid methanol and air to the start-up burner. The combustion products, referred to as burner flue gas, transfers heat to the coolant. In the steady state modeling the flow rate of air is proportional to the flow rate of methanol and therefore the adiabatic combustion temperature. ACT_{sub} is a constant. The heat transferred (Q_{sub-fg}) is calculated by assuming a certain % of the temperature difference, $ACT_{sub} - T_{in}$ as the temperature drop for the burner flue gas through the heat exchanger. By equating the Q_{hx-03} and Q_{sub-fg}, the mass flow rate of the flue gas was found out and consequently the flow rate of liquid methanol into the start up burner was found iteratively. For this model the adiabatic temperature was considered to be 1100°R. If Q_{hx-03} is less than zero, heat (Q_{air}) is removed from the coolant to achieve the required outlet temperature by blowing air through the exchanger. The modeling of this has been done similar to the case when Q_{hx-03} is greater than zero and the flow rate of air is adjusted until $Q_{air} = Q_{hx-03}$.

The chopper in the fuel cell system, controls the voltage generated by the fuel cell to make it compatible to the battery voltage. Consequently there is a reduction in the power output based on the efficiency of the chopper. This has been modeled by fitting a curve between the chopper efficiency and the current output from the fuel cell. The parasitic power requirements of the 50 kW system has been based on the data supplied for the 25 kW system. It has been assumed that for the 50 kW system the power requirement is proportional to the square of the flow rates.

The program assumes that the fuel cell is at minimum power at the beginning of a run. The magnitude of the maximum change in fuel cell output is controlled by the fuel cell response time, the program input parameter TAU. For positive changes in power within the time interval of integration this maximum is:

$$(TFCP(2) - TFCP(1)) \times \frac{DELT}{TAU} \tag{43}$$

where TFCP(2) and TFCP(1) are the fuel cell design power output and minimum power output respectively, DELT is the time interval for integration, and TAU is the fuel cell response time. For negative changes in power the maximum is assumed to be four times that given above.

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Power

The total power required from the power source, battery and fuel cell, is the power input at the motor/generator necessary to produce the desired vehicle acceleration, accounting for all system losses.

The algorithm for the power split between battery and fuel cell considers the fuel cell as the primary source, that is, up to the fuel cell design power output limit the demand is met by the fuel cell. If the total power required of the dual source is less than the fuel cell is capable of producing, excess fuel cell power capacity is used to charge the battery, subject to the battery charging limit. When the total power required exceeds fuel cell capacity, the battery provides additional power within the discharge limit.

Power demands that exceed the total power that can be provided by the battery and fuel cell require additional computations in order to establish all system variables. Instead of proceeding backwards from the road to the power source, calculations start forward from the power source to the motor/generator, transmission, and drive.

Note:
1. This analysis deals with the liquid-cooled fuel cell system. The air-cooled system has also been modeled.

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APPENDIX A

PROGRAM OPERATION

The hybrid computer simulation program is invoked by typing the program name (version 30):

HYBR30

The program then prompts the user for the filename of the input data file describing the vehicle:

Enter input vehicle data filename

and similarly, prompts for each of the other input data files:

Enter input battery data filename

Enter input fuel cell data filename

Enter input route filename

Enter output filename

A summary of the most frequent program error messages is contained in Appendix G with explanation and possible remedy.

To abort the program at any time press Ctrl C.

A sample 3.5" disk, formatted for 1.4 M is supplied with the executable program and sample input files as listed:

HYBR30.EXE	Executable Program File
<u>Vehicle Types</u>	
TBB-30.DAT	Test Bed Bus - Medium Size (30 FT)
TBB-40.DAT	Test Bed Bus - Full Size (40 FT)
G-VAN.DAT	G-Van
<u>Battery Types</u>	
SLI-8D.DAT	8D Size Lead-Acid Cranking Battery (184 AH)
3ET205.DAT	Tubular Lead-Acid Battery (205 AH / G-Van)
NICD-200.DAT	Nickel-Cadmium Battery (200 AH)
<u>Fuel Cell Types</u>	
PAFC-50.DAT	Phosphoric Acid Fuel Cell - 50 kW Output
PAFC-0.DAT	Phosphoric Acid Fuel Cell - 0 kW Output

Routes

TEST.RTE	Test Route to determine vehicle capabilities
GEORGE6.RTE	Georgetown University to Arlington, VA
TCDC.RTE	Transit Coach Duty Cycle by DOT
J227AC1.RTE	Federal Urban Cycle Route

Note: To modify variables in any of the input files, use NORTON or a similar editor.

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APPENDIX B

VEHICLE INPUT DATA DESCRIPTION

An example vehicle data file (TBB-30.DAT) with column number given as an aid to format.

```
                                   Column Number
         1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890

  20000.00   3750.00     0.010     44.00
      2.0       3.0      0.75       0.2        10
     1.42     750.0      6.83       2.5     35.50
     0.96       4.0     0.002
        2
     4000      4000
     1.00      1.00      0.00    0.0000
     1.00      1.00      0.00    0.0000
     1000    216.00      1.39     0.029      2.00   1.00E-4     14.50
     0.96       1.0       1.0      0.96       600       250
      0.9    1250.0   10750.0
   500.00      0.90
```

The variable names corresponding to the above data file are:

```
       WC       WPL       f       CDA
     AMAX      DMAX     DELV     DELT      NSTEP
        R    IOMEGA       RD      IDL         IM
       UD       TDF      CDV
     JMAX
 *DNSHFT(J)  UPSHFT(J)                                                  J = 1,
JMAX-1
     RT(J)     UT(J)    TTF(J)   CTV(J)                                 J = 1,
JMAX
     NMBO      VBO       KT       RA       VBR      KV        RF
   UCA(0)    UCA(1)    UCF(0)   UCF(1)     IMAX    IRMAX0
   UCV       PACC1     PACC2
   PFLNOM    UMNOM
```

Description of variables together with the Fortran format requirements.

Variable Name	Variable Description	Fortran Format
WC	Vehicle curb weight (lb)	F10.2
WPL	Vehicle payload (lb)	F10.2
f	Coefficient of rolling resistance	F10.3
CDA	Drag coefficient × frontal area (ft2)	F10.2
AMAX	Maximum acceleration (ft/sec2)	F10.2
DMAX	Maximum deceleration (ft/sec2)	F10.2

DELV	Vehicle velocity tolerance (mph)	F10.2
DELT	Time interval for integration (sec)	F10.2
NSTEP	Number of time intervals between program output	I10
R	Rolling radius (ft)	F10.2
IOMEGA	Rotational inertia [wheels, tires, brake drums, diff, etc.] (lb-ft2)	F10.2
RD	Final drive ratio	F10.2
IDL	Rotational inertia [drive shaft, diff, pinion, etc.] (lb-ft2)	F10.2
IM	Rotational inertia [motor armature, trans input, etc.] (lb-ft2)	F10.2
UD	Differential torque efficiency	F10.2
TDF	Drive fixed torque loss measured at input (lb-ft)	F10.2
CDV	Drive viscous torque loss coefficient measured at input (lb-ft/rpm)	F10.3
JMAX	Number of gears	I10
DNSHFT(J), UPSHFT(J)	Gear shift point, down and up, vs gear (rpm)	I10
RT(J), UT(J), TTF(J), CTV(J)		
	Transmission ratio vs gear	F10.2
	Transmission torque efficiency	F10.2
	Transmission fixed torque loss measured at input (lb-ft)	F10.2
	Transmission viscous torque loss coefficient at input (lb-ft/rpm)	F10.4
NMBO	Motor base speed at nominal power source voltage, VBO (rpm)	I10
VBO	Nominal power source voltage (volt)	F10.2
KT	Motor torque constant (lb-ft/amp)	F10.2
RA	Armature circuit resistance (ohm)	F10.2
VBR	Brush drop constant (volt)	F10.3
KV	Windage loss constant (watt/rpm2)	E10.2
RF	Hot field resistance (ohm)	F10.2
UCA(0)	Armature controller efficiency [chopping mode]	F10.2
UCA(1)	Armature controller efficiency [weakening mode]	F10.2
UCF(0)	Field controller efficiency [chopping mode]	F10.2
UCF(1)	Field controller efficiency [weakening mode]	F10.2
IMAX	Armature current maximum (amp)	I10
IRMAX0	Nominal regenerative current limit (amp)	I10
UCV	DC/DC converter efficiency	F10.2
PACC1	Accessory power requirement at 28 volts (watt)	F10.2
PACC2	Accessory power requirement at the actual power source voltage (watt)	F10.2
PFLNOM	Nominal field power loss (watt)	F10.2
UMNOM	Nominal motor efficiency	F10.2

* The value of JMAX inputted determines the number of lines of data required for the two entries

	DNSHFT(J)	UPSHFT(J)		
and	RT(J)	UT(J)	TTF(J)	CTV(J)

the input file must contain the lines

DNSHFT(1)	UPSHFT(1)		
DNSHFT(2)	UPSHFT(2)		
.	.		
.	.		
DNSHFT(JMAX-1)	UPSHFT(JMAX-1)		
RT(1)	UT(1)	TTF(1)	CTV(1)
RT(2)	UT(2)	TTF(2)	CTV(2)
.	.	.	.
.	.	.	.
R(JMAX)	UT(JMAX)	TTF(JMAX)	CTV(JMAX)

That is, JMAX-1 lines for the down shift and upshift points (rpm at which gear shifts are to occur, and JMAX lines for the transmission values.

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APPENDIX C

BATTERY INPUT DATA DESCRIPTION

An example battery data file (SLI-8D.DAT) with column number given as an aid to format.

```
                                        Column Number
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

     0.05      1.00
   1.9700    0.1360       108    0.0930    1.4680   -1.2760    0.6803    0.0000
    256.0      0.00     184.0        37      1.04     -0.05      0.70
     65.0      75.0
```

The variable names corresponding to the above data file are:

```
AMPX     VOLTX
V0       V1       NCELL   RFACTR   R1       R2       R3       R4
VGAS     ALPHA    C0      I0       B0       B1       S0
SOCMIN   SOCMAX
```

Description of variables together with the Fortran format requirements.

Variable Name	Variable Description	Fortran Format
AMPX	Current tolerance (amp)	F10.2
VOLTX	Voltage tolerance (volt)	F10.2
V0	Battery voltage constants (volt)	F10.4
V1		F10.4
NCELL	Number of cells	I10
RFACTR	Battery resistance constant (ohm-amp-hr/cell)	F10.4
R1	Battery resistance constants	F10.4
R2		F10.4
R3		F10.4
R4		F10.4
VGAS	Battery gassing voltage (volt)	F10.2
ALPHA	Exponent in battery capacity equation	F10.2
C0	Battery capacity at constant current I0 (amp-hr)	F10.2
I0	Constant current (amp)	I10
B0	Constants for correcting current discharge data	F10.2
B1		F10.2
S0	Initial state of charge	F10.2
SOCMIN	Minimum allowed state of charge (%)	F10.2
SOCMAX	Recovery state of charge (%)	F10.2

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APPENDIX D

FUEL CELL INPUT DATA DESCRIPTION

An example fuel cell data file (PAFC-50.DAT) with column number as an aid to format.

```
                                   Column Number
          1         2         3         4         5
12345678901234567890123456789091234567890123456789 0

      1.0
   40000.0   50000.0
      0.99      0.99      0.60      0.75
      1.5       1.0
    537.0     537.0     825.0    1540.0    1113.0
      1.00      0.05
     20.0      20.0
   2000.0     176.0
      0.90    240
```

The variable names corresponding to the above data file are:

```
   DESIGN
   TFCP(1)    TFCP(2)
    RE(1)      RE(2)     FC(1)     FC(2)
    FMR         E
    TFM       TAIR       TBG       ACT    REJTEM
   XMAIR      DELM
 AVGRP(1)   AVGRP(2)
    CA       CELLNO
   CEFF        TAU
```

Description of variables together with the Fortran format requirements.

Variable Name	Variable Description	Fortran Format
DESIGN	Design Type : 0.0 = ERC AND 1.0 = Booz-Allen & Hamilton	F10.2
TFCP(1)	Fuel cell minimum power output (watts)	F10.2
TFCP(2)	Fuel cell design power output (watts)	F10.2
RE(1)	Reformer efficiency at TFCP(1)	F10.2
RE(2)	Reformer efficiency at TFCP(2)	F10.2
FC(1)	Portion of H2 gas consumed by fuel cell at TFCP(1)	F10.2
FC(2)	Portion of H2 gas consumed by fuel cell at TFCP(2)	F10.2
FMR	Fuel mix ratio, water to methanol	F10.2
E	Multiplying factor for H2 flow rate	F10.2

TFM	Temperature of fuel mix (R)	F10.2
TAIR	Temperature of burner air (R)	F10.2
TBG	Temperature of fuel cell bleed gas (R)	F10.2
ACT	Adiabatic combustion temperature (R)	F10.2
REJTEM	Rejection/exhaust temperature (R)	F10.2
XMAIR	Flow rate of air into the reformer burner (lbMOL/hr)	F10.2
DELM	Change in flow rate of CH3OH into the reformer burner (lbMOL/hr)	F10.2
AVGRP(1)	Reformer pressure for ERC (psia)	F10.2
AVGRP(2)	Reformer pressure for BA&H (psia)	F10.2
CA	Area per cell of the fuel cell (cm**2)	F10.2
CELLNO	Number of cells in fuel cell	F10.2
CEFF	Chopper efficiency	F10.2
TAU	Response time (sec)	I10

APPENDIX E

ROUTE INPUT DATA DESCRIPTION

An example route data file (partial george6.rte) with column number given as an aid to format.

Column Number

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

1 Arlington Guts Bus Route		Dist	Elev	MPH	Dwell
Podium A (Transportation Center)	(pickup)	0	140	0	0
parking lot stop sign #1	(stop sign)	404	153	15	2
parking lot stop sign #2	(stop sign)	236	155	15	2
St. Mary's	(pickup)	165	159	15	20
enter Reservoir Road	(stop sign)	289	162	15	3
apartment entrance (36th St.)		564	182	25	0
Reservoir Road/35th St.	(traffic light)	464	176	25	10
35th St./Volta	(stop sign)	1061	146	25	2
35th St./P St.	(stop sign)	362	133	25	2
35th St./O St.	(stop sign)	362	117	25	2
35th St./N St.	(stop sign)	363	108	25	2
N Street/34th St.	(stop sign)	334	104	25	2
34th St./Prospect St.	(stop sign)	293	103	25	2
34th St./M St.	(traffic light)	283	78	20	50
.....etc.					

The variable names corresponding to the above data file are:

NPASS HEADING
DESC LENGTH ELEV VMAX TDWELL

Description of variables together with the Fortran format requirements.

Variable Name	Variable Description	Fortran Format
NPASS	Number of passes of the complete route	I5
HEADING	Heading	A75
DESC	Segment description	A50
LENGTH	Segment length (ft)	I8
ELEV	Segment elevation (ft)	I8
VMAX	Maximum allowed speed (mph)	I7
TDWEL	Dwell time (sec)	I7

APPENDIX F

PROGRAM OUTPUT DESCRIPTION

The variable names used in this appendix have been explained in previous places in the documentation. A brief description of a typical output file is given here as an aid to understanding the main power balance. Figure 3 shows the output of data from the first segment of a standard test route.

The calculations below are for the output at TIME = 16.00 seconds. Input data pertinent to the calculations given below are:

UCV	=	0.90
PACC1	=	1250.00 watt
PACC2	=	10750.00 watt
RF	=	14.50 ohm
NMBO	=	1000 rpm
VB0	=	216.00 volt
RT(1)	=	1.00
RD	=	6.83
R	=	1.42 ft
fps2rpm	=	60 / 2*pi
UCA(1)	=	1.00
UCF(1)	=	.96
RA	=	0.029 ohm
VBR	=	2.00 volt
KV	=	10^{-4} watt/rpm^2

The total output power (battery plus fuel cell)

$$PB0 = PB1 + PB2$$
$$=10.66+40.00$$
$$=50.66 \text{ kW}$$

$$PB0 = VA \times \frac{IA}{UCA(MODE)} + \frac{PACC1}{UCV} + PACC2 + \frac{PFL}{UCF(MODE)}$$

Field Power Loss

$$PFL - IFF^2 \times RF$$

$$= (14.85)^2 \times \frac{14.50}{1000}$$

$$= 3.20kW$$

Accessory Power Loss

$$\frac{PACC1}{UCV} + PACC2 = 1.39 + 10.75$$

$$=12.14 \text{ kW}$$

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Mode Determination (armature chopping or field weakening)
Motor Base Speed

$$NMB = \frac{NMBO}{VBO} \times VB$$

$$= \frac{1000}{216} \times 220.61$$

$$= 1021.34 \text{ rpm}$$

Motor output speed

$$NMO = RT(J) \times RD \times \frac{V}{R} \times fps2rpm$$

$$= 1.00 \times 6.83 \times \frac{22.79}{1.42} \times \frac{60}{2\Pi}$$

$$= 1046.76 \text{ rpm}$$

Since the motor output speed is greater than the motor base speed, the motor is in the field weakening mode (MODE = 1)

$$PB0 = 35.20 + 1.39 + 10.75 + 3.33$$

$$= 50.67 \text{ kW}$$

which checks with the power delivered by the power source.

Motor output power

$$PMO = VA \times IA - PL$$

$$PL = IA^2 \times RA + VBR \times abs(IA) + KV \times NMO^2$$
$$= 0.74 + 0.32 + 0.11$$
$$= 1.17 \text{ kW}$$

$$PMO = 35.20 - 1.17$$
$$= 34.03 \text{ kW}$$

All numbers in the output have been rounded so the above calculations can be expected to agree to one place past the decimal.

FIGURE 3

PROGRAM OUTPUT

PROGRAM HYBRID FOR GEORGETOWN UNIVERSITY
VERSION 3.0

Date 6 13 1992
Time 21:58:57.80

Vehicle Data File	tbb-30.dat
Battery Data File	sli-8d.dat
Fuel Cell Data File	pafc-50.dat
Route Description File	george6.rte
Output File	tbb-geo6.run

parking lot stop sign #1 (stop sign) Length 404 ft Grade 3.22% VMAX 15 mph DWELL 2 sec

Time (sec)	Distance (ft)	Speed (mph)	Gear	Armature Current (amp)	Armature Voltage (volt)	Field Current (amp)	Motor Output (kW)	Output (kW)	Fuel Cell Current (amp)	Voltage (volt)	Output (kW)	Battery Current (amp)	Voltage (volt)
.00	.00	.00	1	401.18	13.63	15.96	.00	40.00	40.00	.00	-22.16	-95.52	232.03
2.00	4.00	2.73	1	401.61	46.27	15.57	13.10	40.00	355.13	112.63	-4.99	-22.16	225.13
4.00	16.00	5.45	1	402.33	82.54	15.25	27.70	40.00	355.13	112.63	10.10	45.75	220.78
6.00	35.99	8.18	1	403.32	118.80	15.01	42.36	40.00	355.13	112.63	25.32	116.52	217.26
8.00	63.99	10.91	1	404.56	155.07	14.76	57.13	40.00	355.13	112.63	40.65	190.29	213.60
10.00	99.97	13.63	1	406.07	191.34	14.49	72.02	40.00	355.13	112.63	56.12	267.55	209.75
12.00	143.60	15.54	1	159.54	220.61	14.85	34.03	40.00	355.13	112.63	10.66	48.34	220.61
14.00	189.17	15.54	1	159.54	220.61	14.85	34.03	40.00	355.13	112.63	10.66	48.34	220.61
16.00	234.75	15.54	1	159.54	220.61	14.85	34.03	40.00	355.13	112.63	10.66	48.34	220.61
18.00	280.33	15.54	1	159.54	220.61	14.84	34.03	40.00	355.13	112.63	10.66	48.34	220.61
20.00	325.85	15.13	1	-149.34	245.47	16.93	-37.71	40.00	355.13	112.63	-58.90	-239.84	245.57
22.00	364.25	11.04	1	-113.36	242.34	16.71	-28.13	40.00	355.13	112.63	-50.18	-206.95	242.49
24.00	390.65	6.96	1	-74.94	239.00	16.48	-18.25	40.00	355.13	112.63	-41.12	-171.89	239.21
26.00	405.05	2.87	1	-34.22	235.46	16.24	-8.16	40.00	355.13	112.63	-31.77	-134.78	235.72
28.80	408.00	.00	1	.00	.00	.00	.00	40.00	355.13	112.63	-27.86	-118.94	234.24
29.60	408.00	.00	1	.00	.00	.00	.00	40.00	355.13	112.63	-27.86	-118.94	234.24
29.80	408.00	.00	1	.00	.00	.00	.00	40.00	355.13	112.63	-27.86	-118.94	234.24

1 - 1		
	BATTERY AMPERE HRS [amp-hr]	-.01
	AVERAGE CURRENT [amp]	-1.43
	BATTERY IR HEATING [kW-hr]	.01
	AVERAGE BATTERY HEAT LOSS [kW]	.98
	STATE OF CHARGE	.70
	BATTERY ENERGY OUTPUT [kW-hr]	-.01
	FUEL CELL ENERGY OUTPUT [kW-hr]	.33
	AVERAGE ARMATURE POWER LOSS [kW]	2.57
	FUEL CONSUMPTION [mi/gal]	1.35

APPENDIX G

ERROR MESSAGES

If any of the four input files (vehicle, battery, fuel cell, and route) are incorrectly specified, the typical error message would be:

HYBR30.for(lnum) : run-time error F6416: OPEN(fname)
- file not found

where lnum is the program line number where the OPEN error occurred. The file named fname could not be found.

An OPEN error can also occur if the output file specified is a file which already exists.

HYBR30.for(lnum) : run-time error F6415: OPEN(fname)
- file already exists

The output file must be unique.

If an input parameter value is incorrectly specified the error message will contain the file in which the error occurred together with the type of the error. For example, the message

HYBR30.for(lnum) : run-time error F6101: READ(fname)
- invalid INTEGER

would indicate that the program attempted to READ an integer in the file named fname and found a value not formatted as an integer.

When an input parameter value is read as zero and that parameter appears within the program as a divisor the error message

HYBR30.for(lnum) : run-time error F6103: MATH
- floating-point error : divide by 0

The MATH error is more difficult for the user to fix since the faulty input number could be in any one of the four input files. The user should carefully compare the values in the input files with those printed on the first two pages of the output file. The latter contains the values which the program actually read.

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Center for Environment
Office of Energy, Environment, and Technology

THAILAND TUK-TUK ELECTRIC VEHICLE DEMONSTRATION PROJECT

TECHNICAL BACKGROUND OF DRIVE CYCLE APPROXIMATION PROGRAM

Prepared for:

Royal Thai Government
Ministry of Science, Technology and Environment
Pollution Control Department

Prepared by:

Energy Technology Innovation Project
Contract No. DHR-5741-C-00-1061-00
Prime Contractor: Bechtel Corporation

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ETIP

DCAP

Drive Cycle Approximation Program
Version 2.0

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DCAP

Drive Cycle Approximation Program Version 2.0

How To Utilize DCAP for Vehicle Data Analysis with HYBRID309

DCAP acts as a system wrapper to properly format data for use with the simulation program HYBRID309.

1) DCAP takes data output from the FLUKE Data Bucket and performs several levels of data reduction to create the appropriate data files for input into HYBRID309.

2) Since HYBRID309 is limited to only 300 data segments, DCAP iteratively prepares 300 point data sets, launches HYBRID309, extracts the final data state from the HYBRID309 output and uses this final state to start the next interative run of HYBRID309.

3) DCAP accumulates relevant output data and presents this summary at the end of the concatenated output files from multiple runs of HYBRID309.

4) Minimum system requirements to run DCAP: Windows 95 or Windows NT operating systems, Microsoft Excel 5.0 or later and an IBM compatible computer with a 486 or greater processor and 8MB of RAM . HYBRID309, DECAP and all data files must reside in the same directory.

How To Create an Input File for DCAP

1) To create an input file for DCAP, first import the DIF file output by the FLUKE Data Bucket into Microsoft Excel.

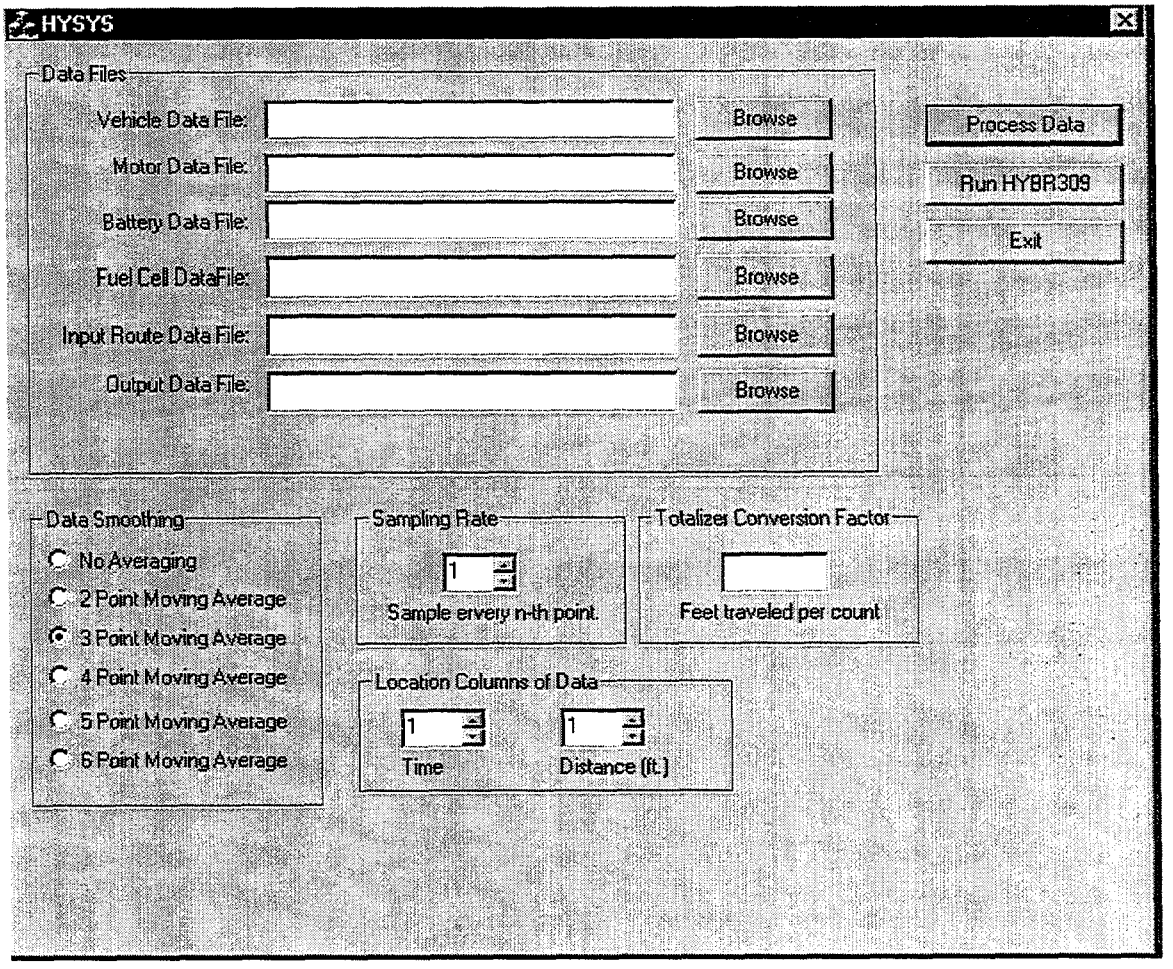
2) The first three lines of this file are used for titles. DCAP will skip the first three lines before beginning to process the data.

3) No data processing by the user is required. Note the column numbers in which the TIME and the TOTALIZER data is stored. These column numbers must be input into the DCAP main entry screen.

4) Save the file out of Excel as a "Tab delimited" text file. Use the Excel command, FILE-SAVE AS and select the tab delimited format. The default file extension is "txt", but you may use any file extension.

How To Run DCAP

1) DCAP.exe is a Windows95/WindowsNT program. Start DCAP from Explorer, a shortcut or run it from the START menu.



DCAP Data Input Window

2) DCAP will prompt you for input on its main window.

3) Click on the BROWSE button and select the filename of the Vehicle data file, formatted to the specifications of HYBRID309.

4) Click on the BROWSE button and select the filename of the Motor data file, formatted to the specifications of HYBRID309.

5) Click on the BROWSE button and select the filename of the Battery data file, formatted to the specifications of HYBRID309.

6) Click on the BROWSE button and select the filename of the Fuel Cell data file, formatted to the specifications of HYBRID309.

7) Click on the BROWSE button and select the filename of the Input Route data file, formatted as a tab delimited text file from Microsoft Excel. This file is the data collected from the FLUKE Data Bucket.

8) Enter the name of the file you wish to store the output of the simulation run.

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How To Process the Data

1) Enter the number of data points to be used to smooth the data using a moving average technique. The default is three data points. You may select 0 through 6 points for averaging.

2) Enter the sampling rate. The data will be sampled at every n-th point. Default sampling is every point. The upper limit is sampling every 100 points.

3) Enter the data column numbers where the TIME and TOTALIZER channels appear in the input data file. Available column numbers are 1 to 21.

4) Enter the Totalizer Conversion Factor in feet. This is the number of feet the vehicle travels in one pulse of the Totalizer channel. This must be calibrated for the vehicle from which the input data was obtained.

5) Click on the PROCESS DATA button.

Running HYBRID309

1) Once the data has been input and processed as above, click on the RUN HYBR309 button to start the simulation.

2) DCAP will select the first 300 data points from the input file and create input files for HYBRID309. DCAP then launches the simulation program and captures all of the output data. The final State of Charge for the batteries is extracted from the HYBRID309 output file and is used as the input State of Charge for the next iteration.

3) DCAP selects the next 300 data points from the input file and create input files for HYBRID309. DCAP then launches the simulation program again and captures all of the output data. The final State of Charge for the batteries is extracted from the HYBRID309 output file and is used as the input State of Charge for the next iteration.

4) This process continues until all of the input data has been used in simulations.

5) All of the HYBRID309 output is concatenated a the single output file. In addition to this output, DCAP extracts certain data from each iteration, accumulates the data over multiple iterations and presents a data summary at the end of the output data file.

6) The following data is summarized by DCAP over the entire simulation run:

```
   Example of DCAP Overall Output Summary:

Total distance traveled [mi]                2.29
Total dwell time [min]                      2.13
BATTERY AMPERE-HRS [amp-hr]                 4.29
BATTERY ENERGY OUTPUT [kw-hr]               0.51
Final State of Charge                        .95
Rate of energy consumption [kw-hr/mi]       0.22
```


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THAILAND TUK-TUK ELECTRIC VEHICLE DEMONSTRATION PROJECT

URBAN IN-SERVICE TESTING

DATA INSTRUCTION MANUAL

Prepared for:

Royal Thai Government
Ministry of Science, Technology and Environment
Pollution Control Department

November 1995

Prepared by:

Energy Technology Innovation Project
Contract No. DHR-5741-C-00-1061-00
Prime Contractor: Bechtel Corporation

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INTRODUCTION

This instruction manual describes the procedures that shall be used for the in-service testing of battery operated tuk-tuks.

The base of operations for the testing is anticipated to be at 24118 Soi Sirthavorn in Kapi.

1) Test Data Storage

2) Downloading Data Sets Larger than 16K records

3) Downloading Data Sets Smaller than 16K records

4) Running HYBRID 309

5) Naming Data Files

6) Storing Data Files

7) Technical Background of Drive Cycle Approximation Program (contained in DCAP)

8) Drive Cycle Approximation Program (contained in DCAP)

1. TEST DATA STORAGE

It is recommended that the totalizer be zeroed every three hours. Assuming a maximum 184 kilometers (115 miles) distance traveled in a shift, the average number of revolutions in three hours is 34,000. The totalizer can accommodate approximately 60,000 pulses.

2. DOWNLOADING DATA SETS LARGER THAN 16K RECORDS

Fill out daily log.

1) Turn off fluke recorder.

2) Remove 2 meg disk from recorder and insert into conversion drive.

3) Using fluke software, save file as *.CSV (comma separated variable format).

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4) From ACCESS database, retrieve the *.CSV file.

a. Query 4 hour segments. The segments will be the following:

02:00-06:00
06:00-10:00
10:00-14:00
14:00-18:00
18:00-22:00
22:00-02:00

If any "spill over" exists from the beginning or ending of shifts (i.e., shift begins at 01:53:24 rather than 02:00:00), include the spill over with that segment. In the above example, the first segment spans 01:53:24-05:59:59, or when the next drive cycle ends.

b. Each query shall be formed in the following manner:

Column 1:	Time stamp
Column 2:	Voltage (optional)
Column 3:	Totalizer
Column 4:	Optional Channel
Column 5:	Optional Channel
Column 6:	Optional Channel
Column 7:	Optional Channel
Column 8:	Optional Channel
Column 9:	Optional Channel

Optional channels are available so that the user can include other data that was recorded, such as load.

c. Export each query as an EXCEL 5.0 file containing no more than 15, 000 records.

5) From EXCEL 5.0, retrieve the *.DIF file.

Use the Excel command FILE-SAVE AS and select the tab delimited format. The default extension is "txt" but you may use any file extension.

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3. DOWNLOADING DATA SETS SMALLER THAN 16K RECORDS

1) Turn off fluke recorder.

2) Remove 2 meg disk from recorder and insert into conversion drive.

3) Using fluke software, save file as *.DIF (Data Interchange Format).

4) From EXCEL 5.0, retrieve the *.DIF file.

   Use the Excel command, FILE-SAVE AS and select the tab delimited format. The default extension is "txt" but you may use any file extension.

4. RUNNING HYBRID 309

1) From the HYBRID 309 subdirectory, make sure that all the input files are present including the drive cycle created above.

   a. Run HYBR309, typing the names of each input file and output file when prompted.

2) Output is generated as a DOS text file and can be evaluated from a text editor or any commercial word processor.

3) All output files shall be named with the nomenclature described below.

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5. NAMING DATA FILES

Files will be named according to date, shift, segment and version. The nomenclature is as follows:

Day: 01, 02, 03 ... 29, 30, 31

Month:

January	J	July	L
February	F	August	G
March	M	September	S
April	A	October	O
May	Y	November	N
June	U	December	D

Year:

1995 = 5
1996 = 6
1997 = 7
1998 = 8

Shift: 1, 2, 3 ... 9

Version of File and Vehicle Identification

Vehicle 1, Blue Taxi:	A, B, ... H
Vehicle 2, Green Taxi:	J, K, ... Q
Vehicle 3, Red Cargo:	S, T, ... Z

Segment of Shift: For instances in which more than one memory card is used.

Example:

For 15 May 1996, Shift 2, Segment 3, File Version 2 for Green Taxi: 15Y6_23K.*,
where *=DIF, CSV, XLS, MDB, etc.

This nomenclature allows for up to nine segments for each shift and up to eight versions of the file for each vehicle.

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6. STORING DATA FILES

Each shift will require one disk to store data. The data must be compressed to fit on a 1.44 megabyte disk. The typical shift will accumulate approximately two megabytes of data.

The following discussion provides an overview of file storage for each format:

Data collected on the Fluke Disk. Will be converted to either a CSV or DIF format and placed on the hard drive. DATA on the fluke disk will be erased as data will be collected from the next day.

Converted CSV/DIF Files. Mandatory. The CSV or DIF file formats are used to import data into ACCESS or EXCEL. These files are a record of the raw data and shall be archived using the nomenclature described in *Naming Files.* The data shall be compressed and copied on two 1.44 megabyte disks, each stored in a separate location. Creating more copies is advisable as a safety measure.

ACCESS Files. Optional. These files will need to be stored until the analysis for that day is complete. However, long term storage is not necessary because these files can be recreated from the converted CSV files.

EXCEL Files. Optional, but desirable. While these files can be recreated from the CSV or DIF formats, the time and effort involved can be lengthy. Therefore, if disk space exists, either a portion or all the files should be stored in case of further use.

Drive Cycles. Mandatory. These files are the final product, which will be used as the input drive cycle file for HYBRID 309. Similar to the CSV/DIF files, at least one back up copy shall be made and stored in a separate location.

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APPENDIX F

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
Bureau for Global Programs, Field Support and Research
Center for Environment
Office of Energy, Environment, and Technology

THAILAND TUK-TUK ELECTRIC VEHICLE DEMONSTRATION PROJECT

DEVELOPMENT OF A METHODOLOGY FOR ASSESSING THE AIR QUALITY IMPACTS OF THE GASOLINE AND LPG VS. ELECTRIC TUK-TUK PROJECT IN THE BANGKOK METROPOLITAN REGION THAILAND

Final Draft Report

June 1995

Prepared for:

Royal Thai Government
Ministry of Science, Technology and Environment
Pollution Control Department

Prepared by:

Energy Technology Innovation Project
Contract No. DHR-5741-C-00-1061-00
Prime Contractor: Bechtel Corporation
Subcontractor: Core International, Inc.

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I. INTRODUCTION

A. OBJECTIVE

This report is the result of a request from the Bechtel Corporation, prime contractor for the USAID Office of Energy Technology and Environment's (EET) Energy Technology Innovation Project (ETIP), for a methodology for assessing the air quality impacts of replacing LPG and gasoline Tuk Tuks with electric Tuk Tuk vehicles in the Bangkok Metropolitan Region (BMR).

Given (i) the air pollution levels in Bangkok, and (ii) the ever increasing population of motor vehicles (automobiles, Tuk Tuk vehicles and motorcycles), EET is interested in developing a methodology which will allow a comparative assessment of ambient air quality impacts of replacing LPG and gasoline with electric Tuk Tuk vehicles. This methodology will consider the gains in air quality by replacing the internal combustion Tuk Tuks with electric Tuk Tuks and also the environmental impacts associated with increased electricity generation. The methodology will convert emissions values to economic inputs which can be used as input data to the economic model.

B. BACKGROUND

Thailand has accomplished a rapid transformation from a predominantly agricultural-based economy in the 1960s to an industrialized economy with a strong private sector and a healthy capability to finance a major portion of the public sector expansion with domestic resources. The economy of Thailand grew by an average of 10% during the period 1987-1994 and is expected to grow at a similar rate in the near future.

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Air quality in the Bangkok Metropolitan Region (BMR) has been monitored and emissions data have been collected by the government for many years. The most complete data base is most likely that of the Department of Pollution Control. In addition, the Office of Environmental Policy and Planning has established guidelines for the evaluation of the environmental impacts associated with infrastructure development. In the BMA, air quality data are collected from curbside monitoring stations and permanent ambient air quality monitoring stations. Gasoline and LPG powered Tuk Tuks produce emissions directly from the operation of the 2 cycle and 4 cycle engines. Electricity powered Tuk Tuks, however, produce no direct emissions, but rather indirect emissions from the generation of the power used to recharge the electric Tuk Tuk batteries.

The emissions and noise data for the Tuk Tuks can be monitored for a specific drive cycle of an individual Tuk Tuk, whereas the emissions and noise associated with a power plant providing electricity to the charging station is most likely a matter of record. The historical data are important because the Tuk Tuk emissions must be correlated with seasonal weather and climatical patterns in the models to allow for correct extrapolation to ambient conditions. In addition to rain and cloud cover, wind speeds and direction are important. Although the focus of the methodology development is on air quality, noise, and battery disposal, there are many environmental impacts that might be marginally effected. These include impacts on the soil and water resources, surface water quality, forestry and wildlife, and to some extent the quality of life for the indigenous population.

C. OVERVIEW OF METHODOLOGY DEVELOPMENT

The focus of this study has been to develop a methodology that will estimate the amount of reduction in emissions by converting LPG and gasoline Tuk Tuks to electricity, the impact of these emissions on ambient air quality, and the value of this reduction in pollutants and the

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improvement in air quality on the health of the population. The quantitative estimate of the value of the reduction in emissions will then be used in the overall economic model used to analyze the benefits and costs of converting the Tuk Tuk fleet to electricity.

The study approach used in developing this methodology is given in Figure 1. As shown in Figure 1, we initially conducted a literature search and identification of models that might be appropriate to the analysis of environmental impacts in the BMA, as well as discussions with modelers and experts on the most recent developments in the modelling of ambient air quality. The bibliography associated with these initial efforts is contained in Annex I.

This led to the identification of the models that have been applied in similar situations to estimate the impact of internal combustion engines and battery operated vehicles on ambient air quality. The bibliography resulting from our literature search and discussions with colleagues is presented in Annex I. From our research, we developed a two phase approach to estimating the air quality impacts. The first phase consists of a technique for estimating the value of converting to electric Tuk Tuks using first a measurement of the emissions from a Tuk Tuk using the same drive cycles as already established, and then information that has been previously estimated with respect to emission factors for internal combustion engines and those resulting from power generation. The second phase consists of an assessment of the identified models to see whether reconfiguration of those models to incorporate Tuk Tuks is cost effective. This second phase is outside the scope of the present study, but should be considered for the future.

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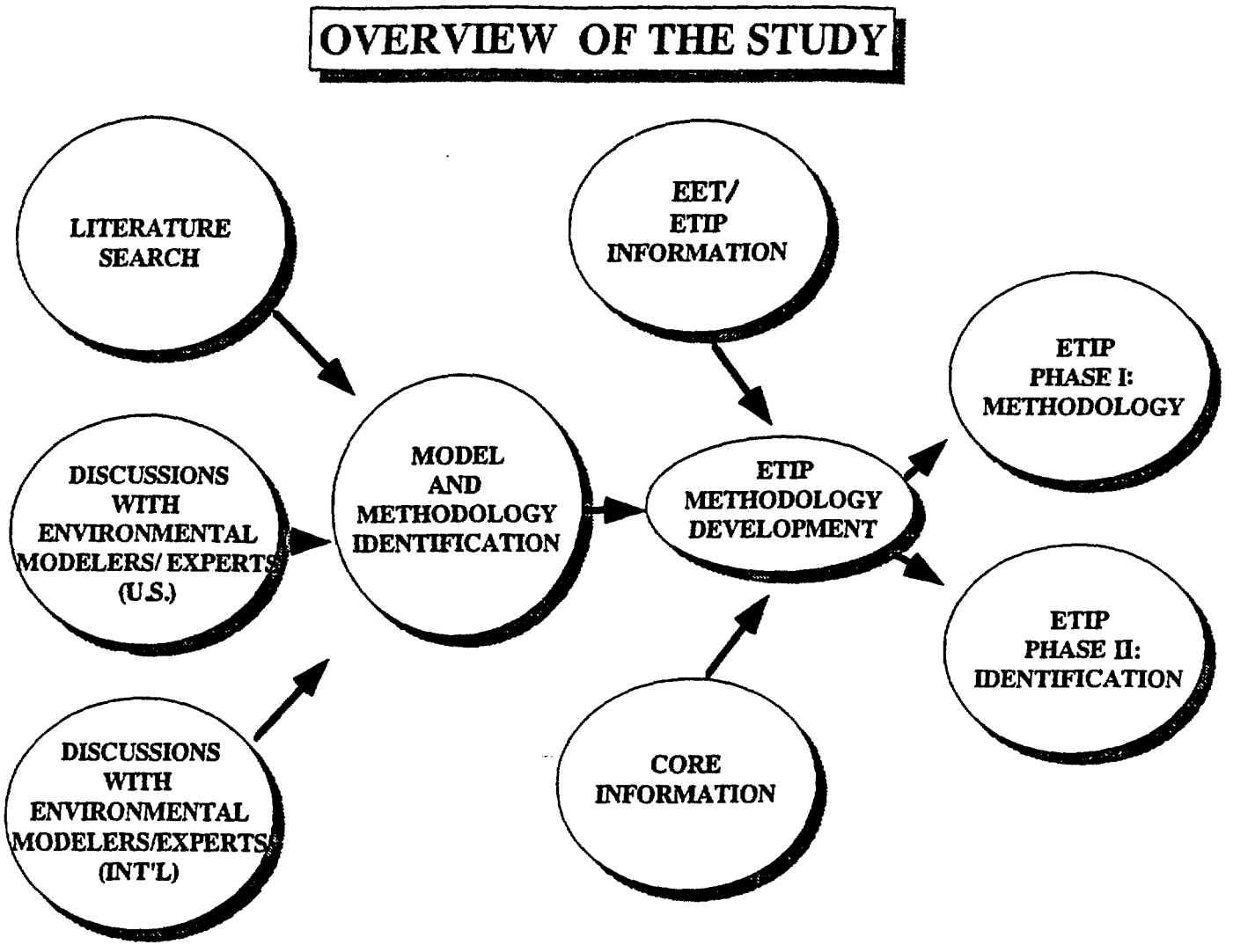
FIGURE 1: OVERVIEW OF THE STUDY PROCESS



II. METHODOLOGY

The proposed methodology compares the relevant contributions of LPG and gasoline Tuk Tuks to degrading ambient air quality versus the contributions of electric Tuk Tuks to improving ambient air quality. LPG and gasoline Tuk Tuks release pollutants directly from their exhausts. The electric Tuk Tuks do not have direct emissions. However, the generation of power to charge the electric tuk Tuk batteries does create air pollutants.

The focus of the methodology developed in this study is to:

- Compare emissions, grams of pollutants, consisting of hydrocarbons (HC), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter
- Compare cumulative loadings to the environment over varying time periods vis-a-vis ambient air quality criteria, and define the receiving environment(i.e., people versus the natural ecosystem, urban versus rural areas)

A. PHASE I: SHORT TERM APPROACH

The Phase I methodology is described in Figure 2. The Phase I approach has three key steps: (1) estimate LPG and gasoline Tuk Tuk emissions; (2) estimate the power plant emissions resulting from electric Tuk Tuk recharging demand; and (3) compare the emissions from the LPG and gasoline Tuk Tuks with those initiated by the electric Tuk Tuk to obtain a net emissions and net impact on the health of the population. Within each of these key steps, we have identified the tasks that are required to complete the steps. The tasks are numbered sequentially across all three steps.

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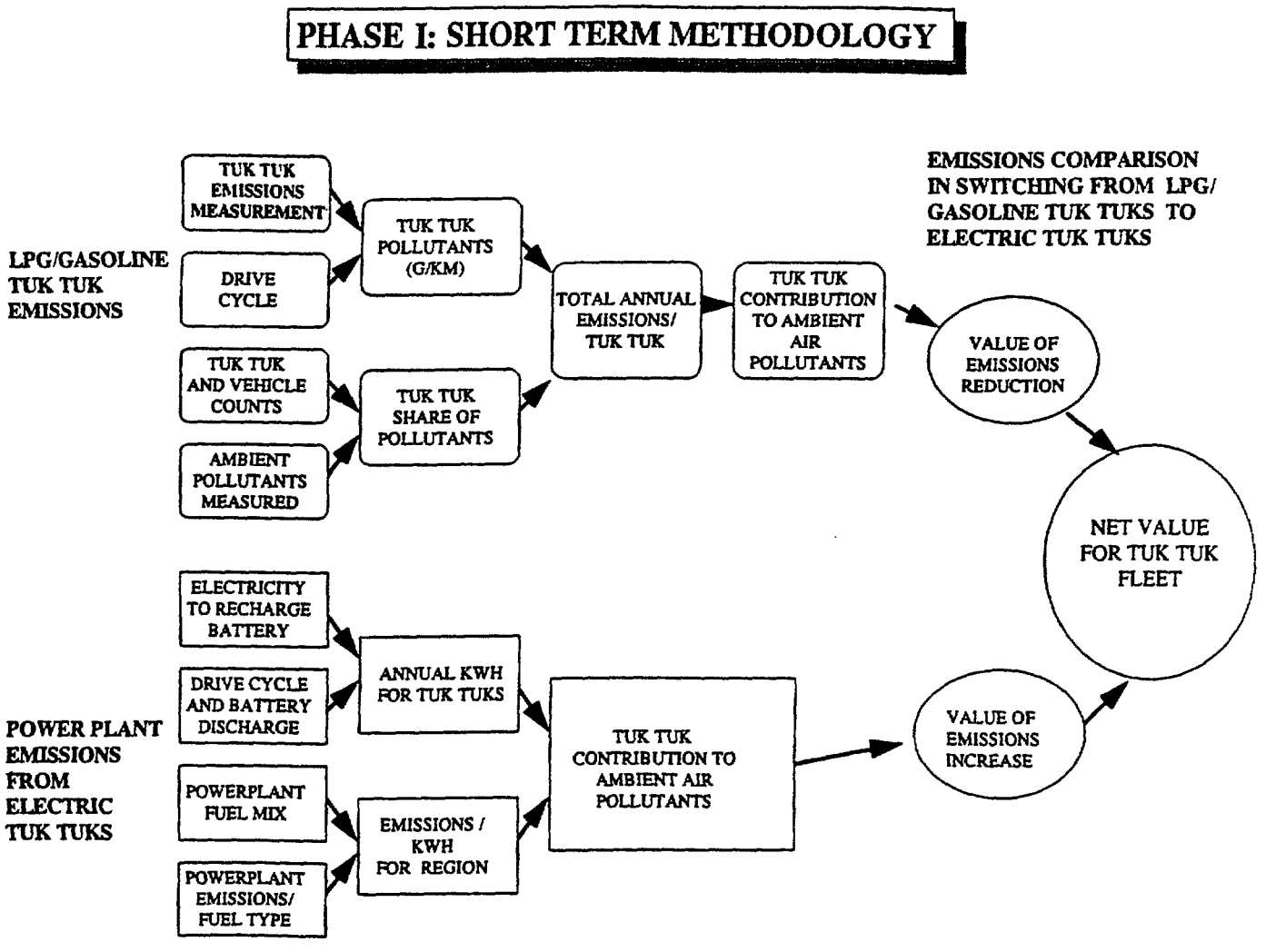
FIGURE 2: PHASE I METHODOLOGY



1. STEP 1: ESTIMATE TOTAL TUK TUK EMISSIONS

a. Rationale

Trying to determine the contribution of Tuk Tuk exhaust emissions to ambient air quality is complicated. All stationary and mobil sources of emissions contribute their share to the ambient air quality. the stationary sources are comparatively easy to characterize and quantify. However, mobil sources are transient and present a variable source strength and location of release of pollutants. The first requirement is to estimate total Tuk Tuk emissions by type of pollutant. Two types of data are required:

- emission rates for the various modes of operation of the Tuk Tuk (acceleration, deceleration, cruise, idle); and
- definition of the modes (time spent on each mode) over typical driving cycles.

To put the contribution of Tuk Tuk into perspective, the same type of emissions data would be required for other modes of transport in use at the same time (cars, trucks, buses, motorcycles, etc.). An approximate contribution could be determined by comparing the proportion of Tuk Tuks to the other modes of transport weighted by their respective emission rates.

Several models exist that can be used to determine emission rates from various vehicle classes. One such model, Mobile 5A, developed for the U.S. Environmental Protection Agency (EPA), is the latest generation used to determine emission rates for the fleet in the United States. It includes estimates for motorcycles fueled by gasoline but not LPG. The model would need to be modified to determine emission rates for both LPG and gasoline fired Tuk Tuks.

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Other models exist that utilize emission rates such as from Mobile 5A in addition to roadway configuration traffic statistics, and meteorological information to calculate expected ambient air quality levels at various receptor sites (i.e., CALINE4 - developed by the California Department of Transportation; AIRVIRO - developed by the Swedish International Cooperation Agency). These models have been developed to respond to a specific objective -- assessment of air pollution impact of selected transportation vehicles and patterns. In their current form, they cannot be applied to the case of Tuk Tuk vehicles in Thailand. A detailed review of the models, input data, and outputs needs to be carried out to assess whether these models could be reconfigured for the Tuk Tuk case.

Values calculated from such models can be compared to actual measured values to validate the model, or alternatively to weight the contribution from the varying modes of transportation to the ambient air quality. Although the technologies and methodologies exist to conduct such evaluations, the relative cost of such an approach, considering the relatively small size of the Tuk Tuk fleet in the BMR may be too high when compared to the overall value. An assessment of these models can be carried out in Phase II which is beyond the scope of this study.

The methodology developed in this report is quite appropriate at the planning level. However, more precise emissions and economic inputs may be required if the results of the analysis are to be used for investment decisions rather than for the purpose of policy development.

b. Methodology Tasks

The tasks for Step 1 are as follows:

- **MEASURE TUK TUK EMISSIONS**

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(1) Collect Emissions Data for Established Drive Cycles

Emissions data can be collected by measuring for various pollutants during the established drive cycle. Several previous studies including the recent study by ETIP have determined typical drive cycles for both the taxi and cargo tuk Tuks. Using dynamometers simulation emission rates can be measured for various cycles (idle, cruise, etc.) Based on the operating patterns of the Tuk Tuks, representative pollutant loading to the ambient environment can be calculated. An example of an emission profile from a Canadian Study is given in Figure 3. Emissions: CO, Particulate, NO_x, SO_2, Pb, HC.

Emission rates change with age, state of maintenance, and use of the vehicles. Therefore, any testing data is only a snapshot in time. If historical data on vehicle maintenance were available, it would be possible to project vehicle deterioration factors. Without historical data, it would be best to establish an average emission rate by testing a series of vehicles in varying states of maintenance. Testing a controlled fleet would provide the most useful information for establishing deterioration factors. Random sampling of in-use Tuk Tuks could enhance the quality of the data base and validate the emission factors.

(2) Expand to Cover Entire Tuk Tuk Fleet

The emissions for an individual Tuk Tuk will be multiplied by the number of Tuk Tuks assuming the identical average drive cycle. Alternately, a statistically valid sample could be obtained for the Tuk-Tuk population.

(3) Expand to Cover a Time Period of a Year

The annual emissions are calculated by multiplying the emissions for each drive cycle by the assumed number of drive cycles for each Tuk Tuk during a year times the number of Tuk Tuk in service on average.

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ICEV EMISSION PROFILES FOR DIFFERENT FUELS (g/km)

FIGURE 3: EMISSIONS FROM ICEV'S IN CANADA

	GASOLINE*	NATURAL GAS	PROPANE	METHANOL 85%
HC	0.2563	0.069**	0.0625	0.0563
CO	2.215	1.89	0.50	0.69
NO_X	0.6250	0.21	0.144	0.094
CO_2	288.000	215.6	NA	274.4
SO_2***	0.00	0.00	0.00	0.00

* Based on present emission standards (i.e. new vehicles meet these standards)
** Non-methane hydrocarbons; Total HC is 0.82 g/km
*** It is assumed that sulphur is completely removed in refining process

Source: "Modeling Study on Comparative Impact of Electric Vehicles vs Other Alternative Fueled Vehicles on Energy Usage and the Environment" Prakash, Chandra, Conservation and Protection Environment Canada and Song, G.S. and Adams, W.A., Electrochemical Science and Technology Centre, University of Ottawa, Canada. September 1992.

- **DETERMINE VEHICLE AND TUK TUK COUNTS AND COLLECT MONITORING STATION DATA**

(4) Obtain Vehicle Counts by Type (with Tuk Tuk Proportion) at Intersections with Curbside Monitoring Stations

The number of vehicles by type of vehicle including Tuk Tuks can be enumerated at specified intersections with established curbside monitoring stations. Because of the drive patterns of Tuk Tuks through alleys and back streets, the establishment of additional curbside monitoring stations in these locations would enable additional emissions data collection and provide a better measure of the pollution impact from Tuk Tuks. Collection of data on vehicle count and pollution monitoring at intersections where Tuk Tuks constitute a significant portion of vehicles, enhances the ability to estimate the impact of Tuk Tuk emission on ambient air quality. Emissions data from the curbside monitoring stations should be collected for a variety of traffic situations to cover most traffic patterns. The Bangkok Metropolitan Administration (BMA) maintains data on road traffic and areas of high concentration of vehicles by type of vehicle. It is recommended that a few additional monitoring stations be set up in areas of high Tuk Tuk traffic in these narrow side streets and alleys.

(5) Obtain Ambient Monitoring Data for the Same Time Period as the Vehicle Counts

"Tuk Tuks, or three-wheeled taxis, are a common sight on the streets of Bangkok throughout the BMR. Although they make up less than 1% of vehicle registration in the BMA, their contribution to overall traffic and emissions is much greater, due to their intensity of use, the fact that they are used primarily in heavily congested areas, and the high level of pollutant emissions they produce."[1]

[1] *Vehicle I/M Test Procedures and Standards*, a Final Report submitted to the World Bank by Engine, Fuel, and Emissions Engineering, Inc., July 28, 1994.

- Existing Curbside Monitoring Stations (16): Measure CO, Particulate, Pb, HC

- Permanent Monitoring Stations: Measure CO, Particulate, SO_2, NO_x, Pb, HC

- Additional Curbside Monitoring Stations in Alleys and Back Streets

An example of data from an existing study is given in Figure 4.

(6) Estimate Tuk Tuk as a Proportion of Total traffic at Each Monitoring site

Divide the number of Tuk Tuks by total vehicles that pass through the intersection in a specified period of time.

- **ESTIMATE TOTAL TUK TUK EMISSIONS**

(7) Relate Proportion of Tuk Tuks Emissions at Monitoring Stations

Engine, Fuel, and Emissions Engineering has estimated some average emissions for certain pollutants in Bangkok. An indication of the relative concentration of emissions from Tuk Tuks and taxis is illustrated in Figures 5 and 6.

(8) Estimate Contribution of Tuk Tuk Emissions Relative to Other Vehicle Emissions

Many studies have estimated emissions from automobiles and vehicles other than Tuk Tuks. For example, Song and Prakash have estimated pollutants from internal combustion engines (ICEVs) for Canada, as indicated in Figure 3 earlier and repeated in Figure 7.

(9) Calculate Tuk Tuk Contribution at Intersections Based on Total Emissions by Type from Monitoring Stations & Tuk Tuk emission Proportion Relative to other Vehicles.

(10) Expand to Cover Entire Tuk Tuk Fleet and Time Period of a Year.

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AMBIENT AIR CONCENTRATION IN 16 CURBSIDE STATIONS IN BANGKOK[11]

FIGURE 4: AMBIENT AIR CONCENTRATIONS AT CURBSIDE STATIONS

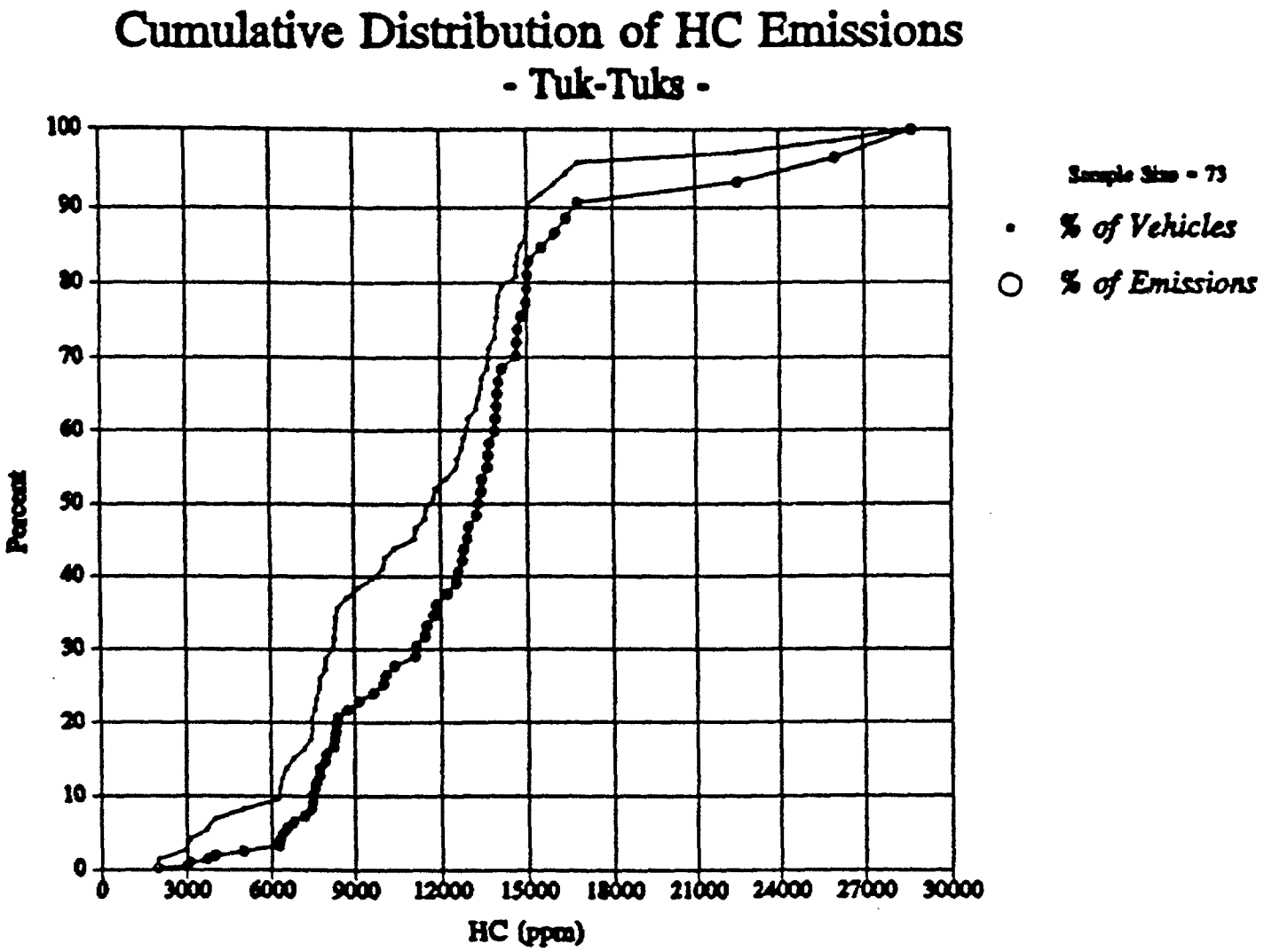
STATIONS	MAX TSP[1] (24 HR)[2] (µg/cu.m)[3]	MAX Pb[4] (24 hr.) (µg/cu.m)	MAX CO (8 hr.)[5] (mg/cu.m)	2ND High CO (8 hr.)[6] (mg/cu.m)
1. Pratoonam	1,530	1.02	9.10	8.84
2. Yaovaraj	860	0.98	11.39	10.58
3. Lanluang	450	0.59	-	-
4. Banglampoo	400	0.61	11.57	11.27
5. Sapankwai	410	0.59	11.43	10.93
6. Silom	500	0.67	15.50	15.29
7. Si Praya	-	-	8.00	7.85
8. Huamark	1110	1.66	18.93	18.72
9. Rama 1	600	0.54	9.89	9.68
10. Bangkhen	410	0.33	11.26	11.12
11. Prannok	750	0.51	20.35	19.61
12. Charansanidwong	460	0.51	15.19	11.32
13. Ban Sondej	800	1.14	17.64	17.48
14. Phrayathai	540	0.48	10.10	9.96
15. Taksin	330	.024	-	-
16. Samsen	460	0.15	-	-
Standard*	330	10.00	20.00	20.00
Proposed Standards**	330	1.25	10.00	10.00

1 = Total Suspended Particulate; 2 = Average readings over 24 hrs.; 3 = Micrograms per cubic meter; 4 = lead; 5 = Reading taken over an average of 8 hrs.; 6 = The second highest reading from the same 8 hr. average (see #5).

* Standard set by ONEB in 1981
** Proposed Interim National Ambient Air Quality Standards for Thailand set by Department of Pollution Control, Air Quality and Noise Management Division, and The World Bank.

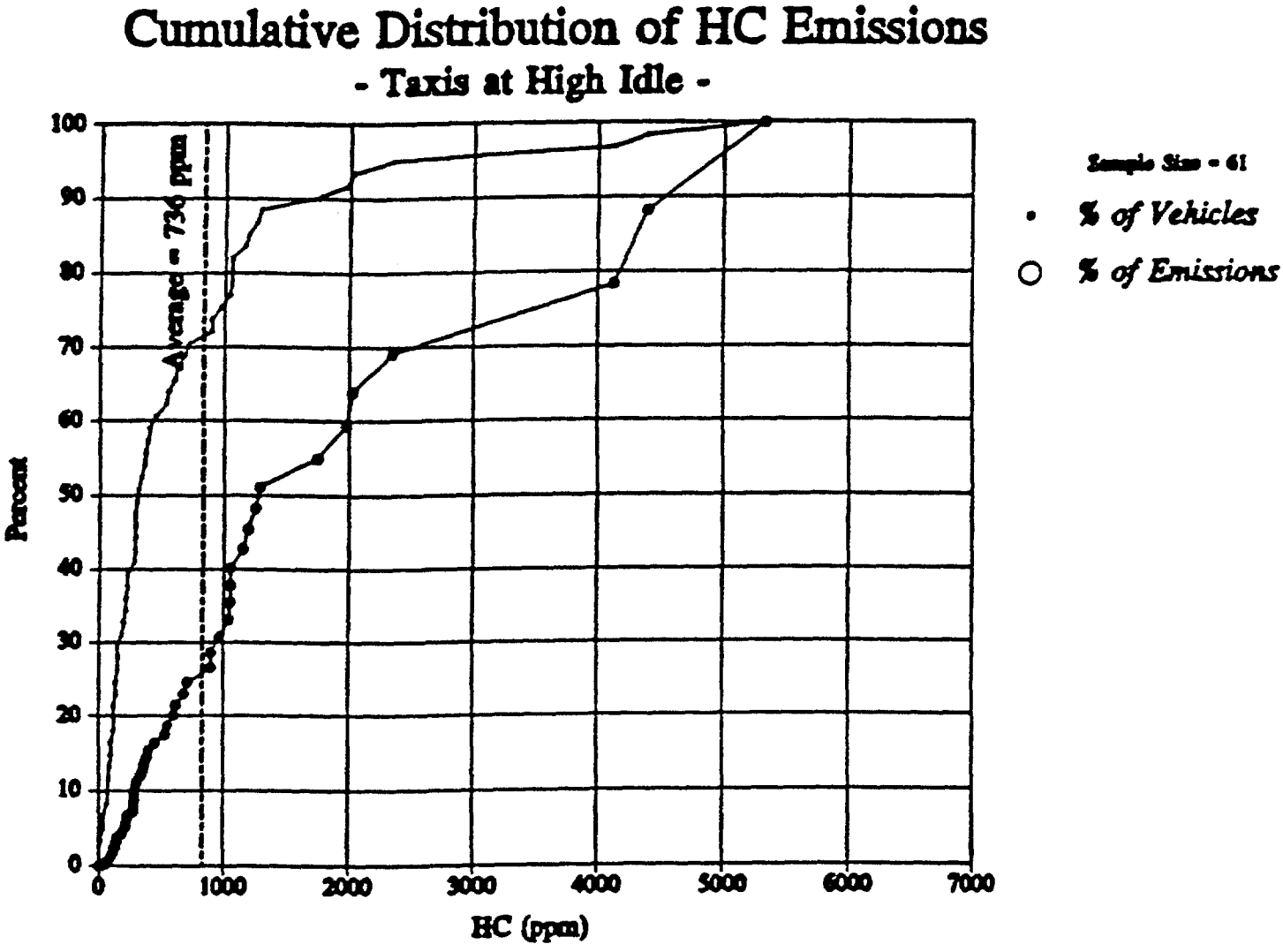
Source: Traffic Crisis and Air Pollution in Bangkok, TEI Quarterly Environment Journal- Vol. 2 No. 3. July-September 1994.

FIGURE 5: ESTIMATES OF THE CUMULATIVE DISTRIBUTION OF TUK TUK HC EMISSIONS



Source: *"Vehicle I/M Test Procedures and Standards", Final Report. Engine, Fuel, and Emissions Engineering, Incorporated. July 28, 1994.*

FIGURE 6: CUMULATIVE DISTRIBUTION OF TAXI HC EMISSIONS



Source: *"Vehicle I/M Test Procedures and Standards", Final Report. Engine, Fuel, and Emissions Engineering, Incorporated. July 28, 1994.*

ICEV EMISSION PROFILES FOR DIFFERENT FUELS (g/km)

FIGURE 7: EMISSIONS FROM ICEV'S IN CANADA

	GASOLINE*	NATURAL GAS	PROPANE	METHANOL 85%
HC	0.2563	0.069**	0.0625	0.0563
CO	2.215	1.89	0.50	0.69
NO_X	0.6250	0.21	0.144	0.094
CO_2	288.000	215.6	NA	274.4
SO_2***	0.00	0.00	0.00	0.00

* Based on present emission standards (i.e. new vehicles meet these standards)
** Non-methane hydrocarbons; Total HC is 0.82 g/km
*** It is assumed that sulphur is completely removed in refining process

Source: "Modeling Study on Comparative Impact of Electric Vehicles vs Other Alternative Fueled Vehicles on Energy Usage and the Environment" Prakash, Chandra, Conservation and Protection Environment Canada and Song, G.S. and Adams, W.A., Electrochemical Science and Technology Centre, University of Ottawa, Canada. September 1992.

2. STEP 2: ESTIMATE POWER PLANT EMISSIONS

a. Rationale

From prototype testing actual power consumption requirements of the electric Tuk Tuks can be determined. As assessment of the power consumption by electric Tuk Tuks will require replicating the typical operating patterns of the Tuk Tuks. Also, the transmission efficiencies will need to be determined to ensure that adequate power is generated to compensate for any losses in distribution to the battery recharging station. Once the power consumption for the electric Tuk Tuks in Kwh per Kilometer (kwh/km) is determined, an emission rate for the electric Tuk Tuks can be calculated in g/km.

Emissions from power production vary depending upon fuel type, boiler configuration, operating conditions, and degree of pollutant emission control. This information is usually a matter of record for the operator. Sampling fuel type to maintain quality control is important in meeting design efficiency requirements. Maintaining optimal operating conditions maximizes cost effectiveness. Pollutant emissions may be continuously measured and therefore would be available or can be estimated. The aforementioned information on fuel quality and quantity, design parameters, and degree of pollution control, can be used to determine emission factors, and is available from EPA Publication AP-42, ***Compilation of Air Pollutant Emission Factors, Volume: Stationary Point and Area Sources.***

The grid that supplies power for the BMR needs to be defined. For each central power plant in that grid, emissions by pollutant type need to be determined. The number of kilowatt hours of electricity produced over the emissions period is also required. Depending on the plant, demand requirements, etc., an average emission rate is determined for each pollutant. From this information, an average emission rate in grams/kwh of electricity can be determined.

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The sample values[2] for various parts of the United States and Canada were compiled by the team based on published data and are presented in Table 1.

Having determined the power consumption requirements for recharging the electric tuk Tuk batteries, an emission rate for these Tuk tuks can be calculated in g/km. These data can be easily compared to the emission rates in g/km for both the LPG and the gasoline fueled Tuk Tuks to compute the incremental change in emissions by pollutant type resulting from the conversion of gasoline and LPG Tuk Tuks to electric Tuk Tuks.

By knowing the fleet size and driving cycles, aggregate pollution loadings can be calculated for any desired time periods for the three categories of Tuk Tuks. To fully explore the pollution impacts, a comparison between stack emissions created during typical power production and the incremental change attributed to recharging the electric Tuk Tuk batteries needs to be made over specified periods. Depending on the recharging requirements for the electric Tuk Tuks, incremental emissions increases could be minimal (i.e. batteries carrying sufficient charge to last two shifts) with charging occurring only at night.

A worst case scenario can be calculated based on the assumption that recharging occurs at the time of maximum electricity demand, with the added emissions potentially coming from the least controlled battery recharging facilities.

Power generating plants are usually significant point sources of pollutants. To determine the potential impacts on the receiving environment, contributions to ground level concentrations

[2]These values are based on various assumptions of fuel mix and quality, facility use, emission standards being met, etc.

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TABLE 1: SAMPLE EMISSIONS IN SELECTED AREAS IN THE U.S. AND CANADA (g/Kwh)

REGION	HC	CO	NO_X	SO_X	PM_{10}
East South Central	0.017	0.137	3.786	13.790	0.157
West South Central	0.033	0.231	2.377	3.213	0.099
Pacific	0.053	0.323	1.571	1.889	0.159
U.S. Total	0.033	0.177	3.252	9.728	0.143
Ontario	0.033	0.609	2.813	3.6	N.A.
Alberta	0.033	0.609	3.186	2.6	N.A.

Source: Compilation by CORE International, Inc. Based on Published Data

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(GLC) of pollutants can be calculated. There are a number of dispersion models that can be used to make these calculations based upon source type, time periods of interest, terrain, and land use. Table 2 lists some plume models and their applications.

The models typically yield sufficient information to evaluate the maximum GLC of the various pollutants and the point of impingement, i.e., the point at which the maximum GLC occurs. With the factors for power plant emissions, the calculations for two different scenarios can be easily performed to assess the impact of the resultant GLC. One scenario would consist of the plant (or plants) operating under normal circumstances; the other scenario would consist of the plants operating with the added power generation requirements for recharging the batteries for the electric Tuk Tuks. A comparison of the two outcomes will yield an evaluation of potential environment impact.

There are several potential outcomes that can result from the analysis of these scenarios:

1) There is an insignificant incremental contribution to the pollutant levels due to increased generation;

2) There are additional pollutants but not sufficient to cause ambient air quality criteria to be exceeded; or

3) The increased levels of pollutants are of sufficient magnitude to cause a violation of AAQ criteria, thereby causing damage to the receiving environment.

In addition to the magnitude of the pollutant loading, the point at which this occurs (point of impingement) is important. This point will change with varying wind speeds and directions. It is important to determine a frequency distribution. When the points of impingement are

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TABLE 2: PLUME MODELS AND APPLICATIONS

Model	Averaging Period	Source Type	Terrain	Land Use
SCREEN2	hourly; daily	point,area; volume	simple; complex	rural; urban
ISCST2	hourly-annual	point,area; volume	simple	rural; urban
ISCLT2	monthly seasonal; annual	point,area; volume	simple	rural; urban
MPTER	hourly to annual	point	simple	rural
COMPLEX 1	hourly to annual	point	complex	rural
SHORTZ	hourly to annual	point; area	complex	urban
LONGZ	seasonal to annual	point; area	complex	urban

Source: Literature Survey by CORE International, Inc.

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known, an assessment of the resources in the receiving environment that are likely to be most susceptible to adverse impact can be made.

b. Methodology Tasks

The tasks for Step 2 are as follows:

- **ESTIMATE THE ENERGY REQUIREMENTS FOR THE TUK TUKS**

  (11) Estimate the Average Electricity Requirement of Electric Tuk Tuks in kwh/km.

  (12) Apply Emissions in g/kwh to the Electricity Consumption of Electric Tuk Tuk in kwh/km to Obtain the Value of Emissions by Pollutant Type in g/km.

  (13) Calculate Electric Tuk Tuk Contribution to Reducing Emissions Levels for Each Type of Pollutant as Compared to the LPG and Gasoline Tuk Tuks for Which Data are Available.

  (14) Expand the Results to Cover Entire Tuk Tuk Fleet for a Time Period of one Year.

  (15) Estimate Energy Requirements for Each Electric Tuk Tuk (Scenario Dependent).

  (16) Estimate Emissions Profiles for Generation Facilities Used in Meeting Tuk Tuk Electricity Demand.

  The fossil fuel electric utility emission profiles can be obtained from the Electricity Generating Authority (EGAT) for the different pollutants. An example of the typical profiles is given in Figure 8.

  (17) Develop Emissions Estimates for Electric Tuk Tuk Fleet

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FOSSIL FUEL ELECTRIC UTILITY EMISSIONS PROFILES BY PROVINCE (g/kWh)

FIGURE 8: FOSSIL FUEL ELECTRIC UTILITY EMISSIONS PROFILES BY PROVINCE OF CANADA (g/kWh)

	ONTARIO			BRITISH COLUMBIA		ALBERTA		
	Coal	Natural Gas	Heavy Oil	Natural Gas	Heavy Oil	Coal	Natural Gas	Heavy Oil
HC	0.0177	0.0050	0.0752	0.0050	0.0752	0.0177	0.0050	0.0752
CO	0.1240	0.0100	1.6930	0.0100	1.6930	0.1240	0.0100	1.6930
NO_x	1.6590	0.8700	5.9080	1.4300	5.9080	2.2000	1.4500	5.9080
CO_2	1002.1	605.0	834.7	539.8	834.7	960.0	526.0	834.7
SO_2*	5.65	0.00	1.55	0.00	1.55	3.65	0.00	1.55

* It is assumed that sulphur is completely removed in refining process

Source: *"Modeling Study on Comparative Impact of Electric Vehicles vs Other Alternative Fuelled Vehicles on Energy Usage and the Environment". Prakash, Chandra, Conservation and Protection Environment Canada and Song, G.S. and Adams, W.A., Electrochemical Science and Technology Centre, University of Ottawa, Canada. September 1992.*

- **ESTIMATE THE ELECTRICITY DEMAND FOR RECHARGING TUK TUK BATTERIES**

  (18) Determine Electricity Requirement to Recharge the Electric Tuk Tuk Battery (Several Different Types of Batteries).

  (19) Determine the Number of Batteries Required per Drive Cycle and Calculate the Total Electricity Required for a Drive Cycle

  (20) Expand to Cover Entire Electric Tuk Tuk Fleet Per Year and Calculate the Total Amount of Electricity Required by the Entire Tuk Tuk Fleet Over a One Year Time Period.

- **DETERMINE THE GENERATION FUEL MIX AND EMISSION FACTORS**

  (21) Obtain Fuel Mix of Generation in the BMR Region.

  (22) Obtain Total Fuel Consumption and/or Emissions Data from EGAT for the BMR on an Annual Basis

  - If Only Fuel Consumption Data are Available, Apply Emissions Factors to Get Total Emissions (grams per kwh); Divide by Operating Time and Convert to g/kwh

  - Measurements of CO, Particulate, SO_2, NO_x, HC

3. STEP 3: COMPARE OVERALL EMISSIONS OF ELECTRIC TUK TUKS VERSUS LPG AND GASOLINE TUK TUKS

a. Rationale

From previous studies, the driving cycles for both the LPG taxi Tuk Tuk and the gasoline fueled cargo Tuk Tuk have been delineated. ETIP intends to obtain emissions measurement utilizing a dynamometer to simulate actual driving cycles. This testing will yield information

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on emissions during idle, acceleration, cruise, and deceleration modes. Multiplying the emission rates by the parameters of the driving cycles, pollution loadings to the environment can be calculated for varying time periods.

Similar types of pollution loading can also be calculated for other modes of transportation. This allows a gross approximation of percent loading contributed by the Tuk Tuk fleet over the entire BMR. Such an approximation, however, fails to recognize that the Tuk Tuk may contribute disproportionately in the more heavily congested areas.

To assess this possibility, vehicle kilometers traveled by the various types of vehicles need to be determined. The Pollution Control Department (PCD) operates a number of curbside monitoring stations in the BMR. A traffic count that enumerated and classified the vehicles that passed these monitoring stations would provide the necessary information. Ratios of Tuk Tuks to cars, buses, trucks, etc., weighted by average emissions rates, would allow for an approximation of Tuk Tuk contribution to ambient air quality. Several sampling sites representative of the different traffic patterns (intersections, secondary streets, major arteries) and conditions should be used to collect the data. This would provide a range of values under different traffic conditions.

There are sophisticated models available to more accurately determine the Tuk Tuk contribution to ambient air quality. The Mobile 5 Model (an emissions factor model) could be modified to assess Tuk Tuks fueled by LPG and provide the necessary input to an appropriate mobile source dispersion model.

These emissions factors, along with the weighted traffic counts, meteorological data and roadway configurations, would allow the AIRVIRO or CALINE 4 models to calculate ambient air

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contributions from the LPG/gasoline Tuk Tuks. The CALINE4 model has the capability to characterize mobile source emissions through intersections.

A basic premise of the model is that some order exists in the traffic flow through the segment of roadway of interest. From anecdotal comments, traffic flow characteristics in the BMR, especially at intersections is far from orderly. This would require a simulation to be developed depicting an orderly form for several representative type intersections. The traffic counts recommended for air quality apportionment and noise evaluation could also be useful for this exercise. Traffic counts by vehicle type, direction flow pattern (straight through or turn) would be necessary. Although this would not be an exact characterization at the intersection, it would approximate the situation. The resultant information when used in the model, could provide relative value for assessing the contribution to ambient air quality from the various vehicle classes, especially the Tuk Tuks.

The major reason for estimating the net effects of reducing air pollutants by converting LPG and gasoline Tuk Tuks to electric Tuk Tuks is to identify the benefits to the BMR and Thailand which could, in principle, offer justification for potential subsidies that may be needed to ensure that Tuk Tuk owners would convert to electricity powered Tuk Tuks.

b. Methodology Tasks

The tasks for Step 3 are as follows:

- **COMPARISON OF TOTAL EMISSIONS**

  (23) Display Level of Emissions for the LPG and Gasoline Tuk Tuk for a Year: CO, Particulate, SO_2, NO_x, P_b, HC

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The levels of emissions for the LPG and gasoline Tuk Tuks and the electric Tuk Tuk can be estimated using the emission factors times the energy demand levels for each type of Tuk Tuk. An example for Canada is provided in Figure 9.

(24) Display Level of Emissions for the Electric Tuk Tuk for a Year: Measurements of CO, Particulate, NO_2, NO_x, P_b, HC

Based on the emissions from the LPG and gasoline Tuk Tuks and the emissions from the powerplants for the electric Tuk Tuks, the total annual emissions can be estimated as indicated in Figure 10.

- **ASSESS POPULATION EXPOSURE FOR CONVERSION FROM LPG AND GASOLINE TO ELECTRIC**

(25) Assess Overall Ambient Air Quality Impacts of Conversion of LPG and Gasoline Tuk Tuks to Electric Tuk Tuks

The exercise to assess impacts on ambient air quality of any new programs is required mainly to determine the impact upon human health and the ecosystem. The process to establish acceptable ambient air quality criteria requires both scientific analyses and social objectives.

Typically, these criteria are expressed as a pollutant concentrations over a specified time period which ensures protection for the receiving environment. The key pollutant types include HC, CO, Pb, NOx, Particulate matter, and SO_2. A number of analysts have developed methodologies to calculate ambient air quality impacts of new technologies and have converted these impacts into economic factors based upon well established factors for the value to society in specific areas.

In a recent report for Environment Canada, the Electrochemical Science and Technology Center of the University of Ottawa, Canada, has developed a methodology to establish economic factors related to total annual output of emissions due to electric

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A COMPARISON OF EV VS. ICEV (GASOLINE) EMISSIONS (g/km)

FIGURE 9: A COMPARISON OF EMISSIONS FROM ETT VERSUS LPG TT

	ONTARIO (TORONTO)		BRITISH COLUMBIA (VANCOUVER)		ALBERTA (CALGARY)		ICEV*
	EV	ICEV*	EV	ICEV*	EV	ICEV*	
HC	0.0012582	2.1900	0.0002203	2.6050	0.003742	2.3000	0.2563
CO	0.117785	18.7350	0.002754	22.1580	0.06544	19.060	2.215
NO_X	0.104179	1.4600	0.03960	1.5750	0.4954	1.6750	0.6250
CO_2	62.917025	288.000	12.8577	288.000	210.6545	288.000	288.000
SO_2***	0.3442875	0.00	0.002325	0.00	0.7202	0.00	0.00

* Average values for the regional fleet
** Based on present emission standards (i.e. new vehicles have these emissions)
*** It is assumed that sulphur is completely removed in refining process

Source: *"Modeling Study on Comparative Impact of Electric Vehicles vs Other Alternative Fuelled Vehicle on Energy Usage and the Environment". Prakash, Chandra, Conservation and Protection Environment Canada and Song, G.S. and Adams, W.A., Electrochemical Science and Technology Centre, University of Ottawa, Canada. September 1992.*

TOTAL ANNUAL EMISSIONS OF GASOLINE FLEET VS AN ELECTRIC FLEET BY REGION

The total annual emissions displaced by EVs, by percentage EV penetration of the ICEV (Gasoline) fleet, by region; and the total annual emissions from a 100% ICEV (Gasoline) fleet (T/yr except CO_2 in kT/yr); Assuming the entire ICEV (Gasoline) fleet to be made up of vehicles conforming to the latest emission standards (i.e. They are all new vehicles).

FIGURE 10: TOTAL EMISSIONS OF A GASOLINE FLEET VERSUS AN ELECTRIC FLEET

REGION	PERCENT EV PENETRATION	HC	CO	NO_X	CO_2	SO_2 *
TORONTO (ONTARIO)	5	278.5	2,273	564.6	244.0	-373.2
	10	552.9	4,547	1,129	488.0	-746.4
	25	1,382	11,370	2,823	1220	-1,866
	100% ICEV	5,556	48,020	13,550	6244	N/A
VANCOUVER (B.C.)	5	113.9	983.7	260.3	122.3	-1.034
	10	227.7	1967.4	520.6	244.7	-2.068
	25	569	4,918	1,302	611.7	-5.169
	100% ICEV	2,279	19,700	5,558	2561	N/A
CALGARY (ALBERTA)	5	90.91	773.7	46.62	27.84	-259.2
	10	181.8	1,548	93.25	55.68	-518.5
	25	545.4	3,869	233.2	139.2	-1,296.2
	100%ICEV	1,845	15,950	4,499	2073	N/A

*** It is assumed that sulphur is completely removed in refining process**

Source: *"Modeling Study on Comparative Impact of Electric Vehicles vs Other Alternative Fueled Vehicles on Energy Usage and the Environment." Prakash, Chandra, Conservation and Protection Environment Canada and Song, G.S. and Adams, W.A., Electrochemical Science and Technology Centre, University of Ottawa, Canada. September 1992.*

vehicles in Ontario, Canada. This report has developed economic factors for emissions from electric vehicles in Ontario based on a methodology established by the California Energy Commission (CEC) and published in its 1992 Electricity Report, for the San Francisco Bay Area.

The CEC report developed economic (cost) factors for the San Francisco Bay Area for a variety of pollutants. The basic thrust of the methodology developed by CEC is to estimate a "damage function" for the society. Alternatively the methodology also uses estimates of pollutant control costs to convert emissions rates to economic or cost factors. For instance, the CEC has determined the following factors for value to society as they apply to the San Francisco Bay Area:

1. Reduction of one air pound of CO = $1.29
2. Reduction of one pound of HC = $5.99
3. One pound reduction of Particulate matter = $1.53
4. Reduction of one pound of NO_x = $6.11

Similar economic factors for incremental emissions resulting from the conversion of LPG and gasoline Tuk Tuks to electric Tuk Tuks in the BMR can be estimated. These will serve as inputs to the economic model.

(26) Use Established Health Factors to Relate Emission Gains and Losses to Population Exposure Gains and Losses.

(27) Apply Value of Health Exposure Factors to the Incremental Pollutant Emissions to Estimate the Overall Population Exposure.

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B. PHASE II: MEDIUM/LONG TERM APPROACH

The development of a medium/long term methodology (model) is outside the scope of the current study. Such a methodology (model) can provide a more in-depth and sophisticated modeling framework for determining the incremental emissions impact resulting from the conversion from the conversion of gasoline and LPG Tuk Tuks to electric Tuk Tuks. This long term methodology will use an approach, illustrated in Figure 11, that is consistent with prior analyses by the Thailand Environment Institute (TEI) and the Pollution Control Department (PCD) to ascertain the impacts of Tuk Tuk emissions on ambient air quality. The methodology proposes to combine models existing in the Pollution Control Department with other models to allow the comparison of the reduction in Tuk Tuk emissions to the increase in emissions from additional electricity production from power plants in the BMR.

This includes emissions testing data for the Tuk Tuks consistent with the defined drive cycles as obtained from the short term methodology: (i) actual emissions for the LPG and gasoline powered Tuk Tuks and (ii) emissions resulting from electricity used for the electric powered Tuk Tuks. A Transport Sector Demand Model was used by TEI in a previous analysis to determine the mix of vehicles on specified roads and zones. The overall procedure for estimating traffic volumes used in the study is given in Figure 12. The structure of the model is shown in Figure 13. Mobile 5, also used by Ministry of Science, Technology, and Energy (MOSTE) in previous policy analyses, can provide the emissions factors for the Tuk Tuks once the model has been adjusted to include Tuk Tuks. The AIRVIRO dispersion model can then be used to estimate the contribution/impact of the Tuk Tuk emissions on ambient air quality. The inputs to the AIRVIRO model are given in Figure 14.

A Canadian model to compare the amount of emissions and impacts of electricity generation by fuel type on ambient air quality has been extensively used for comparing changes in emissions

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FIGURE 11: PHASE II METHODOLOGY

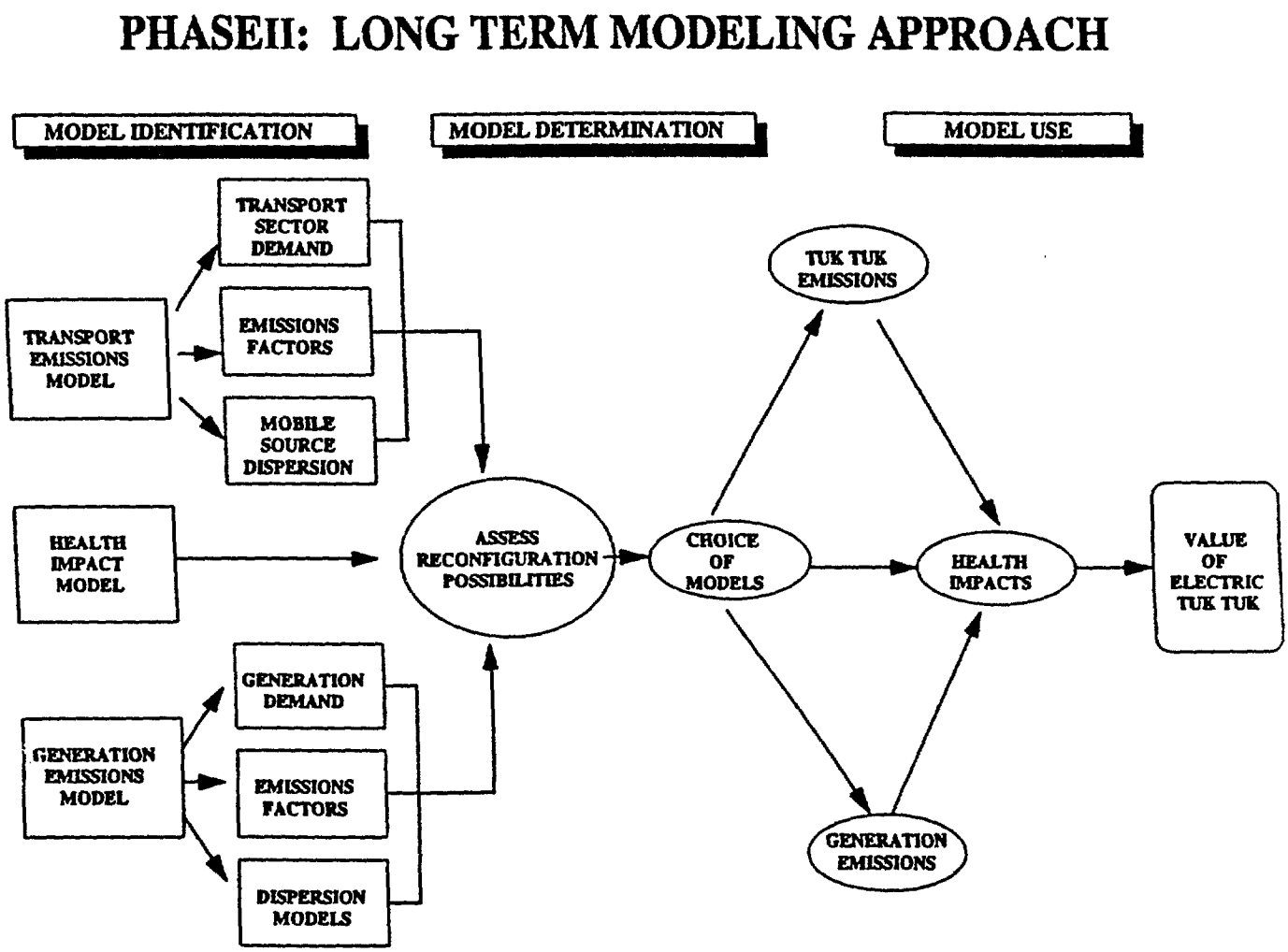
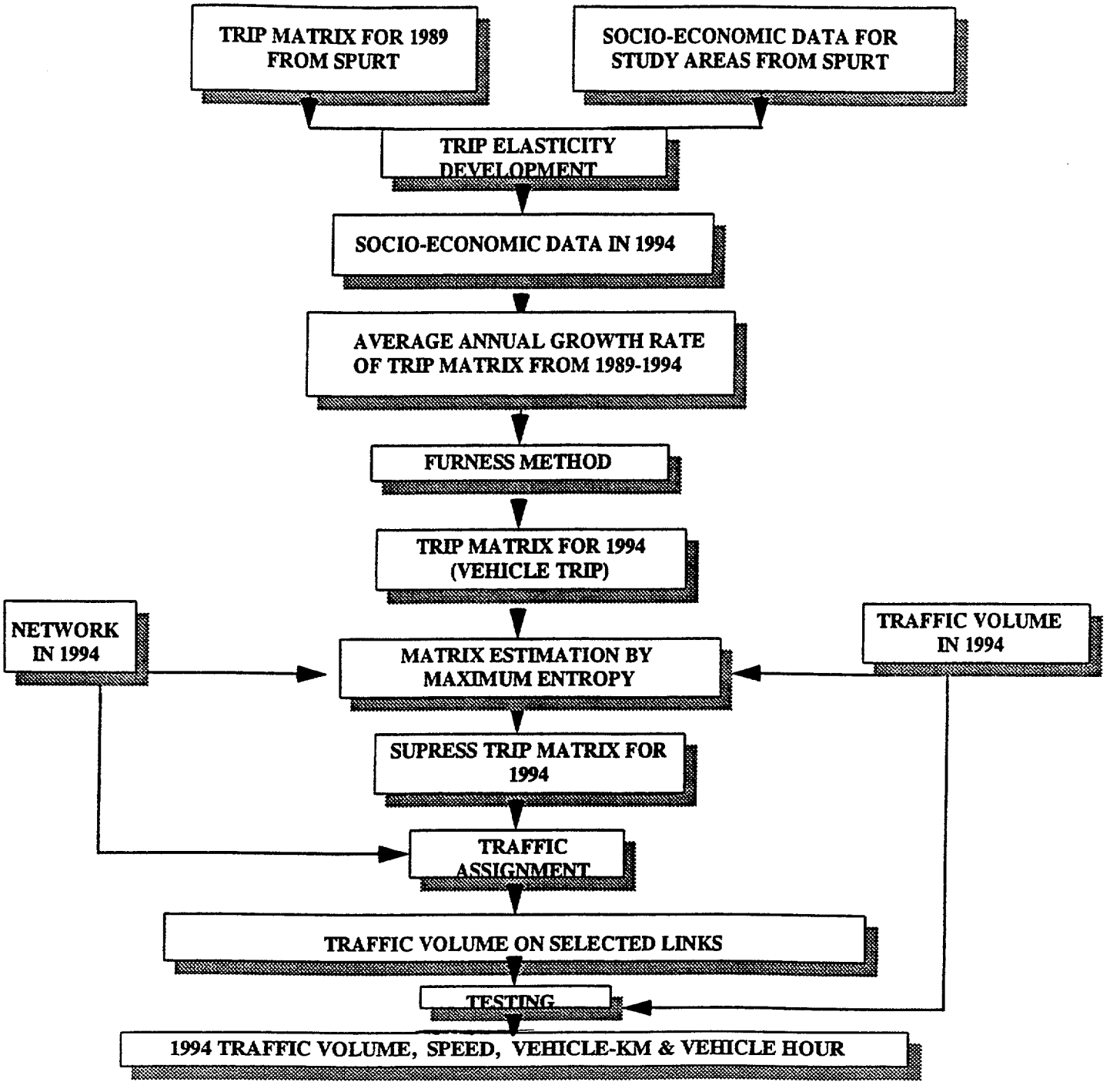
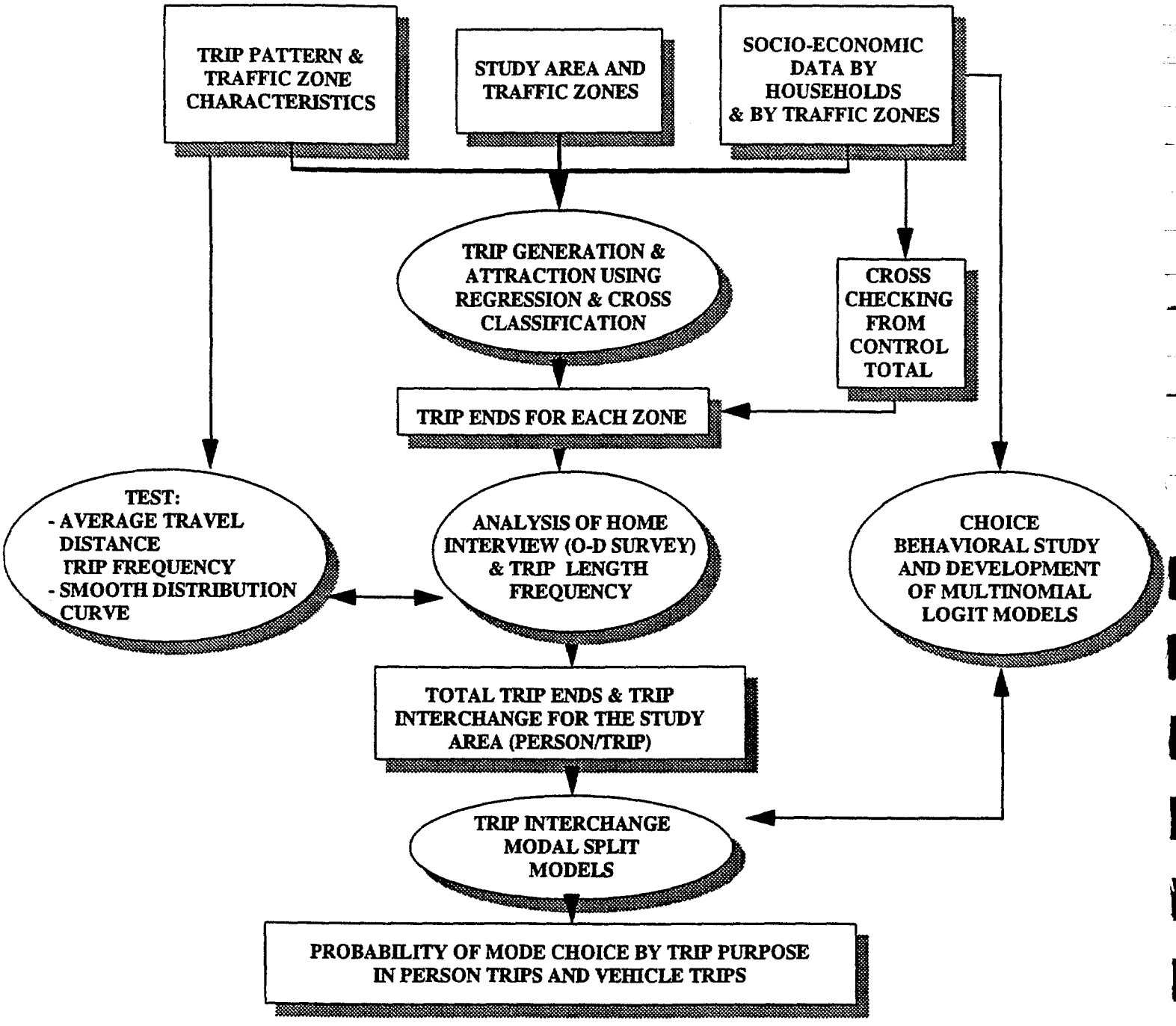


FIGURE 12: METHODOLOGY FOR CALCULATING TRAFFIC ASSIGNMENT



Source: *"Traffic Crisis and Air Pollution in Bangkok". TEI Quarterly Environment Journal - Vol. 2 No. 3, July-September 1994.*

FIGURE 13: TRANSPORT SECTOR DEMAND MODEL



Source: *"Traffic Crisis and Air Pollution in Bangkok". TEI Quarterly Environment Journal - Vol. 2 No. 3, July-September 1994.*

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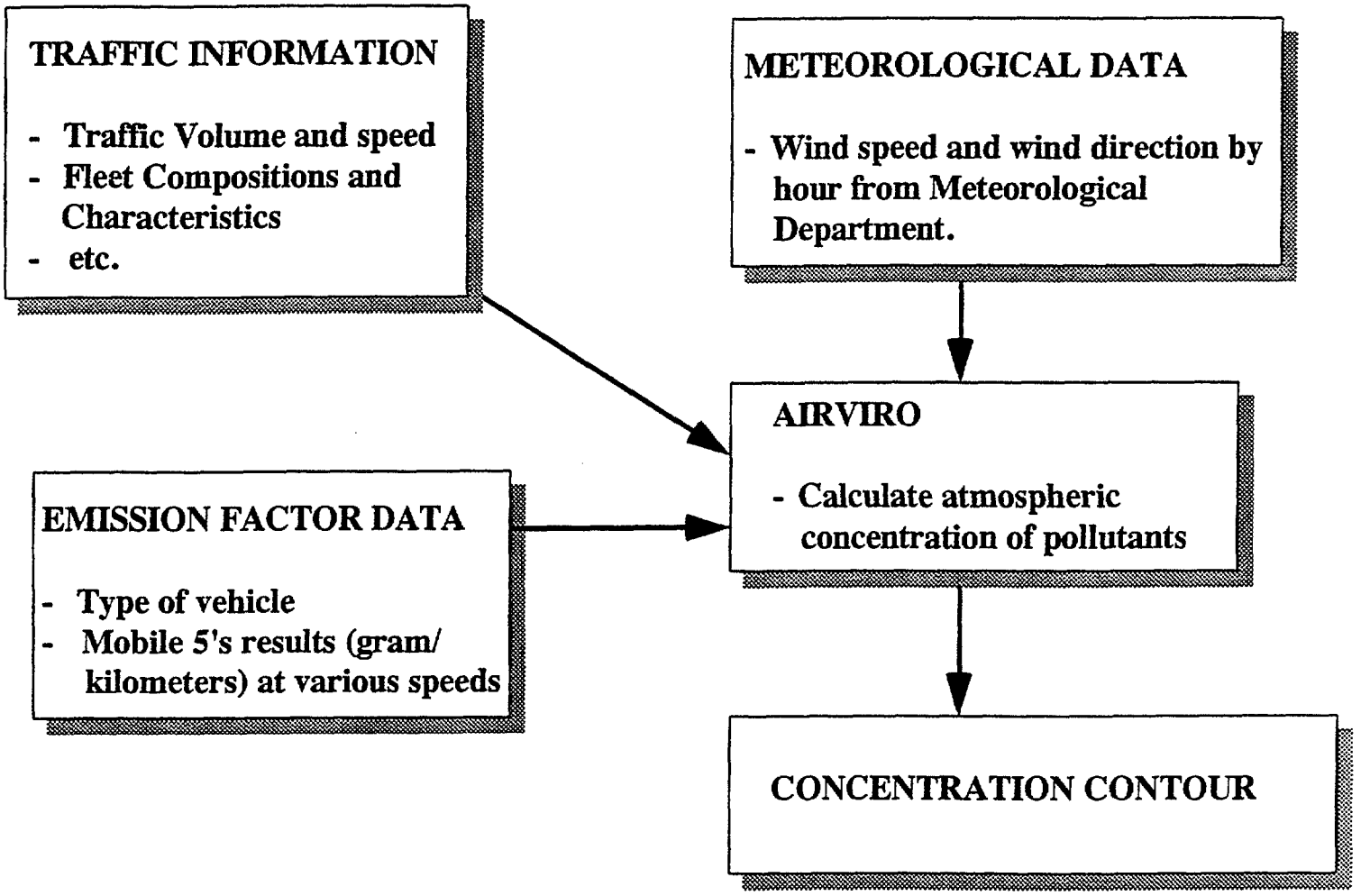
FIGURE 14: INPUTS TO THE AIRVIRO DISPERSION MODEL



Source: *"Traffic Crisis and Air Pollution in Bangkok". TEI Quarterly Environment Journal - Vol. 2 No. 3, July-September 1994.*

of of vehicles fueled by different sources. This model can most likely be reconfigured to fit the conditions of electricity generation in the BMR. Based on the energy efficiency of the electric Tuk Tuk in replicating the typical drive cycle and based on the fuel mix of the power station that supplies the electricity, emissions by pollutant type can be determined and converted to grams/kwh and subsequently to grams/km based on actual distances traveled by the Tuk Tuk.

The emissions estimates from this methodology can be used to determine pollutant ground level concentrations and be compared to the pollutant levels resulting from the MOBILE 5 and AIRVIRO models. This comparison will provide a measure of the reduction of pollutants resulting from the reduction of LPG and gasoline use versus the increase in pollutants due to the increase in electricity production.

This activity is outside the scope of the current study.

III. CONCLUDING REMARKS

A. EMISSIONS

The character of the receiving environment is important in evaluating the environmental impact of different pollutants. All pollutants do not have the same effect in all environments. Priority, in general, has been given to human health with welfare being a major consideration. Direct comparisons between impacts on human health and the natural ecosystem are difficult, and are seldom made. This may be the case in assessing incremental environmental impacts of converting the Tuk Tuk fleet from LPG and gasoline to electricity.

The methodology provided in Section II determines the following:

- the contribution/significance of emissions of primary pollutants (HC, CO, NO_x, Particulate) from Tuk Tuk operations;
- the contribution of Tuk Tuk emissions to secondary pollutant formation (O_3, sulfates, etc.) in the BMR;
- the Tuk Tuk contribution to health related impacts.

The methodology also presents the procedure to determine incremental changes to the ambient air quality levels, pollutant loadings, and population exposure, as a result of emission reductions from the conversion of LPG and gasoline powered Tuk Tuks to electric Tuk Tuks. This factors in the emissions impacts resulting from the additional electricity generating capacity required to power the electric Tuk Tuk.

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B. NOISE IMPACTS

Determining a quantifiable noise impact of converting from an obviously offensive sounding form of propulsion to a quieter form is complex at best. The team has identified a possible methodology to assess the benefit of noise reduction. The U.S. Department of Transportation uses and recommends a model in highway design efforts. Its purpose is to help evaluate potential noise issues and to resolve problems. The inputs to the model consist of the mix of vehicle types, maximum noise levels for each category, and the numbers of the various types of vehicles traveling the roadway of interest. The result, or output, of the model is a series of contours depicting noise levels.

The applicability of this model to the BMR cannot be assessed without a more detailed review and analysis. This model is known to work well in open areas but is less useful where sound (noise) can reflect and reverberate as in roadways lined by tall buildings. It may be possible to modify the model for use in the BMR, or to find a situation or location in the BMR where the model can be effectively applied.

Eventuality, if the model were exercised with data from the traffic counts and Tuk Tuk tests, noise contours both with and without the LPG/gasoline Tuk Tuks could be developed. The change in contour locations would indicate the areas of reduced noise levels. The resultant sound levels could then be compared to noise level criteria. Whether any reductions in noise would be of sufficient magnitude to provide a quantifiable benefit would need to be assessed. There are some property valuation techniques[3] related to noise impacts which may serve as useful indicators of the financial value of noise reduction. If no quantifiable value can be

[3]Nelson, Jon P., *Economic Analysis of Transportation Noise Abatement.*

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allocated to the reduction in Tuk Tuk noise contribution, there would still be an improvement in the quality of life for passenger and driver, and the population in general.

C. STUDY BOUNDARIES

There are three areas that need to be addressed in a separate study. These include the following:

- The methodology for assessing the upstream energy impacts of the conversion of LPG and gasoline Tuk Tuks to electric Tuk Tuks.
- The costs of recycling and disposal of batteries.
- The secondary impact on the environment in terms of non-point source contribution to water quality from street run-off.

D. BATTERY USE AND DISPOSAL[4]

The considered approach to electrifying the Tuk Tuks is to use lead acid batteries. With the present state of the art, batteries will need to be replaced over the life cycle of the Tuk Tuk. In general, the technology exists to recycle these batteries. Pyrometallurgical and hydrometallurgical techniques are well established. However, to minimize environmental pollution caused by careless disposal practices, government involvement in the form of legislation, public awareness programs, and effective collection programs is necessary. As battery technology changes, so will the issues of use and disposal.

[4] Although there are potential emissions associated with the production of the batteries, they were not considered a part of this evaluation. If electric vehicle transport becomes significant, this area needs to be assessed.

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E. PHASE II MODELLING

There are three different options for assessing whether the use of a model to determine the changes in emissions as a result of the conversion of LPG and gasoline Tuk Tuks to electric Tuk Tuks is advisable.

(1) Thai experts may wish to evaluate the existing models and assess if they can be configured without a major cost and applied to the Tuk Tuk case.

(2) The initial results from the Phase I methodology may be sufficiently acceptable for planning purposes and the Thai authorities may wish to postpone any decision with respect to the development and use of a comprehensive analytical model until such time when the added costs of such a model are justified.

(3) Another option is for EET, ~~USAID~~ to initiate a follow on effort for ETIP to coordinate with the Thais and reconfigure one of the existing models to explicitly incorporate Tuk Tuk parameters.

ANNEX I: BIBLIOGRAPHY

BIBLIOGRAPHY

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APPENDIX G

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
Bureau for Global Programs, Field Support and Research
Center for Environment
Office of Energy, Environment, and Technology

THAILAND TUK-TUK ELECTRIC VEHICLE DEMONSTRATION PROJECT

ELECTRIC TUK-TUK INFRASTRUCTURE REQUIREMENTS AND COST STUDY

Prepared for:

Royal Thai Government
Ministry of Science, Technology and Environment
Pollution Control Department

Prepared by:

Energy Technology Innovation Project
Contract No. DHR-5741-C-00-1061-00
Prime Contractor: Bechtel Corporation
Subcontractor: Viking Systems International, Inc.

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THAILAND

ELECTRIC TUK-TUK INFRASTRUCTURE REQUIREMENTS AND COST STUDY

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1. **Background**
2. **Project / Study Objectives**
3. **Expected Outcomes**
4. **Statement of Work**

Task 1: Qualitative Evaluation of Electric Tuk-Tuk Infrastructure Project Needs.

Task 2: Facility Needs for Tuk-Tuk Repair/Maintenance

Task 3: Facilities for Battery Recharging, Storage, Evaluation and Disposal

- Battery Recharging Facility
- Battery Testing/ Evaluation
- Battery Storage Facility
- Battery Disposal and Recycling Program

Task 4: Evaluation of Billing System for Battery Charging

Task 5: Computer Software and Hardware for Project Performance Monitoring

Task 6: Tools and Spare Parts

5. **Study Organization and Management**
6. **Level of Effort**
7. **Deliverables and Reporting**

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1. Background

Thailand is experiencing very rapid economic development and an even more rapid growth in demand for public transport needs. Associated with this growth are substantial environmental challenges; no matter what specific development path Thailand chooses, there will be environmental consequences to the country. With few exceptions, motor vehicles and Tuk-Tuks (3-wheel drive two-stroke and four-stroke engines) are the major cause of air and noise pollution in Bangkok city. At present, most Tuk-Tuks are 3-wheeled gasoline LPG (and gasoline) fueled vehicles used mostly as taxis and for deliveries. Public transport Tuk-Tuk populations in Bangkok and surrounding outskirts have been growing exponentially, doubling every seven/eight years. Owing to the high cost of Tuk-Tuk ownership, scrappage rates are low, resulting in an old and often poorly maintained vehicle fleet. Many Tuk-Tuks and motorcycles are powered by old design, two-stroke engines that emit up to ten times more hydrocarbons and smoke per kilometer than do the four-stroke engines of cars and trucks.

Also, insufficient urban road space and ineffective traffic management cause traffic congestion. Bangkok has massive traffic jams that delay commuters for hours; peak-hour speed in Bangkok averages around 16 kilometers per hour. Besides being costly in terms of time lost and the drag on commerce, stationary vehicles sitting in traffic contributes significantly added noise and air pollutions. Urban air in Bangkok is filled with increasing amounts of organic and inorganic chemicals, as well as suspended particles emanating from motor vehicles, Tuk-Tuks, industrial plants, cottage industry, and natural sources. New Delhi, Calcutta, Jakarta, and Bangkok ranked 4th, 6th, 8th and 12th, respectively, among the 41 cities analyzed by the UN-sponsored Global Environmental Monitoring System (GEMS) in 1980-84 for concentrations of suspended particulate matter.

Proposed Intervention

USAID/Bangkok, through the Office of Energy & Infrastructure of G/E&I, has embarked on a demonstration project of battery-powered Tuk-Tuks for the city of Bangkok that is expected to achieve the multiple objectives of enhancing the environment, leveraging Federal funds, and increasing US exports of battery technologies. Because Tuk-Tuks will improve air quality and reduce noise pollution, battery power will require changes in the present Tuk-Tuk infrastructure system. New technologies and strategies to improve air quality and reduce noise in Bangkok, without disrupting the economic and social fiber of the country, can be expected to receive high recognition and strong public and private sector support.

2. Project/Study Objectives

The fuel delivery (battery-charging facility), Tuk-Tuk recharging billing system, repair/maintenance requirements and the battery recycling and/or disposal infrastructure needs for electric Tuk-Tuks are unknown at this time due to various options and uncertainties of commercialization. The infrastructure need will also vary depending on whether the electric Tuk-Tuks are fleet-operated or individually-owned and/or operated. For a fleet-operated system, centrally located rapid charging stations and related repair/maintenance workshops can be economically justified. However, for individually-owned or operated Tuk-Tuks, a centrally located charging-station is unlikely to be widely effective. For non-fleet electric Tuk-Tuks, most recharging will likely be accomplished at home stations offering overnight recharging. However, other related infrastructure needs, such as electric motor repair/maintenance, battery disposal and/or recycling, and a time-of-use meters or pre-pay magnetic billing systems have to be implemented. Although additional generating capacity may eventually be required to support a large number of electric Tuk-Tuks, thousands of electric Tuk-Tuks can be recharged daily with no additional generating capacity, if the recharging is accomplished at night, after the evening peak demand.

Therefore, the objectives of this study are three-fold:

(a) to define the scope of infrastructure needs for the commercial phase of the electric Tuk-Tuk project that will help the Ministry of Science, Technology and Environment (MOSTE) to develop institutional capabilities necessary to implement the project;

(b) to develop an approach for the infrastructure cost/benefit study that will evaluate various commercial infrastructure technologies based on the life-cycle cost comparison of electric Tuk-Tuks; and

(c) to identify information gaps and the ways in which such data can be obtained in the demonstration phase of this project.

This study can assist the MOSTE and the USAID in identifying environmental concerns that can affect the extent of future bilateral and multilateral development assistance and private investment. The results of the infrastructure need study can be used to determine the viability of introducing electric Tuk-Tuks to other countries that currently experience similar air-quality and noise problems, such as India and Indonesia.

3. Expected Outcomes

By the end of the study the infrastructure needs are expected to include:

1. the identification of investment requirements for:

   a) charging stations for fleet-operated electric Tuk-Tuks;

   b) repair/maintenance workshops;

   c) a battery recycling and/or disposal system; and

   d) a Billing system for Tuk-Tuk battery charging.

2. an improved modular infrastructure program that can be duplicated in other cities or countries; and

3. strengthened ties with US technological and equipment manufacturers to address electric Tuk-Tuk infrastructure issues.

4. Statement of Work

A comprehensive assessment of the commercial phase of the electric Tuk-Tuk infrastructure requirements for the city of Bangkok will be carried out by the Contractor. Each major task described below must include the following features:

a) preparation of the action plan to accomplish the intended objective, with appropriate time schedule for achievement of "milestones".

b) review of existing data and incorporation of work done by others as appropriate.

c) following completion of each major task;, an interim task completion report shall be prepared and submitted.

Task 1: Qualitative Evaluation of Electric Tuk-Tuk Infrastructure Project Needs

To meet the electric Tuk-Tuk service reliability needs of both the fleet-operated or individually-owned and/or operated that will depend on a reliable supporting

infrastructure. The Contractor will develop the overall framework and define all parameters for the subsequent tasks of this study in the following areas:

A) Battery Charging Stations :

The primary objective is to define the electric characteristics of the battery charging station(s) - whether it should be a single-phase 220 Volt or three-phase 440 Volt and current rating. The circuit size will depend on the number of electric Tuk-Tuks and chargers used. Also, the Contractor will identify whether the charger needs to be adjusted to match the specific voltage that will be selected for the commercial phase of this project. Some other key questions in this area of inquiry need to be defined are provided below:

- Physical structure - indoor stations are recommended in areas of the heavy rains, cold climates, and outdoor stations should be weather proofed. Assigning one parking space to each vehicle charging station simplifies power consumption monitoring.
- Battery storage facility.
- Battery recovery/recycling and disposal facility.
- Maintenance and repair facility needs.

B) Tools and Equipment Needs:

The objective in this area of inquiry will be to identify for the battery charging stations and maintenance/repair facility all tools and equipment requirements to meet the conceptual plan of the facility and also in the areas of:

- Computer hardware and software for data management.
- Billing system - time-of-use meter or a prepay meter.

C) Training Programs:

The Contractor will focus on the high priority issue of training needs at all levels to establish this infrastructure system. As an essential component of strengthening newly

established infrastructure system performance, training needs will be identified at the following levels:

- Professional skill training.
- Technical training for maintenance/repair shop personnel.
- Managerial/supervisory training.

All subsequent tasks (Task 2, 3, 4, 5 and 6) life-cycle costing studies will be carried out by the Contractor based on the above defined framework and parameters.

Task 2: Facility Needs for Tuk-Tuk Repair / Maintenance

The primary objective of this task will be to assess the infrastructure set-up for scheduled and unscheduled maintenance/repair practices which will have impact on tuk-tuk system service reliability and performance. Experience has demonstrated that mechanical maintenance for electric vehicles is simpler than for conventional vehicles, primarily because the electrical vehicle propulsion system has fewer mechanical parts. For instance, there is no clutch to adjust, no ignition system to check, no distributor to tune, and no exhaust system to test. Recommended mechanical maintenance includes a motor brush inspection, a motor filter changer, and lubrication of the drive shaft and steering components every six months.

Maintenance for the electric propulsion system requires few special tools, and can be performed by regular fleet technicians in a well-ventilated, flat, clean area with conventional garage facilities. Because working with electricity involves some hazards, battery maintenance should be performed in accordance with manufacturer safety guides.

The Contractor shall highlight all key issues and investment needs in the following areas:

A) Quality and Maintenance Management:

In order to provide improved maintenance management in an effort to control overall expenses, several key questions in this area include:

- What should be adequate spare parts availability?

- What should be the mix of mechanical, electrical, and instruments and control technician appropriate?

- Coordination of tuk-tuk operations and maintenance.

B) Quality of Training:

Training programs for maintenance crews will be critical in the Tuk-Tuk system operations, quality of service, and safety. Under this task, the Contractor will address all key issues listed above as well as other areas necessary to establish a comprehensive Tuk-Tuk maintenance practice. The major activities that will be performed are as follows:

- General practice requirements:

  - Identify scheduling and staffing practices.

  - Identify key workload indicators.

  - Identify needs for planned maintenance programs for routine overhauls, major overhauls, and preventive maintenance.

C) Service Reliability and Quality Monitoring:

- Provide performance criteria and monitoring practices for the Tuk-Tuk fleet.

- Recording practices for service interruption (frequency and faults) and causes of faults by Tuk-Tuk component classes.

Task 3: Facilities for battery Recharging, Storage, Evaluation, and Disposal

The Contractor shall provide infrastructure life-cycle cost comparison of two types of facilities: a) fleet-operated Tuk-Tuks, and b) individually-owned and/or operated Tuk-Tuks. The study will address the following infrastructure needs:

- Battery Recharging Facility

- Battery Storage Facility
- Battery Testing/Evaluation Equipment
- Battery Disposal and Recycling Program

A) Battery Recharging Facility:

The cost of the station will depend on the voltage (for example : 220 volt and 30 amp outlet or 400 volt and 60 amp outlet), ampere rating, ground-fault circuit interrupter to guard electrical shock and a billing system for recording charging rates. Based on the battery recharging tariff structure, batteries can be charged continuously (24 hours) or only during the off-peak hours. Conceptually, sets of batteries will be connected to the off-board charger by plugging a cable into a socket either in the front of the Tuk-Tuk or without Tuk-Tuk (for off-peak hours charging). The charger will automatically charge the battery (or a set of batteries) to a pre-determined current profile and will maintain the charged state by sending periodic refresher chargers to the battery. The total duration of recharging a fully discharged battery will depend on the battery technology for the storage-capacity-to-weight ratio.

The key to easy battery maintenance is the Autofil unit, a central automatic battery watering system. The Contractor shall provide the design specification and cost for the Autofil cart to replace the water lost in the batteries during battery charging. Once attached, the watering system should not need any supervision. Facility design should allow only fully charged batteries to be watered. Although requirements will vary with use and climate, most manufacturers recommend watering every two to three weeks.

B) Battery Testing/Evaluation:

As a part of this project, different battery technology will be tested and evaluated for the Tuk-Tuk application in this infrastructure facility. The Contractor will provide a detailed description of the test facility and cost estimate as part of the infrastructure costs. The Tuk-Tuks will require periodic battery tests to monitor the voltage of each cell in the battery pack, as a low-voltage cell affects vehicle performance. In addition, continued operation of a battery containing cells with improper voltage can permanently damage those cells. Battery technology will determine the duration of equalizing charge to correct improper voltage.

The Contractor shall provide the outline of the training course for the maintenance personnel which will give thorough instructions for performing these tests and battery maintenance that can be completed in one working day.

In addition, the Contractor shall provide generic detail procedures for inspection and tests of battery packs. The procedure must include tools and equipment (for example, a fork lift or similar instrument equipped with a load spreader) and steps involved in supporting the pack under the Tuk-Tuk vehicle, releasing fittings attached at several points, disconnecting electrical and watering connections, etc.

C) *Battery Storage Facility:*

For a fleet-operated infrastructure system, large battery storage facilities will be required. The Contractor shall provide the design and cost of such storage area which will include all safety measures for the abatement of hazards (including the danger of explosion due to the ignition of hydrogen gas that is given off during battery charging). The facility should be designed to prevent short circuits while batteries are being charged, tested, or handled because of the danger of sparks setting of an explosion of accumulated hydrogen gas, resulting in serious burns.

The storage facility must incorporate the following design/safety measures:

- Battery rooms shall be well ventilated with vents sized and located to allow gases to escape.
- Battery racks shall be substantial and treated to resist acid, and floors shall be acid resistance or protected from acid accumulation.
- Battery storage shall be done in designated areas, that are railed or roped-off from other areas of equipment, and smoking shall not be permitted in the area.
- Protective equipment (dielectric face shields, aprons, and acid-resistance gloves) shall be provided at all battery installations and charging areas, and the equipment shall be worn by all employees when handling batteries and battery acid and while making specific gravity readings.
- Appropriate signs shall be suggested for posting at battery installations to indicate that protective equipment must be worn.
- Fixed or portable facilities for quick drenching of the eyes and body shall be provided within 25 feet of the work area for emergency use.

- Portable eye/body wash bottles shall be filled with potable water only and shall be used for eye- and body-drenching purposes only.
- Deteriorated or defective portable eye/body wash bottles shall be replaced.
- Open flames, smoking, and spark-producing equipment are prohibited, unless proper ventilation and safe working practices are used, when working with or near acid in metal containers, such as tanks.
- Acids, in any quantity, shall be kept in a container labeled to indicate the type and concentration of the acid.
- Acids shall not be stored near heaters, steam pipes, or other sources of heat.
- Containers shall be securely stored and easily accessible.
- Chemical pumps shall be washed externally before repacking or making other repairs.

D) Battery Disposal and Recycling Program:

The Contractor shall provide a detailed description of Tuk-Tuk battery recycling and disposal program including a draft legislation (if such legislation is not existence in Thailand) for battery recycling.

Research has found that lead may be absorbed into the blood stream causing serious liver and kidney damage in adults and neurological damage in children. In addition to the many ways lead may be absorbed from battery products, the improper disposal of batteries creates yet another health threat. Lead from landfilled lead-acid batteries may leach into groundwater supplies or contaminate surrounding soil. Lead processing facilities are another source of contamination. In the U.S., according to *Resource Recycling* (April 1991), more than "50 operating or former lead smelters are either on the National Priority List (also known as Superfund) or subject to corrective action under the Resource Conservation and Recovery Act."

The Contractor shall address the following issues for recommending a Battery Disposal and Recycling Program for the MOSTE:

- Would the MOSTE support legislative action to pressure the battery industry to take responsibility for the waste generated by its products?

- What recycling or hazardous waste landfilling options exist in Thailand?

- What are the costs of these options?

- Is the proposed recycling or disposal option environmentally sound, i.e., is it unlikely to create similar or worse contamination in another location?

The Contractor shall provide guidelines for all safety questions regarding the storage, handling, and equipment of mercury and lithium batteries.

The Contractor shall provide a model legislation for battery recycling which will incorporate:

- Prohibition of individuals from disposing of used lead acid batteries except by delivery to the following:

  - Battery retailers or wholesalers.

  - Government authorized collection or recycling facilities.

  - A secondary lead smelter permitted by the environmental agency in Thailand.

- Each battery improperly disposed of would constitute a separate violation, with such violation subject to the penalties deemed appropriate by the MOSTE.

- Retailers/wholesalers/importers responsibility.

- Enforcement -- violations would be a misdemeanor under the model legislation.

- Severability -- this section should contain standard severability language.

Task 4: Evaluation of Billing System for Battery Charging

As a part of this infrastructure study, the Contractor will perform the following subtasks to evaluate the battery recharging billing technology. The Contractor will evaluate the technical and economic importance of using modern technology to meet the following requirements.

- High measuring accuracy in light of increasing energy costs.
- Ease of maintenance to ensure optimum operational reliability with minimum personnel.
- Flexibility to accommodate a wide variety of tariff applications for Tuk-Tuk battery recharging meters.
- Data exchange with higher level system to optimize energy usage.

The Consultants will also provide technical and economic justifications for the selection of any of the following meters for the pilot project demonstration:

Individual Tuk-Tuk Metering:

- Tamper-resistant meters for domestic customers.
- Card-operated prepayment meters.
- The solid-state domestic Watt-hour meter.

Fleet Operated Tuk-Tuk Metering:

- Three-phase solid-state meters.
- Microprocessor-controlled measuring and recording equipment.
- Time-of-use metering.

The Contractor will prepare equipment specifications and budgeting cost estimates for the selected metering technologies or meter for the commercial phase of the project.

Task 5: Computer Software and Hardware for Project Performance Monitoring

The Contractor will develop a computer software and hardware system for the performance monitoring of each Tuk-Tuk for the commercial phase of the project. Additionally, for the commercial phase, the Contractor shall evaluate computer software and hardware costs for the billing and infrastructure facility management, which will have the following features:

A) *Tuk-Tuk Meter File.*

- Tuk-Tuk meter number can be fleet and/or manufacturer serial numbers.
- Meter inventory is kept by inventory code (active, idle, out for test, etc.).
- Test data is kept for prior two testings.
- Facilitates kWh, KW, KVAR, and TOD readings.
- Options for meter reading books or sheets.
- Facilitates meter test scheduling.
- All detail on meter type is kept in meter file.

B) *Tuk-Tuk Performance Data File.*

- Direct access to all information by:
  - Name (alpha)
  - Account number (Operator separator)
  - Location number (map grid)
  - Meter number
  - Reading sequence
  - Maintenance service order
- Alpha cross reference inquiry to capital/credit/deposit accounts for Tuk-Tuk if they are leased to an independent operator.
- Inquiries available on posting screens to allow instant access if questions arise.

- Inquiries and reports pull information from files designed to retain original posting detail.
- Users can exit inquiry at any level with a single key stroke.
- Inquiry screens are printable for use in customer service.
- Cash search inquiry selects records in amount sequences.
- Inquiry to all of a Tuk-Tuk's accounts by Operator's ID number.
- Inquires interface with outage reporting or service order.

C) *Battery Performance Data File.*

- Charge and discharge cycles for energy per pound and battery and types of battery (manufacturer's trade name).
- Battery charging time, for example: to 50% and 100% capacity by manufacturer's trade name.
- The total number of charge/discharge cycles battery sustain per period (weekly or monthly).
- Acceleration (or peak power capacity) of battery as function of age.
- Comparison of various manufacturer's battery costs/cycle (purchase energy per estimated cycle life).

Task 6: Tools and Spare Parts

The proposed facility must have adequate tools required for Tuk-Tuk and battery maintenance. The facility needs to keep an extensive spare parts inventory, particularly spare parts procured from the U.S. (or overseas) so that the downtime is minimum. As a part of infrastructure site preparation inspection, the Contractor shall review existing Tuk-Tuk maintenance workshop tools with fleet personnel to determine what additional equipment must be procured.

The garage should have access to a fork lift or pallet loader equipped with a load spreader for battery removal. Each Tuk-Tuk also requires an off-board charger, delivered with the Tuk-Tuk, and one Autofil trolley, which can service a large number of vehicles. In cold climates, electric vehicles will operate more efficiently with a battery heater, available as an option. The Contractor shall recommend whether to purchase an extra off-board charger to place at an exterior site for "opportunity" charging, to extend the range of the Tuk-Tuk during the daily run. As an example, in Table 1, parts in the quantities suggested should service 1-10 Tuk-Tuks.

5. Study Organization and Management

Prospective contractor is expected to work closely with the MOSTE staff in completing the feasibility study for the commercial phase of the project. The Contractor will be responsible for the writing and preparation of the final feasibility study report. Additionally, the Contractor will be fully responsible for:

a) All field data collection for battery recharging facility and repair/ maintenance workshop;

b) Developing methodology for the cost/benefit analysis and developing an overall infrastructure management and organizational program;

c) Preparation of technical specifications and cost estimates for the implementation of the commercial phase of the project; and,

d) The infrastructure feasibility study report.

The Contractor will provide technical manuals, reference books, computer model(s), metering, and testing equipment to carry out the work in a satisfactory manner. All such manuals, equipment, and instruments would become the property of the existing Tuk-Tuk fleet infrastructure facility upon completion of the feasibility study, so that MOSTE would be in a position to monitor the performance of the pilot project during the implementation of the commercial phase of the infrastructure of the project..

GOT will provide the following direct local support for the feasibility study activities:

a) Counterpart professionals for Contractor field personnel;

b) Monitoring and logging of measured data;

Table 1
Typical Tools and Equipment of an Electric Tuk-Tuk Recharging Station

Vehicle	
Battery location pin	2
Autofil connector block	1
Bayonet plug	2
Battery pack fuse	1
Vaqualok assembly	4
Rubber tubing	5
Elbow connector	20
In-line connector	20
Battery pack vyon flame arrestor	4
Ceramic vyon flame arrestor	4
Flame arrest device	2
Motor filter	4
Erma insulating cap	2
Fuses (type and quantity to be determined)	
Charger	
Fuse - (TIS 63A)	2
Fuse - (SOA GSA)	2
Optional Charger Spares	
Spegel PCB	1
Cell selector PCB	1
Charger contactor	1
Charger plug assembly	1
Tools and Equipment	
Vaqualok tool	1
Digital multimeter (Fluke recommended)	1
Battery removal equipment	
Battery watering trolley	

c) Provide assistance in the technical analysis of preparing a computer model for Tuk-Tuk performance monitoring and data base management;

d) Provide office space, equipment and furnishings for the Contractor and counterparts.

The study team (Contractor and MOSTE staff) must prepare and present a detailed work plan within four weeks after commencement of work. The plan will identify all the resources required and the schedule to complete each of the activities in the "Statement of Work."

6. Level of Effort

The total level of effort for this feasibility study by the Contractor is about six man-months or 26 weeks -- 12 weeks in Thailand for the data collections and analyses; and 14 weeks in home office for preparation of the draft feasibility study report and the final report. *Table 2* shows a detailed breakdown of in-country and home-office level of efforts by the Contractor and the MOSTE staff. All tasks are divided into three steps. The *first step* involves in-country review of the Tuk-Tuk fleet system operations and a preliminary evaluation of the overall infrastructure needs for the commercial phase of the project. The *second step* also involves in-country (in Bangkok) preparation of cost/benefit analyses of various infrastructure facility options, programs, and analyses of the measured field data; and, the *third step* will require home office preparation of the draft feasibility study report of the project and after receiving comments from the USAID and MOSTE staff, the Contractor will submit the final feasibility study report.

7. Deliverables and Reporting

The contractor and MOSTE will:

- Provide feasibility study reports for each component of the most promising Tuk-Tuk infrastructure facility program for the commercial phase of the project; and

- Prepare integrated final implementation/action plans for the commercial phase of the project incorporating the results of Tasks 2, 3, 4, 5, 6, and priority ranking assessments.

TABLE 2

Breakdown of Level of Effort By Contractor and MOSTE Staff

ACTIVITIES	MONTHS					
	1	2	3	4	5	6
Step # 1 In-Country Data Collections and Infrastructure need evaluation - Contractor - MOSTE Staff						
Step # 2 In-country Data Analysis and Infrastructure technical specification of equipments for procurement - Contractor - MOSTE Staff						
Step # 3 Preparation of Draft Feasibility Study Report of Tuk-Tuk Infrastructure - Contractor - MOSTE Staff Preparation of the Final Feasibility Study Report of Tuk-Tuk Infrastructure						

In addition to providing the above reports, the contractor and MOSTE will submit the following reports during the implementation and testing period of the pilot project:

- Monthly status report
- Mid-project report
- Final report, and
- Technical reports.

APPENDIX H

U. S. AGENCY FOR INTERNATIONAL DEVELOPMENT
Bureau of Global Programs, Field Support and Research
Center For Environment
Office of Energy, Environment, and Technology

ELECTRIC TUK-TUK ECONOMIC FEASIBILITY MODEL

Preliminary Model

June 22, 1995

PREPARED FOR:

Royal Thai Government
Ministry of Science, Technology, and Environment
Pollution Control Department

PREPARED BY:

Energy Technology Innovation Project
Contract No. DHR 5741-Q-00-1062-00
Prime Contractor: Bechtel Corporation

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ELECTRIC TUK-TUK ECONOMIC FEASIBILITY MODEL ANALYSIS

1.0 Discounted Cash Flow Analysis

Based on discussions with the Royal Thai Government, no economic/financial feasibility analysis of the tuk-tuk industry has been conducted to date. It is therefore assumed the economic/financial feasibility of substituting electric tuk-tuks for gas-powered tuk-tuks has not been conducted.

The use of discounted cash flow (DCF) analysis for financial/economic analyses is common. According to Brigham and Gapenski (1994), DCF techniques are used when new projects are being evaluated, when firms are analyzing lease versus buy decisions, and when firms are deciding to refund a bond issue. DCF is used to calculate the present value of the future cash flows.

All discount rates (opportunity cost of capital) are based on the prime lending rate as stated in *The Far Eastern Economic Review* of June 8, 1995.

2.0 Tuk-tuk Industry

2.1 Current Industry

The taxi tuk-tuk industry in Thailand is comprised of several "associations." The associations are analogous to unions or a Chamber of Commerce where individuals, in this case tuk-tuk fleet owners, work to attain similar goals (i.e., financial well-being). There are two main tuk-tuk associations operating in Bangkok. The associations are defined by territorial boundaries. Each fleet owner operates his/her fleet within his/her association's territory. Fleet owners define their tuk-tuks by color.

To control the tuk-tuks population in Bangkok, the Government limits the number of tuk-tuk medallions for taxi purposes. Similar to Boston, a medallion is required to operate a taxi tuk-tuk. Because the supply of medallions is limited, street prices are approximately $20,000. Thus, buying and selling of medallions is limited to wealthy citizens who own and operate fleets.

Fleet owners collect revenue by charging a rental fee to tuk-tuk drivers. Costs for the owner include the capital cost of the vehicle, and operations and maintenance. Drivers tend to be lower-economic-class citizens. Revenues for the drivers are derived from fares obtained during one of two daily shifts: 2 a.m. to 12 p.m.; and 2 p.m. to 12 a.m. Drivers rent the tuk-tuk and pay to fuel it with liquified petroleum gas (LPG) and lube oil. Lube oil is required to lubricate engine parts.

The average life of an LPG tuk-tuk is 15 years. Rarely is a tuk-tuk scrapped. Instead, parts are refurbished for use in a "new" vehicle. Junkyards filled with tuk-tuk replacement parts are common.

2.2 Projected Structure of the Electric Tuk-tuk Industry

The basic owner-driver structure of the tuk-tuk industry is not altered for the electric vehicle industry. Owners own and maintain the fleet(s). Tuk-tuk drivers operate the electric tuk-tuks. Contrary to the current industry, two additionally parties enter the decision-making process--the Royal Thai Government and a charging station owner/operator.

For the analysis, an the Government entity such as the Metropolitan Electricity Authority builds, owns, and operates a battery charging station. The entity bills a driver for each "fill-up." There are two primary ways to fill-up an electric tuk-tuk. First, the driver enters the charging station and the battery pack from his/her tuk-tuk is removed. The charging station operator replaces the battery pack with a battery pack previously charged to full capacity. The charging station operator recharges the depleted battery pack during the operator's next shift. This scenario is the "replacement" method. The main advantage is the quick turnaround time. It is estimated to take 15 minutes to remove an old pack and install a new pack. The major disadvantage is higher battery pack capital cost because each tuk-tuk needs 2 battery packs; one is in use while the second is being charged. In the "quick-charge" method, the driver waits as the battery pack is

recharged. This option requires greater energy charges and reduces battery life cycle. The "quick-charge" battery pack capital cost is less for the "replacement" method because 50% fewer batteries are required. The capital and operating costs of "quick-chargers" is higher than those required for slow charging. The "quick-charge" method is not considered in this analysis since data are not available.

For the proposed electric tuk-tuk industry, the Government plays an important role. First, the Government oversees the electric tuk-tuk program. The Government incurs a cost to monitor program effectiveness and to regulate the charging station owner/operator. Second, the Government subsidizes the electric tuk-tuk industry. Potential subsidies may be needed to offset battery and/or electric vehicle capital costs. The Government will receive societal and environmental benefits from this endeavor. Each LPG tuk-tuk replaced by an electric tuk-tuk represents less pollutants that cause ecological and/or health problems in Bangkok.

3.0 Decision Criteria for Key Players

The economic/financial model considers four parties: tuk-tuk drivers, tuk-tuk owners, the Government, and a government entity that owns and operates a charging station.

3.1 Driver Indifference

For successful economic/financial feasibility, a tuk-tuk driver need to be indifferent in his/her choice of a tuk-tuk. The appeal of the tuk-tuk is the least-coast form of transportation it provides for lower economic class citizens. Passengers will not pay a premium to ride in an electric tuk-tuk because all tuk-tuks are open to the elements and subjected to the same air and noise pollution from surrounding vehicles. Thus, an electric tuk-tuk driver charges an identical fare and transports as many passengers as an LPG tuk-tuk driver. The electric tuk-tuk driver only makes a profit equivalent to an LPG tuk-tuk driver if the operating expenses for the electric tuk-tuk are less than or equal to the operating expenses for the LPG taxi tuk-tuk. Assuming the vehicles perform identically, the driver is indifferent when the his/her profit is identical profit regardless of vehicle operated.

Because tuk-tuk drivers are lower economic class citizens, their concern is short-term profits. Even though the model calculates after-tax income for 15 years, the key decision criteria for the driver is the first year income. The model discounts the driver's after-tax cash flow at prime--13.50%. This discount rate reflects two considerations:

- Economic opportunities available to tuk-tuk drivers are limited. The prime lending rate approximates interest rates for saving accounts that a driver is likely to invest.

- Drivers incur the same risk operating electric tuk-tuks and LPG tuk-tuks. Thus, the discount rate includes no risk premium.

3.2 Owner Indifference

Tuk-tuk drivers receive the same fare regardless of tuk-tuk, and owners charge identical rent for both tuk-tuks. The driver will not pay a premium for an electric vehicle that cannot generate profits in excess of the LPG tuk-tuk. The owner is indifferent when the return on equity (ROE) for utilizing either vehicle is identical. The owner incurs debt to purchase an electric tuk; the owner pays 100% equity (cash) to buy an LPG tuk-tuk. ROE allows comparison of different equity investment streams that occur because of the higher capital cost of the electric vehicle.

The model calculates ROE by determining the rate at which the owner's equity grows at to equal the cumulative present value of the after-tax cash flows. The model discounts the owner's after-tax cash flows at 21.00%. Because of the significant technical and commercial risk associated with electric vehicles, the owner commands a premium of 7.50% above the Thai prime lending rate.

3.3 Charging Station Owner

The model treats the charging station as a utility selling electricity to individual customers (drivers). Based on utilitity operations in the United States, the model assumes the charging station owner earns a predetermined return on equity. Equity investors in the charging station operator require a risk premium in excess of the Thai prime lending rate. The model calculates the ROE assuming a risk premium of 1.50% for a total required return of 15.00%.

The model discounts the after-tax cash flows at 21.00%. The discount rate includes a maturity premium in addition to the risk premium. Because the ROE depends on the charging station operating for 15 years, maturity premium is required for calculating the discount factor. The combined premium for calculating the charging station discount rate is 7.00%.

3.4 Government

The Government's decision criteria differs from the other parties. The Government is concerned with cash flow; however, the Government substituting electric tuk-tuks for LPG tuk-tuks provides indirect monetary benefits. Reducing pollution lessens societal and environmental degradation. For example, health of the population increases as air pollution decreases. Environmental remediation costs less when there are fewer pollutants to clean. These benefits reduce the Government's burden of providing services to the population. Measuring indirect monetary benefits requires additional analyses not completed at the time. The model is designed to accomodate the results of these analyses to provide a better portrayal of the Government's decision criteria.

The model calculates a base case to determine if the Government needs to introduce economic and/or financial incentives to make the project viable. Because environmental and societal benefits are not considered, the model gives the user the option to calculate subsidies.

The decision criteria for the Government is the net present value for the 15 year analysis. The model discounts the after-tax cash flows at the Thai prime lending rate. Prime approximates the interest rate at which the Government can raise funds on capital markets. Thus, the Government requires an equivalent return.

4.0 Model

4.1 Limitations

The model evaluates economic/financial feasibility of taxi tuk-tuks. All parties act in a rational manner when making economic and financial decisions.

Data inputs are based on 1) USAID field mission to Bangkok, 2) discussions with MOSTE and the Government; 3) discussions with tuk-tuk drivers, owners, and the associations; and 4) independent USAID research. Technical information for the electric tuk-tuks were provided using a simulation model. In certain cases, it is necessary to estimate inputs. Thus, the results of the model are only as good as the data collected.

The model analyzes twenty electric tuk-tuks purchased in Year 0; more than likely, the industry will purchase electric tuk-tuks at more frequent interval. Modeling difficulties preclude analysis of constant purchases.

The model calculates data on a monthly basis. For tuk-tuk drivers, monthly flows are broken down to weekly flows to better model the industry. Investments occur at the end of the individual analysis period, and expenses occur at the beginning of the period.

4.2 Data Input

4.2.1 Fare Data

Fare cost, number of fares per shift, and distance per shift for a liquified petroleum gas tuk-tuk are based on data collected by USAID during field tests. The maximum number of LPG shifts in one year is calculated as two shifts per day times 365 days per year. An LPG driver works one shift per day and 70% of the year; each driver works approximately 260 shifts per year. Similarly, each LPG tuk-tuk is only available for 70% of the maximum number of LPG shifts per year. Downtime provides for repairs and preventive maintenance.

The annual fare data is calculated for one driver. The annual mileage data is for one LPG tuk-tuk.

4.2.2 LPG Operating Cost Data

The rental fee, LPG cost, LPG tuk-tuk fuel efficiency, lube oil cost, and lube oil efficiency were collected during USAID field tests. The LPG capital cost is based on discussions with MOSTE. LPG tuk-tuks are bought with 100% equity. However, the model can evaluate different debt-equity structures.

The O&M annual cost figure is based on USAID field test data. Other annual costs include items such as fees.

4.2.3 Financial/Economic Data

The exchange rate is the current baht/dollar exchange rate. All discount factors are in real terms. The income tax rate for tuk-tuk owners is 30%. The current interest rate is 15%. Electricity cost of 1.25 Baht/kWh is based on rate information supplied by MOSTE via the Metropolitan Energy Authority of Thailand.

4.2.4 Time Frames

The tax, or depreciable, life of a tuk-tuk is five years. The economic life, or operating life, of a tuk-tuk is 15 years. There is no salvage value for an electric or LPG tuk-tuk after 15 years. At the end of the economic life the vehicle is scrapped, and a new vehicle is purchased.

4.2.5 Electric tuk-tuk Cost Data

The capital cost of an electric tuk-tuk is 100,000 Baht. This does not include batteries. The model accounts for four different battery purchasing scenarios. For certain scenarios a government subsidy may be included in the calculations. Electric tuk-tuks are available 70% of the maximum number of annual shifts. For this analysis, an owner purchasing an LPG tuk-tuk or an electric tuk-tuk contributes identical amounts of equity. Because the capital cost of the electric tuk-tuk is higher than the LPG tuk-tuk, the owner incurs debt to purchase a electric tuk-tuk. The model can be modified to evaluate different debt/equity structures. The annual O&M cost is based on discussions with the electric tuk-tuk manufacturer.

4.2.6 Charging Station Data

Each 20-unit charging station is estimated at 750,000 Baht. O&M costs are derived from conversations with manufacturers. Various debt/equity structures can be evaluated. Charging station effiency is assumed at 90%. Insurance expenses and net working capital percentages are USAID estimates. Net working capital represents the funds required to finance the difference between current assets and current liabilities. Net working capital is included in the operating expenses.

4.2.7 Tuk-tuk Annual Fare Data

Because of mechanical considerations, a tuk-tuk is available for 70% of the shifts per year. Considering limitations on drivers, an electric tuk-tuk driver work the identical number of shifts as an LPG driver (260 shifts per year). The annual fare revenue for one driver and the annual mileage for one LPG tuk-tuk are calculated using these availability factors. Electric tuk-tuks and LPG tuk-tuks are considered technically equivalent; therefore, both cover identical distances and generate the same revenues annually.

4.2.8 LPG Tuk-tuk Annual Operating Cost Data

All annual operating costs are based on one driver.

4.2.9 Charging Station Data

The number of recharges per year is dependent on the type of battery analyzed. The electricity consumed is based on the number of recharges.

4.3 Battery Information

Two battery types and one scenario are considered in the model. The recharge scenario involves replacing the spent battery pack with a fully charged pack. A battery pack change takes the same amount of time as an LPG fueling.

The Horizon batteries have greater range and a longer life cycle than the Yuasa batteries. One Horizon battery last the equivalent of one LPG tuk-tuk shift. For the Yuasa battery, each battery must be replaced three times to cover the distance traveled during two LPG shifts. The cost of the Horizon batteries is 150% more than the Yuasa batteries.

According to the battery simulation model, the average energy needed to charge both batteries is 12 kWh. Based on the average distance per tuk-tuk shift, the energy per distance is calculated. Battery Life and Total Batteries are based on the Life Cycles and the number of batteries needed per day.

4.4 Modeling Techniques

4.4.1 Drivers

LPG drivers earn revenue from fares only. Costs include tuk-tuk rental, LPG, and lube oil. Income tax can be included if desired. A driver's after-tax income is discounted annually and summed to determine net present value over 15 years. However, tuk-tuk drivers primary concern is short-term profits. Therefore, after-tax and discounted after-tax incomes are listed annually.

Based on the model assumptions, fares and rental fees for electric tuk-tuks are the same as fares and rental fees for LPG tuk-tuks. The driver of an electric tuk-tuk is concerned with short-term results. Thus, the difference in net present value between the electric tuk-tuk and LPG tuk-tuk driver is presented each year. When the difference in net present value between the two types of tuk-tuks is zero in year 1, the driver is indifferent to the type of tuk-tuk he/she drives to earn a profit. A caveat towards the driver's indifference is the technical capabilities of the electric version. The model assumes that the electric and LPG tuk-tuks are technically similar.

Fares and tuk-tuk rental are escalated at the Apparent Inflation Rate. Fuel and lube oil are escalated at the Apparent Fuel Inflation Rate. Fares, tuk-tuk rental, and electricity cost are escalated at the Apparent Inflation Rate. Because electricity inflation escalates slow than LPG inflation, electric tuk-tuk drivers will earn more money than LPG drivers after Year 1 of the 15 year evaluation.

4.4.2 Owners

The model analyzes one owner purchasing twenty (20) electric tuk-tuks in Year 0. Currently, LPG tuk-tuk fleets average 40 vehicles. A sample of twenty vehicles was selected because it is unlikely that any fleet owner will introduce electric tuk-tuks on a wide scale until technical and economic/financial concerns are eliminated. Charging station capacity is also important in selecting the fleet size.

For the base case, the owner purchases the LPG tuk-tuk with 100% equity. The purchase price of a tuk-tuk reflects the true cost to the owner: It is not the retail price. The owner earns revenue solely from driver rental fees. Costs that the owner deducts from his taxable income include depreciation, operations and maintenance costs, interest payments and other costs (fees). The vehicle depreciates according to the tax life of the vehicle. Straight line techniques are used to calculate the annual cost. The model calculates after-tax income using the owner's tax rate and discounts the value to a present value using the owner's discount rate.

Because the owner incurs debt to purchase the tuk-tuk, the owner procures a bank lown to pay down the debt portion of the vehicle. The owner pays an equity amount equivalent to an LPG purchase on a one-to-one vehicle basis. Debt repayment occurs over the tax life of the vehicle. Summing the interest and principal payments gives the total cost of the project. Because depreciation is a non-cash expenditure, the annual amount is added back in the cash flow calculation. Principal payments are not tax deductible but do figure prominently in the cash flow analysis.

The model presents annual discounted cash flows to verify if debt service can be met. ROE is calculated to determine the return on the owner's initial investment for the economic life of the project.

4.4.3 Charging Station

The debt-equity ratio for the charging station investment is dependent on user input. Electricity revenues are received from 20 electric tuk-tuks "filling-up" at their defined availability factor. The revenue earned by the charging station is determined by adding the price the charging station pays to MEA for electricity and the price it needs to charge to recoup its costs and meet investors expectations. MEA charges for electricity based on facility size and electricity needs. User input determines the cost that covers all charging station requirements.

Tax-deductible costs to the charging station include depreciation, interest on the bank loan, insurance and other taxes, and O&M expenses. A flat energy charge is paid to the local electricity authority. The charge is documented in information supplied by the Metropolitan Energy Authority of Bangkok.

The electricity cost that the charging station charges to meet its costs and investors' returns is less than the price the drivers pay for a fill-up. Because the energy cost of one electric tuk-tuk shift is less than the energy cost of one LPG tuk-tuk shift, the Government can levy an additional tax. The tax serves to reduce any potential subsidy the Government may require to entice the drivers, owners, or charging station to introduce electric tuk-tuks. The rate charged to the electric tuk-tuk drivers cannot exceed the equivalent energy charge for one LPG tuk-tuk shift. Thus, the Government may not be able to fully recover any subsidy.

Principal is not tax deductible. Depreciation is added-back in the cash flow analysis.

4.4.4 Government

The Government collects two direct forms of revenue in the proposed electric tuk-tuk industry. First, the Government collects income tax from the charging station operator, owners and drivers. Taxes collected from the owners and drivers may decrease when substituting one electric tuk-tuk for one LPG tuk-tuk. To handle this case, the model calculates the difference in income taxes for one electric and one LPG tuk-tuk for the owner and the driver. Secondly, the Government levies a tax on the price of electricity charged by the charging station owner to tuk-tuk drivers. The charging station owner pays this tax directly to the the Government to offset any subsidies needed to make the project feasible.

The Government collects two indirect revenues. Electric vehicles reduce noise and air pollution paying societal and environmental benefits to the Government. Reducing pollution lessens the populations exposure to health risks and reduces medical bills. Similarly, less money is required to stem environmental degradation. Estimates of these values will be supplied by a subcontractor performing an environmental assessment.

Subsidies represent the largest cost to the Government. Driver and owner indifference may require a Government subsidy depending on the battery purchase and battery type scenarios. The Government also pays to monitor the electric tuk-tuk demonstration project in Bangkok.

4.5 Inflation

Annual Inflation averages 5.0% annually for the 15 year project. This is consistent with projections from various publications' forecasts; Emerging Markets Monitor forecasts a 5.4% inflation rate for 1996. Real Cost Escalation averages 2.5% annually. Apparent Inflation is 7.63% annually. Fuel escalates at 3.5% annually. Apparent Fuel Inflation is 8.68% annually.

5.0 Model Runs

5.1 Base Case Development

The model base case consists of eight scenarios. The primary input is the type of battery selected. The user can select either Yuasa or Horizon. Simple mathematics shows that the economics of both batteries are similar. Where you need twice as many Yuasa batteries, the life span is half as much as the Horizon battery.

Developing the model, it became obvious that economic and financial feasibility depends on Government subsidies. The primary cause is the high capital cost of the battery packs. Whereas the LPG tuk-tuks need one fuel tank, the electric tuk-tuks require new fuel tanks every one to three years. This recurring cost adversely affects the cash flow analysis of whichever party absorbs the cost.
An analysis of the cash flow analysis for the owner reveals a second reason for subsidies. The ROE for an owner of one electric tuk-tuk is less than the ROE for an owner of one LPG tuk-tuk because of the higher capital cost of the electric tuk-tuk. The owner will prefer the LPG tuk-tuk as he/she will be able to generate excess profits. If the Government pays a subsidy to the owner, indifference occurs when the ROE for both vehicles is identical.

To analyze potential subsidies, the base model can analyze four different battery purchase/subsidy scenarios scenarios.

1. The owner purchases the batteries. The Government pays a subsidy to the owner that covers the battery cost and electric tuk-tuk capital cost.

2. The charging station purchases the batteries. The Government pays one subsidy to the charging station to offset the cost of the batteries. A second subsidy is paid to owner to equate ROE for both vehicles.

3. The owner purchases the batteries. The Government pays the subsidy in the form of reduced tax rates for the electric tuk-tuk owner.

4. The Government purchases the batteries. Nonetheless, the owner requires a subsidy to be indifferent.

Each option presents advantages and disadvantages. The flexibility to analyze various option allows the user to decide the best course of action.

5.2 Base Case Selection

For this analysis, I selected subsidy option three. Allowing the charging station operator to purchase the batteries simplifies the industry. First, the owner's outlays are limited as only the cost of the vehicle itself is considered. Second, issues regarding battery damage and charge capacity are better handled by the charging station owner. Overuse of a battery pack reduces pack lifetime and increases recharging time. In the replacement scenario considered, the charging station operator monitors battery performance because it has an economic incentive. This enables the charging station to levy fines for misuse. If the owner is responsible for battery purchase, the burden of battery monitoring is hampered because even though the owner has an economic incentive his/her opportunities to check batteries is limited.

Because the charging station purchases the batteries, the Government must subsidize the charging station to enable the operator to meet its ROE requirements. The electric tuk-tuks owner also requires a subsidy to meet his/her ROE requirement. Instead of a direct Government subsidy, the Government permits a 3.70% tax rate reduction. This method provides a better incentive because the owner retains more income from his/her tuk-tuk activities rather than receiving a handout from the Government.

For the base case, I selected battery option one--the Horizon battery--because the Horizon battery economics are better than the Yuasa battery. In technical terms, the Horizon battery has greater range and a longer life cycle. An additional consideration is that the Horizon battery is closer to actual production than the Yuasa battery. For the base case, the maximum cost the charging station can levy to recharge the Horizon battery is 8.35 Baht/kWh. This represents the breakeven electricity cost for the driver.

6.0 Sensitivity Analysis

Eight sensitivities are analyzed in regards to the base case. In each case, one factor is changed and all factors are held constant. Appendix B includes a table of each sensitivity and its effect.

USAID data for the cost of the LPG tuk-tuk is limited. Increasing LPG tuk-tuk cost from 25,000 Baht to 50,000 Baht adverseley impacts the owner's ROE. The ROE decreases from 18.58% to 12.72%. The need for greater equity outlays--LPG tuk-tuk purchases are 100% equity--in Year 0 decrease the returns to investors. The tax rate reduction needed by the electric tuk-tuk owner and the Government's burden are decreased.

Base case cost data for the electric tuk-tuk approach a maximum cost. Analyzing decreasing capital cost for the electric tuk-tuk, from 100,000 Baht to 50,000 Baht, shows that the lower the cost of the electric vehicle the better the opportunity to make the project feasible to the owners. Reducing the price to 50,000 Baht actually increases the ROE for an electric tuk-tuk over an LPG tuk-tuk ROE. The Government's burden decreases because it collects tax revenues that previously served as a subsidy.

Modifying the price the charging station pays for purchasing the batteries only affects the Government. The cost of the batteries is so significant that the value of the charging station's subsidy equals the annual cost of the batteries. Thus, the charging station's ROE and NPV are unchanged. The main effect is a reduction in the Government's net present value. As the cost of the batteries fall halve, the Government's net present more than halves. Also, examined is a 5% decrease in battery cost for the first five years. The battery cost remains constant for the last ten years. The Government's net present value falls significantly.

Increasing the driver's discount rate decreases the net present value of the driver. This is not significant because the decision criteria for the driver is his/her after-tax income in Year 1. Modifying his/her discount rate does not affect this variable.

The owner's ROE decreases as the discount rate increases. Conversely to the sensitivity analysis of LPG tuk-tuk capital cost, the tax rate reduction required increases as the capital cost decreases. The increase in discount factor affects both the electric and LPG tuk-tuk drivers. Thus, the electric tuk-tuk driver needs additional incentive to make the project feasible.

The charging station charges a maximum of 8.35 Baht/kWh. This price covers all fixed and O&M costs, a flat charge to MEA, and a Government electricity tax. Increasing the charging station's discount rate, increases the percentage of the maximum charge that is needed to cover fixed and operating charges. The Government's burden increases as well because the amount of its electricity tax must decline to meet the maximum charge amount.

Finally, charging station cost data are primitive. To account for variations, the model analyzes cost changes in both directions from 500,000 Baht to 1,000,000 Baht (base case is 750,000 Baht). The Government's electricity tax increases as the charging station charges less to drivers

when the cost of the station decreases. This reduces the burden of the Government and enables the charging station to meet is ROE requirement.

ELECTRIC TUK-TUK ECONOMIC FEASIBILITY MODEL
TAXI DOCUMENTATION

All calculations are based on discounted cash flow methodology. For issues such as taxation and depreciation, U.S. techniques are employed.

Page A: Inputs

All inputs are based on data collected during: 1) USAID field mission; 2) discussions with MOSTE; and 3) independent USAID research. In certain cases, best judgments are used to estimate inputs.

TT Fare Data

Fare cost, number of fares per shift, and distance per shift for a liquified petroleum gas (LPG) tuk-tuk (TT) are based on USAID field tests in Bangkok. The maximum number of LPG TT shifts in one year is calculated as two shifts per day times 365 days per year. A driver of an LPG TT only works one shift per day and two out of every three days; each driver works approximately 240 shifts per year. Each LPG TT is available for 70% of the maximum number of LPG shifts per year. Downtime is for repairs and preventive maintenance.

The annual fare data is calculated for one driver. The annual mileage data is for one LPG TT.

LPG TT Operating Cost Data

The rental fee, LPG cost, LPG TT fuel efficiency, lube oil cost, and lube oil efficiency are based on USAID field test results. The LPG TT capital cost is based on discussions with MOSTE and Pholasith. LPG TT's are purchased with 100% equity--all cash. The model can evaluate different debt-equity structures.

O&M annual cost is based on field test data. Other annual costs include items such as fees.

Financial/Economic Data

The exchange rate is based on the current baht/dollar exchange rate. The discount rate and return on equity are assumptions based on current economic factors in Thailand. All discount factors are in real terms. The income tax rate for TT owners is 30%. The current interest rate is 15%. Electricity cost is provided by MEA. The energy cost is 1.03 Baht/kWh. The demand charge is 188 Baht/kW. This is based on three month consumption not exceeding 355,000 kWh.

Time Frames

The tax, or depreciable, life of a tuk-tuk is 5 years. The economic life, or operating life, of a tuk-tuk is 15 years. There is no salvage value for an electric or LPG TT after 15 years. At the end of the economic life the vehicle is scrapped, and a new vehicle is purchased.

ETT Cost Data

The capital cost of an electric tuk-tuk (ETT) is 100,000 Baht. This cost does not include a battery pack (see **Page 2** discussion). For certain scenarios, a government subsidy may be included in the calculations. ETT are available 70% of the maximum number of annual shifts. For this analysis, the owner of an LPG TT and an ETT contribute identical amounts of equity to purchase one vehicle. The model can evaluate different debt/equity structures if desired. The annual O&M cost is based on discussions with the ETT manufacturer.

Charging Station Data

Each 20 unit charging station is estimated at 750,000 Baht. O&M costs are 382,500 Baht per year. USAID contractors supplied these estimates. Charging station effiency is 90%. Insurance expenses are USAID estimates. Net working capital represents the funds required to finance the difference between current assets and current liabilities. Net working capital is included in O&M costs.

Page B: Calculated Data

TT Annual Fare Data

The maximum number of tuk-tuk shifts in one year is 730. Because of mechanical considerations, the tuk-tuk is only available for a percentage of those shifts. For the base case, a 70% availability results in 511 tuk-tuk shifts per year. Considering limitations on drivers, a driver work approximately 260 shifts per year. The annual fare revenue for one driver and the annual mileage for one tuk-tuk are calculated using these availability factors. It is assumed the ETTs and LPG TTs cover the same distance per shift and generate the same revenues annually.

LPG TT Annual Operating Cost Data

All annual operating costs are based on one driver.

Charging Station Data

The number of recharges per year is dependent on the type of battery analyzed. The amount of electricity consumed is based on the number of recharges.

Page C: Battery Info

Two battery types and one scenario are considered. The recharge scenario involves replacing a spent battery pack (defined as 20% charge remaining) with a fully charged pack. The time required to change packs is consistent with the time needed to fuel an LPG tuk-tuk.

The Horizon batteries have greater range and a longer life cycle than the Yuasa batteries. One Horizon battery pack is sufficient to last one tuk-tuk shift. For Yuasa, each battery pack must be replaced 3 times during every 2 shifts to cover the required distance. The cost of the Horizon batteries is 2.5 times more than the Yuasa batteries.

According to a battery simulation model, the average energy needed to charge a battery is 12 kWh. Battery Life and Total Batteries are based on the Life Cycles and the number of

batteries needed per day.

For modeling purposes, battery packs can be purchased by either the owners, the RTG, or the charging station owner.

Page D: Driver = 1 LPG TT

The driver's revenue is based on fares only. Costs include tuk-tuk rental, LPG cost, and lube oil cost. Income tax can be included but is not required. The driver's after-tax income is discounted annually and summed to determine a net present value for the project over 15 years. However, the tuk-tuk driver primarily is concerned with short-term profits. Therefore, it is important to note the annual after-tax and discounted after-tax incomes for the first several years of the analysis.

Fares and tuk-tuk rental escalate at the Apparent Inflation Rate. Fuel and lube oil escalate at the Apparent Fuel Inflation Rate.

Page E: Owner = 1 LPG TT

For the base case, the owner purchases the LPG TT with 100% equity. The purchase price of a tuk-tuk reflects the true cost to manufacture for the owner; it is not the retail price. The revenue for the owner comes solely from driver rental fees. Tax deductible costs for the owner include depreciation, operations and maintenance costs, interest payments and other costs. Depreciation is calculated using the tax life of the vehicle and straight line depreciation methods. After-tax income is calculated using the owner's tax rate and discounted to a present value using the owner's discount rate. If part of the tuk-tuk purchase is debt, it is assumed that the owner receives a loan from the bank on the day of purchase. Repayment of debt occurs over the tax life. Summing interest and principal payments equals the total cost of debt for the project. Since depreciation is a non-cash expenditure, the annual amount is added-back in the cash flow calculation. Principal payments are not tax deductible.

Annual discounted cash flows are presented to verify if debt service can be met. The return on equity, ROE, is calculated to determine the return on the owner's initial investment of the economic life of the project.

Page F: Driver = 1 ETT

Based on model assumptions, fares and rental fees for drivers of electric tuk-tuks are the same as fares and rental fees for drivers of LPG TTs.

Fares, tuk-tuk rental, and electricity cost escalate at the Apparent Inflation Rate.

The driver of an ETT is concerned with short-term profits. The difference in net present value is presented each year. Because the difference in net present value between the two types of tuk-tuks is zero (essentially) in year 1, a driver will be indifferent as to which tuk-tuk is driven to generate a profit. A caveat towards the driver's indifference is the technical capabilities of the electric version. It is assumed that the electric and LPG tuk-tuks are technically similar. Due to a lower rate of inflation for electricity, the driver of the electric tuk-tuk will make more money than an LPG driver over a 15 time horizon. However, the length of a tuk-tuk driver's career is not known.

Page G: Owner = 20 ETTs

For the base case, the owner purchases 20 ETT's. This size fleet coincides with the capacity of one charging station. The owner outlays an identical amount of equity for ETT's as LPG TTs. In the base case, the owner has a equity/debt ratio of 37.5:62.5. The purchase price of an ETT is based on discussions with AECT and reflects the true cost to manufacture. It is not the retail price.

The revenue for the owner comes solely from driver rental fees. Tax deductible cost for the owner include depreciation, operations and maintenance costs, interest payments and other costs. Depreciation is calculated using the tax life of the vehicle and straight line depreciation methods. After-tax income is calculated using the owner's tax rate and discounted to a present value using the owner's discount rate. If part of the tuk-tuk purchase is debt, it is assumed that the owner receives a loan from the bank on the day of purchase. Repayment of debt occurs over the tax life. Summing interest and principal payments equals the total cost of debt for the project. Since depreciation is a non-cash expenditure, the annual amount is added-back in the cash flow calculation. Principal payments are not tax deductible.

Annual discounted cash flows are presented to verify if debt service can be met. The return on equity, ROE, is calculated to determine the return on the owner's initial investment of the economic life of the project.

Page H: Government

The Royal Thai Government (RTG) plays a role in the electric tuk-tuk industry. The RTG collects two direct forms of revenue. First, the RTG collects income tax from the charging station operator, owners, and drivers. Secondly, a tax is levied on drivers to fill-up their electric tuk-tuks. This tax offsets any subsidy needed to make the project feasible.

The RTG collects two indirect revenues. Electric vehicles reduce noise and air pollution. Societal and environmental externalities are paid to the RTG. Reducing pollution lessens the populations exposure to health risks and reduces medical bills. Similarly, less money is required to stem environmental degradation. Estimates of these values will be supplied by the environmental assessment.

Subsidies represent the largest cost to the RTG. Driver and owner indifference are achieved only if the RTG pays a subsidy to one or both parties depending on the scenario. RTG also pays a program cost to monitor the electric tuk-tuk demonstration project in Bangkok.

Net present value for RTG is the sum of the discounted annual cash flows.

Page I: Charging Station Owner

The debt-equity ratio for the charging station investment is dependent on user input. Electricity revenues are received from 20 electric tuk-tuks "filling-up" at their defined capacity for each year. Tax-deductible costs to the owner include depreciation, interest on the bank loan, insurance and other taxes, and O&M expenses. A flat energy charge is paid to the local electricity authority. The charge is documented in information supplied by the Metropolitan Energy Authority of Bangkok. Principal is not tax deductible. Depreciation is added-back in the cash flow analysis.

Page J: Inflation

Annual Inflation is assumed to average 5.0% annually for the 15 year project. Real Cost Escalation will average 2.5% annually. Apparent Inflation is 7.63% annually. Fuel escalate at 3.5% annually. Apparent Fuel Inflation is 8.68% annually. All values are estimates based on available data.

Pages K-M: Variables, Macros, Range Names, Summary Sheet

Variables includes inflation calculations for a fifteen year period. The number of electric tuk-tuk's introduced and charging stations required are determined.

Macros are formulas used by Lotus 1-2-3 to facilitate operations such as printing.

Range Names list all names used by the program.

Summary Sheet facilitates users' ability to examine different options. Changing user inputs requires recalculation of certain variables to determine feasibility and size of subsidy.

ELECTRIC TUK-TUK ECONOMIC FEASIBILITY MODEL
Base Case Development

This Lotus 1-2-3 model allow users to evaluate the economic feasibility of various scenarios in which electric tuk-tuks replace fossil-fuel powered tuk-tuks. Instructions for using the model are listed below.

To run the model, the user's computer setup must meet minimum system requirements:

- Lotus 1-2-3 version 3.1
- WYSIWYG (Lotus add-on)
- 386 20 MHz Computer
- 8 MB of RAM
- Hard drive
- 3.5" floppy drive

Labeling conventions used in the instructions include the following:

- **Bold**: Information input by the user
- xxx: File, directory, or cell name
- X:\: Path

Instructions

1 Create directory TT on hard drive. See DOS or Windows manual if you are not familiar with this process.
2 Insert disk labelled Tuk-tuk Models into drive A:\.
3 Copy NU-DISC.WK3 and NU-DISC.FM3 from A:\ to C:\TT.
4 Enter Lotus 3.1 and retrieve NU-DISC.WK3.
5 The model is automated to open at Page A. The model contains Page A through Page M. See your manuals for help using Lotus and/or the WYSIWYG interface.
6 On Page A, answer each question to define a specific scenario. Default values are included. Only change values shown in red type; values in black type are calculated by the model.

7 After the input parameters are specified, move to Page M. Hit the "Ctrl" and "Page Up" keys simultaneously to move between pages.

8 On Page M:

8.1 Select a subsidy option.

8.1.1 Four options are included. Enter the number corresponding to the option subsidy desired in Cell B1. For additional information on the four options, see the model writeup.

8.2 Select the type of battery.

8.2.1 The different types of batteries--Yuasa and Horizon--are described on Page C. Enter the number corresponding to the desired battery in Cell B7.

8.3 Charging Station Decision Criteria

8.3.1 Goto Cell I21--"Elec. Charge to Meet Rev. Req'mnts."

8.3.2 Change (iterate) Cell I21 until Cell C22--"Charging Station ROE"--equals 15%.

8.4 Driver Decision Criteria

8.4.1 Goto Cell I24--"Govt ETT Tax" to calculate driver indifference.

8.4.2 Iterate Cell I24 until Cell C13--"Year 1 NPV"--is zero.

8.5 Owner Decision Criteria

8.5.1 Goto Cell E17.

8.5.2 Follow instructions in Cell E17-E19 to determine correct cell to iterate.

8.5.3 Enter zero in the two cells that are NOT to be iterated.

8.5.4 Note whether the cell to be iterated is a percentage or a number.

8.5.5 Iterate the applicable cell until Cell C18--"Owners ROE Difference"--is 0%.

At this point, the model identifies a base case for the defined inputs. Most likely, the Government's return on the project--Cell A26--is a negative net present value because indirect benefits such as environmental and societal externalities are not evaluated. The Government's NPV gives the user an approximation of the required subsidy to make the project feasible for all parties.

INPUTS

LPG Tuk–Tuks

Shift Data:

What is the average number of fares per shift for one driver?	25
What is the average distance covered by an LPG TT in one shift?	130 km
How many shifts per day are operated?	2
What are the maximum days per year an LPG TT can be operated?	365
By percentage, what is the availability of an average LPG TT?	70.00%
By percentage, what is the availability of an average TT driver?	70.00%

Driver Cost Data:

What is the average rental fee for an LPG TT?	250 Baht
What is the average fare charge?	45 Baht
What is the average cost of LPG?	5.80 Baht/Liter
What is the average fuel efficiency for an LPG TT?	10.32 km/Liter
What is the average cost of lube oil?	95.00 Baht/Liter
What is the average efficiency for lube oil?	463.00 km/Liter

Owner Cost Data:

What is the average capital cost of an LPG TT?	37,500 Baht
What percentage of an average LPG TT purchase is cash?	100.00%
What is the average annual O&M cost?	17,500 Baht/yr
What is the average annual cost of other expenses (fees, titles, etc.)	625 Baht/yr
How many tuk–tuks do you want to model?	20
What is the average life of an LPG TT?	15

Financial/Economic Data

What is the current Baht/US$ exchange rate?	25.00
What is the average loan interest rate in Bangkok?	15.00%
What is the average income tax rate for TT owners?	30.00%
What is the average income tax rate for charging station operators?	30.00%
Are TT drivers subject to income tax? 1=yes 2=no	2
***	
Enter the Prime Lending Rate for Thailand: May 29	13.50%
TT drivers discount rate	13.50%
TT owners discount rate	21.00%
Royal Thai Government discount rate	13.50%
Charging Station Operator discount rate	17.00%
Are the tax lives identical for LPG and ETT? 1=yes 2=no	1
What is the tax life for a TT?	5 years
***	
What is the loan tenor for the charging station?	5 years
What is the tax life for the charging station?	5 years
How many years can a loss be carried forward?	5 years
What is the economic life of the project?	15 years

ETT Data

What is the capital cost for an ETT less the battery pack?	100,000 Baht
What is the average annual O&M cost for an ETT?	13,000 Baht
Based on the equity in an LPG TT purchase, the percentage of ETT equity is:	37.50%
By percentage, what is the average availability of an ETT?	70.00%

Charging Station

Cost Data:

What is the capital cost of a charging station?	750,000 Baht
What is the average annual O&M cost of a charging station?	400,000 Baht/yr
By percentage, how much funds are required to pay insurance and other taxes?	2.50%
By percentage, what amount of a charging station investment is cash?	25.00%

Technical Data:

How many ETT can one charging station service?	20
What is the efficiency of the charging station?	90.00%
What is the maximum power requirement for each charger?	25 kW
What is the standard demand charge for electricity into the chargin station?	1.03 Baht/kWh
What is the standard energy charge for the charging station's power requirements?	188 Baht/kW

CALCULATED DATA

TT Annual Fare Data

Max. Shifts per year	730 Shifts/Year
LPG Shifts/year	511 Shifts/Year
Driver Shifts/year	260 Shifts/Year
Fare revenue = one driver	292,500 Baht/yr
LPG TT Mileage = one TT	33,800 km/yr

LPG Annual Operating Cost Data = one driver

Tuk–Tuk Rental	65,000 Baht/yr
LPG Fuel Cost	18,996 Baht/yr
Oil Cost	6,935 Baht/yr

Charging Station Data

# of Recharges per year	10,220
kWh/year for 20 ETT	136,267 kWh/yr

BATTERY INFO

Battery Type/Charge Scenario	BP/day	BP/shft	Life Cycles	kWh/chrg	kWh/km	Battery Life (years)	Cost/Battery (Baht)	Total Batteries
Horizon – replace	2	1	600	12	0.0923	2.35	100,000	13

#	Battery Type/Charge Scenario	BP/day	BP/shft	Life Cycles	kWh/chrg	kWh/km	Battery Life (years)	Cost/Battery (Baht)	Total Batteries
1	Horizon – replace	2.0	1	600	12	0.0923	2.35	100,000	13
2	Yuasa – replace	3.0	1.5	250	12	0.0923	1.47	40,000	31
3	Horizon – quick charge	1.0		540	12	0.0923	1.06	100,000	15
4	Yuasa – quick charge	1.0		200	12	0.0923	0.39	40,000	39

VARIABLES

Inflation	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Annual Inflation		5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%
		105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%
Inflation Factor	1.0000	1.0500	1.1025	1.1576	1.2155	1.2763	1.3401	1.4071	1.4775	1.5513	1.6289	1.7103	1.7959	1.8856	1.9799	2.0789

Real Cost Escalation	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Annual Real Escalation		2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%
		102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%
Real Esc. Factor	1.0000	1.0250	1.0506	1.0769	1.1038	1.1314	1.1597	1.1887	1.2184	1.2489	1.2801	1.3121	1.3449	1.3785	1.4130	1.4483
Apparent Esc. Factor	1.0000	1.0763	1.1583	1.2466	1.3417	1.4440	1.5541	1.6728	1.8001	1.9374	2.0851	2.2441	2.4152	2.5984	2.7976	3.0109

Fuel Inflation	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Annual Fuel Inflation		3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%
		103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%
Fuel Inflation Factor	1.0000	1.0350	1.0712	1.1087	1.1475	1.1877	1.2293	1.2723	1.3168	1.3629	1.4108	1.4600	1.5111	1.5640	1.6187	1.6753
Apparent Fuel Inflation Factor	1.0000	1.0868	1.1810	1.2835	1.3946	1.5158	1.6473	1.7902	1.9455	2.1143	2.2977	2.4970	2.7137	2.9491	3.2049	3.4829

ETT Parameters	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ETTs Introduced Per Year		20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Charging Stations Per Year		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DRIVER = 1 LPG TT

Driver = 1 LPG TT	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Revenues:																
Fares	0	294,065	297,394	300,762	304,167	307,611	311,094	314,617	318,179	321,782	325,425	329,110	332,836	336,605	340,416	344,271
Total	0	294,065	297,394	300,762	304,167	307,611	311,094	314,617	318,179	321,782	325,425	329,110	332,836	336,605	340,416	344,271
Costs:																
LPG TT Rental	0	65,348	66,088	66,836	67,593	68,358	69,132	69,915	70,706	71,507	72,317	73,136	73,964	74,801	75,648	76,505
Fuel Cost	0	19,176	19,541	19,912	20,291	20,676	21,069	21,470	21,876	22,293	22,717	23,149	23,589	24,037	24,494	24,959
Lube Oil Cost	0	7,001	7,134	7,270	7,408	7,549	7,692	7,838	7,987	8,139	8,294	8,451	8,612	8,776	8,942	9,112
Total	0	91,525	92,762	94,018	95,291	96,583	97,893	99,223	100,571	101,939	103,327	104,736	106,164	107,614	109,084	110,576
Income:																
Net Income	0	202,539	204,632	206,744	208,876	211,028	213,201	215,394	217,608	219,842	222,098	224,374	226,672	228,991	231,332	233,695
Income Taxes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
After-tax Income	0	202,539	204,632	206,744	208,876	211,028	213,201	215,394	217,608	219,842	222,098	224,374	226,672	228,991	231,332	233,695
Cash Flow:																
Present Value of After-tax Income	0	178,449	158,848	141,399	125,865	112,037	99,727	88,769	79,015	70,331	62,602	55,721	49,596	44,144	39,291	34,971
Cumulative Present Value	0	178,449	337,297	478,695	604,560	716,597	816,325	905,094	984,109	1,054,440	1,117,041	1,172,762	1,222,359	1,266,503	1,305,794	1,340,765

NPV:	1,340,765

OWNER = 1 LPG TT

Owner = 1 LPG TT	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Investment:																
Equity	37,500															
Debt	0															
Total Investment	37,500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Revenues:																
Rental Fees	0	128,433	129,888	131,358	132,846	134,350	135,871	137,409	138,965	140,539	142,130	143,739	145,367	147,013	148,678	150,361
Total Revenues	0	128,433	129,888	131,358	132,846	134,350	135,871	137,409	138,965	140,539	142,130	143,739	145,367	147,013	148,678	150,361
Costs:																
Depreciation: Vehicle	0	7,500	7,500	7,500	7,500	7,500	0	0	0	0	0	0	0	0	0	0
O&M	0	18,203	19,568	20,910	22,343	23,874	25,510	27,259	29,127	31,124	33,257	35,536	37,972	40,575	43,356	46,327
Interest Payments	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other -- Fees, etc.	0	650	699	751	808	868	933	1,003	1,079	1,159	1,246	1,340	1,440	1,548	1,665	1,789
Total Tax-Deductible Costs	0	26,353	27,767	29,161	30,650	32,242	26,444	28,262	30,206	32,283	34,503	36,876	39,412	42,123	45,020	48,117
Income:																
Net Income	0	102,080	102,120	102,197	102,195	102,108	109,427	109,147	108,759	108,256	107,627	106,863	105,955	104,890	103,657	102,244
Income Taxes	0	30,624	30,636	30,659	30,659	30,632	32,828	32,744	32,628	32,477	32,288	32,059	31,786	31,467	31,097	30,673
After-tax Income	0	71,456	71,484	71,538	71,537	71,475	76,599	76,403	76,132	75,779	75,339	74,804	74,168	73,423	72,560	71,571
Cash Flows:																
Investment Outlay	(37,500)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bank Loan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
After-tax Income	0	71,456	71,484	71,538	71,537	71,475	76,599	76,403	76,132	75,779	75,339	74,804	74,168	73,423	72,560	71,571
Depreciation Add-Back	0	7,500	7,500	7,500	7,500	7,500	0	0	0	0	0	0	0	0	0	0
Principal Payments	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
After-Tax Cash Flow	(37,500)	78,956	78,984	79,038	79,037	78,975	76,599	76,403	76,132	75,779	75,339	74,804	74,168	73,423	72,560	71,571
Present Value of Cash Flow	(37,500)	65,253	53,947	44,615	36,871	30,448	24,407	20,119	16,568	13,630	11,199	9,169	7,530	6,161	5,032	4,102
Cumulative Present Value	(37,500)	27,753	81,700	126,315	163,186	193,635	218,042	238,161	254,729	268,359	279,558	288,747	296,277	302,438	307,469	311,571

NPV:	311,571
ROE:	15.16%

DRIVER = 1 ETT

Driver = 1 ETT	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Revenues:																
Fares		294,065	297,394	300,764	304,174	307,623	311,111	314,639	318,206	321,814	325,463	329,153	332,885	336,660	340,477	344,338
Total	0	294,065	297,394	300,764	304,174	307,623	311,111	314,639	318,206	321,814	325,463	329,153	332,885	336,660	340,477	344,338
Costs:																
ETT Rental		65,348	66,088	66,836	67,594	68,361	69,136	69,920	70,712	71,514	72,325	73,145	73,975	74,813	75,662	76,519
Electricity Cost		26,177	26,474	26,774	27,077	27,384	27,695	28,009	28,326	28,647	28,972	29,301	29,633	29,969	30,309	30,652
Total	0	91,525	92,561	93,610	94,671	95,745	96,830	97,928	99,039	100,162	101,297	102,446	103,608	104,782	105,970	107,172
Income:																
Net Income	0	202,540	204,833	207,154	209,503	211,878	214,281	216,710	219,167	221,652	224,166	226,707	229,278	231,878	234,507	237,166
Income Taxes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
After-tax Income	0	202,540	204,833	207,154	209,503	211,878	214,281	216,710	219,167	221,652	224,166	226,707	229,278	231,878	234,507	237,166
Cash Flow:																
Present Value of After-tax Income	0	178,449	159,004	141,679	126,243	112,488	100,232	89,312	79,581	70,910	63,184	56,300	50,166	44,701	39,830	35,491
Cumulative Present Value	0	178,449	337,453	479,132	605,375	717,863	818,095	907,407	986,988	1,057,898	1,121,083	1,177,383	1,227,550	1,272,250	1,312,080	1,347,571

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OWNER = 20 ETTs

Owner = 20 ETTs	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Investment:																
Equity	750,000															
Debt	1,250,000															
Total Investment	2,000,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Revenues:																
Rental Fees	0	2,568,666	2,597,751	2,627,187	2,656,975	2,687,101	2,717,569	2,748,382	2,779,545	2,811,061	2,842,934	2,875,168	2,907,768	2,940,736	2,974,082	3,007,803
Total Revenues	0	2,568,666	2,597,751	2,627,187	2,656,975	2,687,101	2,717,569	2,748,382	2,779,545	2,811,061	2,842,934	2,875,168	2,907,768	2,940,736	2,974,082	3,007,803
Costs:																
Depreciation: Vehicle	0	400,000	400,000	400,000	400,000	400,000	0	0	0	0	0	0	0	0	0	0
Batteries Expense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subsidy from Govt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M	0	270,446	290,729	310,656	331,949	354,701	379,012	404,990	432,748	462,409	494,103	527,969	564,157	602,824	644,142	688,292
Interest Payments	0	159,616	124,471	89,326	54,181	19,037	0	0	0	0	0	0	0	0	0	0
Other -- Fees, etc.	0	13,002	13,977	15,026	16,153	17,364	18,666	20,066	21,571	23,189	24,928	26,798	28,808	30,968	33,291	35,788
Total Tax-Deductible Costs	0	843,064	829,178	815,008	802,283	791,101	397,678	425,056	454,319	485,598	519,031	554,767	592,964	633,793	677,433	724,080
Income:																
Net Taxable Income	0	1,725,602	1,768,573	1,812,179	1,854,692	1,896,000	2,319,891	2,323,326	2,325,225	2,325,462	2,323,902	2,320,401	2,314,804	2,306,946	2,296,648	2,283,723
Loss Carryforward	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Income Taxes	0	453,833	465,135	476,603	487,784	498,648	610,131	611,035	611,534	611,597	611,186	610,266	608,793	606,727	604,019	600,619
After-tax Income	0	1,271,769	1,303,438	1,335,576	1,366,908	1,397,352	1,709,759	1,712,291	1,713,691	1,713,866	1,712,716	1,710,136	1,706,011	1,700,219	1,692,630	1,683,104
Cash Flows:																
Investment Outlay	(2,000,000)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bank Loan	1,250,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
After-tax Income	0	1,271,769	1,303,438	1,335,576	1,366,908	1,397,352	1,709,759	1,712,291	1,713,691	1,713,866	1,712,716	1,710,136	1,706,011	1,700,219	1,692,630	1,683,104
Depreciation Add-Back	0	400,000	400,000	400,000	400,000	400,000	0	0	0	0	0	0	0	0	0	0
Principal Payments	0	(250,000)	(250,000)	(250,000)	(250,000)	(250,000)	0	0	0	0	0	0	0	0	0	0
After-Tax Cash Flow	(750,000)	1,421,769	1,453,438	1,485,576	1,516,908	1,547,352	1,709,759	1,712,291	1,713,691	1,713,866	1,712,716	1,710,136	1,706,011	1,700,219	1,692,630	1,683,104
Present Value of Cash Flow	(750,000)	1,175,016	992,716	838,569	707,649	596,571	544,782	450,900	372,949	308,254	254,584	210,083	173,204	142,658	117,373	96,456
Cumulative Present Value	(750,000)	425,016	1,417,734	2,256,302	2,963,951	3,560,523	4,105,305	4,556,204	4,929,153	5,237,407	5,491,992	5,702,075	5,875,279	6,017,936	6,135,309	6,231,765

GOVT = 20 ETTs

Government = 20 ETTs	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Revenues:																
Taxes: Charging Station	0	47,815	61,266	75,376	90,045	105,622	164,847	177,386	190,878	205,389	220,998	237,788	255,847	275,271	296,164	318,635
Taxes: Drivers and Owners	0	130,401	162,603	196,610	232,553	326,542	357,565	390,999	427,026	465,842	507,660	552,706	601,225	653,480	709,753	777,698
Societal Externalities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Environmental Externalities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Revenues	0	178,216	223,869	271,987	322,599	432,164	522,412	568,387	617,904	671,232	728,658	790,494	857,072	928,751	1,005,917	1,096,333
Costs:																
Batteries Expense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subsidy	0	1,802,914	1,938,019	2,083,248	2,239,360	2,407,171	2,587,557	2,781,461	2,989,895	3,213,948	3,454,792	3,713,683	3,991,975	4,291,122	4,612,685	4,958,346
Program Costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Costs	0	1,802,914	1,938,019	2,083,248	2,239,360	2,407,171	2,587,557	2,781,461	2,989,895	3,213,948	3,454,792	3,713,683	3,991,975	4,291,122	4,612,685	4,958,346
Net Cash Flow	0	(1,624,698)	(1,714,150)	(1,811,261)	(1,916,762)	(1,975,007)	(2,065,145)	(2,213,074)	(2,371,991)	(2,542,716)	(2,726,133)	(2,923,189)	(3,134,904)	(3,362,371)	(3,606,769)	(3,862,013)
Present Value of Cash Flow	0	(1,431,452)	(1,330,629)	(1,238,778)	(1,155,007)	(1,048,551)	(965,996)	(912,063)	(861,283)	(813,458)	(768,402)	(725,943)	(685,921)	(648,186)	(612,599)	(577,931)
Cumulative Present Value	0	(1,431,452)	(2,762,082)	(4,000,860)	(5,155,867)	(6,204,417)	(7,170,414)	(8,082,477)	(8,943,760)	(9,757,218)	**********	**********	**********	**********	**********	**********

CHARGING STATION OPERATOR = 20 ETTs

Charging Station Owner = 20 ETTs	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Investment:																
Equity	187,500															
Debt	562,500															
Total Investment	750,000															
Revenues:																
Electricity Sales	0	914,202	982,710	1,056,351	1,135,511	1,220,602	1,312,071	1,410,393	1,516,084	1,629,694	1,751,819	1,883,095	2,024,208	2,175,896	2,338,951	2,514,224
Total Revenues	0	914,202	982,710	1,056,351	1,135,511	1,220,602	1,312,071	1,410,393	1,516,084	1,629,694	1,751,819	1,883,095	2,024,208	2,175,896	2,338,951	2,514,224
Costs:																
Depreciation	0	150,000	150,000	150,000	150,000	150,000	0	0	0	0	0	0	0	0	0	0
Batteries Expense	0	1,802,914	1,938,019	2,083,248	2,239,360	2,407,171	2,587,557	2,781,461	2,989,895	3,213,948	3,454,792	3,713,883	3,991,975	4,291,122	4,612,885	4,958,348
Subsidy from Govt	0	(1,802,914)	(1,938,019)	(2,083,248)	(2,239,360)	(2,407,171)	(2,587,557)	(2,781,461)	(2,989,895)	(3,213,948)	(3,454,792)	(3,713,883)	(3,991,975)	(4,291,122)	(4,612,885)	(4,958,348)
Interest	0	71,736	55,941	40,146	24,351	8,556	0	0	0	0	0	0	0	0	0	0
Flat Energy Charge	0	97,773	105,100	112,976	121,442	130,543	140,325	150,841	162,144	174,295	187,356	201,396	216,488	232,711	250,149	268,895
Ins, Other Taxes	0	19,254	20,215	21,225	22,791	23,930	25,127	26,383	27,702	29,087	30,542	32,069	33,672	35,356	37,124	38,980
O&M Costs	0	416,057	447,235	480,750	516,775	555,501	597,129	641,878	689,976	741,680	797,260	857,004	921,225	990,259	1,064,466	1,144,234
Total Tax-Deductible Costs	0	754,820	778,491	805,096	835,359	868,530	762,581	819,099	879,822	945,063	1,015,157	1,090,469	1,171,385	1,258,326	1,351,739	1,452,108
Income:																
Taxable Income	0	159,383	204,219	251,255	300,152	352,073	549,490	591,294	636,261	684,632	736,661	792,626	852,823	917,570	987,212	1,062,116
Loss Carryforward	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Income Taxes	0	47,815	61,266	75,376	90,045	105,622	164,847	177,388	190,878	205,389	220,998	237,788	255,847	275,271	296,164	318,635
After-tax Income	0	111,568	142,953	175,878	210,106	246,451	384,643	413,906	445,383	479,242	515,663	554,838	596,976	642,299	691,048	743,481
Cash Flows:																
Investment Outlay	(750,000)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loan from Bank	562,500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
After-tax Income	0	111,568	142,953	175,878	210,106	246,451	384,643	413,906	445,383	479,242	515,663	554,838	596,976	642,299	691,048	743,481
Depreciation Add-back	0	150,000	150,000	150,000	150,000	150,000	0	0	0	0	0	0	0	0	0	0
Debt Service (Principal)	0	(112,500)	(112,500)	(112,500)	(112,500)	(112,500)	0	0	0	0	0	0	0	0	0	0
After-Tax Cash Flow	(187,500)	149,068	180,453	213,378	247,606	283,951	384,643	413,906	445,383	479,242	515,663	554,838	596,976	642,299	691,048	743,481
Present Value of Cash Flow	(187,500)	127,408	131,823	133,227	132,135	129,513	149,949	137,911	126,837	116,649	107,277	98,656	90,725	83,430	76,720	70,548
Cumulative Present Value	(187,500)	(60,092)	71,732	204,959	337,094	466,607	616,556	754,467	881,304	997,954	1,105,231	1,203,887	1,294,611	1,378,041	1,454,761	1,525,308

Subsidy -- Select one: 0

0 CS buys batteries; RTG grants owner tax credit
1 Owner buys batteries; RTG offsets as needed
2 CS buys batteries; RTG offsets as needed
3 RTG buys batteries; RTG offsets as needed

Select Battery Scenario #: 1

Driver Decision Criteria

Year >= 0; Diff >0

	Year 0	1	2	3	4	5
Annual (1st 5 years)	0	0	156	281	378	451

Lifetime	NPV:	1,347,571
	Diff:	6,806

ETT Owner Decision Criteria

ROE Diff>0%	NPV:	6,231,765
	ROE:	15.16%
	Diff:	0.00%

Owner Addtl Subsidy

Enter Zero (0) in Cell H26:	0	=H26
Enter Zero (0) in Cell H27:	0	=H27
Enter tax rate credit (%):	3.70%	=H28

CS Decision Criteria

ROE = 15%	NPV:	1,525,308
	ROE:	15.00%

Elec. Cost

Elec. Charge to Meet Rev. Req'mnts	5.42 Baht/kWh
MEA Energy Charge	1.03 Baht/kWh
ELEC. CHARGE TO MEET REV. REQ.	6.45 Baht/kWh
Govt ETT Tax	1.90 Baht/kWh
TOTAL TO CUSTOMER	8.35 Baht/kWh

Government	NPV:	(13,776,199)

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ELECTRIC TUK-TUK FEASIBILITY MODEL
CARGO DOCUMENTATION

All calculations are based on discounted cash flow methodology. For issues such as taxation and depreciation, U.S. techniques are employed.

Page A: Inputs

All inputs are based on data collected during: 1) USAID field mission; 2) discussions with MOSTE; and 3) independent USAID research. In certain cases, best judgments are used to estimate inputs.

Shift Data

Cargo tuk-tuks cover 65 kilometers per shift. There is one shift per day. Cargo tuk-tuks operate 70% of the year.

Cost Data

Cargo tuk-tuks are fueled with gasoline. Fuel efficiency and gasoline cost are estimates.

Capital Cost Data

The average cost of a cargo tuk-tuk is identical to the capital cost of an LPG tuk-tuk. O&M and other costs are based on USAID research. All purchases of cargo tuk-tuks are in cash.

Financial/Economic Data

The tax, or depreciable, life of a tuk-tuk is 5 years. The economic life, or operating life, of a tuk-tuk is 15 years. There is no salvage value for an electric or LPG TT after 15 years. At the end of the economic life the vehicle is scrapped, and a new vehicle is purchased.

CETT Data

The capital cost of an cargo electric tuk-tuk (CETT) is 100,000 Baht. This cost does not include a battery pack (see later discussion). For certain scenarios, a government subsidy may be included in the calculations. CETT are available 70% of the maximum number of annual shifts. For this analysis, the owner of an LPG TT and a CETT contribute identical amounts of equity to purchase one vehicle. The model can evaluate different debt/equity structures if desired. The annual O&M cost is based on discussions with the CETT manufacturer.

Page B: Calculated Data

TT Annual Fare Data

The maximum number of cargo tuk-tuk shifts in one year is 365. Because of mechanical considerations and work schedules, the tuk-tuk is only available for a percentage of those shifts. For the base case, a 70% availability results in 256 cargo tuk-tuk shifts per year. Considering these limitations, the annual mileage for one tuk-tuk is calculated. It is assumed the ETTs and LPG TTs cover the same distance per shift and generate the same revenues annually.

Cargo TT Annual Operating Cost Data

All annual operating costs are based on one cargo tuk-tuk.

Page C: Battery Info

Two battery types are considered--Horizon and Yuasa. The recharge scenario involves recharging a spent battery pack (defined as 20% charge remaining) on the vehicle owner's property. This allows the CETT owner to reduce electricity costs because recharging costs are levied at the owner's facility cost. In most cases, the price an owner pays for electricity is significantly less at his/her business than the payment required at a newly constructed charging station. The time required to change packs is not a factor as the packs are recharged during non-business hours.

The Horizon batteries have greater range and a longer life cycle than the Yuasa batteries. One Horizon battery pack is sufficient to last one tuk-tuk shift. For Yuasa, each battery pack must be replaced 3 times during every 2 shifts to cover the required distance. The cost of the Horizon batteries is 2.5 times more than the Yuasa batteries.

According to a battery simulation model, the average energy needed to charge a battery is 12 kWh. Battery Life and Total Batteries are based on the Life Cycles and the number of batteries needed per day.

For modeling purposes, battery packs can be purchased by either the owners, the RTG, or the charging station owner.

Page D: Owner = 1 Cargo TT

For the base case, the owner purchases the Cargo TT with 100% equity. The purchase price of a tuk-tuk reflects the true cost to manufacture for the owner; it is not the retail price. The revenue for the owner comes solely from driver rental fees. Tax deductible costs for the owner include depreciation, operations and maintenance costs, interest payments and other costs. Depreciation is calculated using the tax life of the vehicle and straight line depreciation methods. After-tax income is calculated using the owner's tax rate and discounted to a present value using the owner's discount rate. If part of the tuk-tuk purchase is debt, it is assumed that the owner receives a loan from the bank on the day of purchase. Repayment of debt occurs over the tax life. Summing interest and principal payments equals the total cost of debt for the project. Principal payments are not tax deductible.

The revenues earned by an owner using a cargo tuk-tuk do not change irregardless of the vehicle. Thus, revenues are not considered. For this case, the model calculates the net present cost of the Cargo TT option.

Page E: Owner = 1 CETT

Based on model assumptions, revenues are not considered since they are independent of the vehicle type. The owner outlays an identical amount of equity for ETT's as LPG TTs. In the base case. The purchase price of an CETT is based on discussions with AECT and reflects the true cost to manufacture. It is not the retail price.

Tax deductible cost for the owner include depreciation, operations and maintenance costs, interest payments and other costs. Depreciation is calculated using the tax life of the vehicle and straight line depreciation methods. After-tax income is calculated using the owner's tax rate and discounted to a present value using the owner's discount rate. If part of the tuk-tuk purchase is debt, it is assumed that the owner receives a loan from the bank on the day of purchase. Repayment of debt occurs over the tax life. Summing interest and principal payments equals the total cost of debt for the project. Principal payments are not tax deductible.

The model calculate net present cost for the 15-year period. The vehicle with the lower net present cost is the least cost option. To be economic feasible, the difference in net present cost between the owner of a cargo tuk-tuk and a CETT must be less than or equal to zero. Annual discounted cash flows are presented to verify if debt service can be met. The return on equity, ROE, is calculated to determine the return on the owner's initial investment of the economic life of the project.

Page F: Government

The Royal Thai Government (RTG) plays a role in the cargo electric tuk-tuk industry. The RTG collects two direct forms of revenue. First, the RTG collects income tax from the owners. Secondly, if a tax is levied to fill-up their electric tuk-tuks. This tax offsets any subsidy needed to make the project feasible.

The RTG collects two indirect revenues. Electric vehicles reduce noise and air pollution. Societal and environmental externalities are paid to the RTG. Reducing pollution lessens the populations exposure to health risks and reduces medical bills. Similarly, less money is required to stem environmental degradation. Estimates of these values will be supplied by the

INPUTS

Cargo Tuk–Tuks

Shift Data:

What is the average distance covered by an Cargo TT in one shift?	65 km
How many shifts per day are operated?	1
What are the maximum number of days per year a Cargo TT can be operated?	365
By percentage, what is the availability of an average Cargo TT?	70.00%

Cost Data:

What is the average cost of gasoline?	10.00 Baht/Liter
What is the average fuel efficiency for a Cargo TT?	10.32 km/Liter

Capital Cost Data:

What is the average capital cost of a Cargo TT?	40,000 Baht
What percentage of an average Cargo TT purchase is cash?	100.00%
What is the average annual O&M cost?	17,500 Baht/yr
What is the average annual cost of other expenses (fees, titles, etc.)	625 Baht/yr

Financial/Economic Data

What is the tax life for a Cargo TT?	5 years
How many years can a loss be carried forward?	5 years
What is the economic life of a Cargo ETT (CETT)?	15 years

CETT Data

What is the capital cost for an CETT less the battery pack?	100,000 Baht
What is the average annual O&M cost for an CETT?	13,000 Baht
By percentage, what amount of an CETT purchase is cash?	25.00%
By percentage, what is the average availability of an CETT?	70.00%

CALCULATED DATA

TT Annual Fare Data

Max. Shifts per year	365 Shifts/Year
Cargo Shifts/year	256 Shifts/Year
Cargo TT Mileage = one TT	16,640 km/yr

Cargo TT Annual Operating Cost Data

Gasoline Fuel Cost	16,124 Baht/yr

Data from Taxi Worksheet

Charger Power	25 kW
Energy Charge	1.03 Baht/kWh
Flat Charge	188 Baht/kW

BATTERY INFO

Select battery type 2
1=Horizon
2=Yuasa

Battery Type/Charge Scenario	BP/day	BP/shft	Life Cycles	kWh/chrg	kWh/km	Battery Life (years)	Cost/Battery (Baht)	Total Batteries
Yuasa – replace	3	1.5	250	12	0.0923	1.47	40,000	31

OWNER = 1 LPG TT

Owner = 1 LPG TT	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Investment:																
Equity	40,000															
Debt	0															
Total Investment	40,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Costs:																
Fuel Oil Cost	0	17,523	19,043	20,695	22,490	24,441	26,561	28,866	31,370	34,091	37,046	40,262	43,755	47,551	51,678	56,159
Depreciation: Vehicle	0	8,000	8,000	8,000	8,000	8,000	0	0	0	0	0	0	0	0	0	0
Depreciation: Tax Shield	0	(2,400)	(2,400)	(2,400)	(2,400)	(2,400)	0	0	0	0	0	0	0	0	0	0
O&M	0	18,634	20,270	21,816	23,480	25,270	27,197	29,271	31,502	33,904	36,490	39,272	42,266	45,489	48,958	52,691
Other -- Fees, etc.	0	673	724	779	839	902	971	1,045	1,125	1,211	1,303	1,403	1,510	1,625	1,748	1,882
Monthly Payment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual Costs	0	42,630	45,637	48,890	52,408	56,214	54,729	59,182	63,997	69,206	74,841	80,937	87,531	94,665	102,382	110,732
Bank Loan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annual Cost	40,000	42,630	45,637	48,890	52,408	56,214	54,729	59,182	63,997	69,206	74,841	80,937	87,531	94,665	102,382	110,732
Present Value of Costs	40,000	35,231	31,171	27,597	24,449	21,673	17,439	15,584	13,928	12,447	11,125	9,943	8,887	7,943	7,100	6,346
Cumulative Present Value	40,000	75,231	106,402	133,999	158,448	180,121	197,560	213,144	227,072	239,519	250,644	260,586	269,473	277,416	284,515	290,861

NPC: 290,861

P&I Calc:																
Principal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Interest	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total P&I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cumulative P&I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum of Principal – Loan Amount	0															

OWNER = 1 Cargo ETT

Owner = 1 Cargo ETT	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Investment:																
Equity	40,000															
Debt	60,000															
Total Investment	100,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Costs:																
Electricity Cost	0	6,761	7,277	7,831	8,429	9,071	9,763	10,507	11,309	12,171	13,099	14,098	15,173	16,330	17,575	18,915
Depreciation: Vehicle	0	20,000	20,000	20,000	20,000	20,000	0	0	0	0	0	0	0	0	0	0
Depreciation: Tax Shield	0	(6,000)	(6,000)	(6,000)	(6,000)	(6,000)	0	0	0	0	0	0	0	0	0	0
O&M	0	13,991	15,058	16,206	17,442	18,772	20,203	21,744	23,402	25,186	27,107	29,173	31,398	33,792	36,369	39,142
Monthly Payment	0	21,000	19,200	17,400	15,600	13,800	0	0	0	0	0	0	0	0	0	0
Other -- Fees, etc.	0	673	724	779	839	902	971	1,045	1,125	1,211	1,303	1,403	1,510	1,625	1,748	1,882
Total Tax-Deductible Costs	0	56,425	56,259	56,217	56,309	56,546	30,938	33,297	35,835	38,568	41,509	44,674	48,080	51,746	55,692	59,938
Bank Loan	60,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annual Cost	40,000	56,425	56,259	56,217	56,309	56,546	30,938	33,297	35,835	38,568	41,509	44,674	48,080	51,746	55,692	59,938
Present Value of Costs	40,000	46,632	38,425	31,733	26,269	21,801	9,858	8,766	7,799	6,937	6,170	5,488	4,881	4,342	3,862	3,435
Cumulative Present Value	40,000	86,632	125,058	156,791	183,059	204,860	214,718	223,486	231,285	238,221	244,391	249,879	254,761	259,103	262,964	266,399
Difference between ETT & LPG	---	11,401	7,255	4,136	1,820	128	(7,581)	(6,816)	(6,129)	(5,511)	(4,955)	(4,455)	(4,005)	(3,601)	(3,238)	(2,911)

NPC:	266,399
Diff:	(24,462)

P&I Calc:																
Principal	0	12,000	12,000	12,000	12,000	12,000	0	0	0	0	0	0	0	0	0	0
Interest	0	9,000	7,200	5,400	3,600	1,800	0	0	0	0	0	0	0	0	0	0
Total P&I	0	21,000	19,200	17,400	15,600	13,800	0	0	0	0	0	0	0	0	0	0
Cumulative P&I	0	21,000	40,200	57,600	73,200	87,000	0	0	0	0	0	0	0	0	0	0
Sum of Principal -- Loan Amount	0															

GOVT = 1 ETT

Government = 20 ETTs	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Revenues:																
ETT Tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Societal Externalities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Environmental Externalities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Revenues	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Costs:																
Batteries Expense	0	88,970	95,754	103,055	110,913	119,370	128,472	138,268	148,811	160,158	172,370	185,513	199,659	214,883	231,268	248,902
Program Costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Costs	0	88,970	95,754	103,055	110,913	119,370	128,472	138,268	148,811	160,158	172,370	185,513	199,659	214,883	231,268	248,902
Net Cash Flow	0	(88,970)	(95,754)	(103,055)	(110,913)	(119,370)	(128,472)	(138,268)	(148,811)	(160,158)	(172,370)	(185,513)	(199,659)	(214,883)	(231,268)	(248,902)
Present Value of Cash Flow	0	(78,388)	(74,330)	(70,483)	(66,834)	(63,375)	(60,094)	(56,984)	(54,034)	(51,237)	(48,585)	(46,070)	(43,686)	(41,424)	(39,280)	(37,247)
Cumulative Present Value	0	(78,388)	(152,718)	(223,200)	(290,035)	(353,410)	(413,504)	(470,488)	(524,522)	(575,759)	(624,345)	(670,415)	(714,100)	(755,525)	(794,805)	(832,052)

NPV: (832,052)

VARIABLES

Inflation	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Annual Inflation		5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%
		105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%	105.00%
Inflation Factor	1.0000	1.0500	1.1025	1.1576	1.2155	1.2763	1.3401	1.4071	1.4775	1.5513	1.6289	1.7103	1.7959	1.8856	1.9799	2.0789

Real Cost Escalation	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Annual Real Escalation		2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%
		102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%	102.50%
Real Esc. Factor	1.0000	1.0250	1.0506	1.0769	1.1038	1.1314	1.1597	1.1887	1.2184	1.2489	1.2801	1.3121	1.3449	1.3785	1.4130	1.4483
Apparent Esc. Factor	1.0000	1.0763	1.1583	1.2466	1.3417	1.4440	1.5541	1.6726	1.8001	1.9374	2.0851	2.2441	2.4152	2.5994	2.7976	3.0109

Fuel Inflation	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Annual Fuel Inflation		3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%
		103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%	103.50%
Fuel Inflation Factor	1.0000	1.0350	1.0712	1.1087	1.1475	1.1877	1.2293	1.2723	1.3168	1.3629	1.4106	1.4600	1.5111	1.5640	1.6187	1.6753
Apparent Fuel Inflation Factor	1.0000	1.0868	1.1810	1.2835	1.3948	1.5158	1.6473	1.7902	1.9455	2.1143	2.2977	2.4970	2.7137	2.9491	3.2049	3.4829